Performance Optimization of Tesla Valve Microchannel Cold Plates for Li-Ion Battery

Fen Liu[1], Jianfeng Wang[2](✉), and Yanbing Lu[2]

[1] School of Energy Science and Engineering, Harbin Institute of Technology, Harbin 150001, China
[2] School of Automotive Engineering, Harbin Institute of Technology, Weihai 264209, Shandong, China
`Wjfeee123@163.com`

Abstract. The development of energy-efficient battery thermal management technology is of great significance for lithium-ion batteries. In this paper, a Tesla valve type channel cold plate was designed for square batteries, also liquid cooling experimental studies were carried out to verify the optimized cold plate parameters. The maximum error between liquid cooling simulation and experiment under the optimal configuration did not exceed 1.25 °C. The experimental analysis found that when the inlet flow rate exceeded 398mL/min, the improvement of battery cooling effect and temperature uniformity gradually tended to saturate. The coolant inlet temperature was too high or too low would cause the unbalanced performance of the cold plate.

Keywords: Battery thermal management · Tesla valve · Optimization experiment

1 Introduction

Under the severe situation of global environmental pollution and shortage of fossil energy, electric vehicles with the advantages of environmental protection and energy saving, low noise and simple structure have developed rapidly and become an indispensable part of the automobile market [1, 2]. The performance of automotive lithium-ion batteries is more sensitive to temperature, and it is of great significance to develop energy-efficient battery thermal management technologies to ensure that lithium-ion batteries operate within the optimal range of 15–35 °C [3–6]. Liquid cooling is currently the most widely used method of heat dissipation in electric vehicles. Compared with traditional liquid cooling technology, microchannel heat sink is a highly efficient heat exchanger with advantages such as small size, large heat transfer coefficient and high efficiency of heat transfer.

Naqiuddin et al. introduced a new segmented microchannel to improve the thermal performance of a straight channel heat sink, which could improve the heat transfer performance with minimum pressure drop [7]. Rao et al. used the Jaya algorithm to optimize the microchannel heat sinks of rectangular and trapezoidal cross-sections, and

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obtained better results than other methods [8]. Osanloo et al. investigated a two-layer microchannel heat sink with upper and lower tapered staggered channels and obtained the optimal combination of coolant flow and tapered inclination [9]. Lu et al. proposed a special structure of the Tesla valve to achieve enhanced heat transfer and further improve the heat transfer efficiency of the microchannel heat sink [10].

In this paper, the optimal cold plate parameters obtained by the central composite design response method for different flow rates and different cooling temperature experimental conditions are verified experimentally [10].

2 Battery Microchannel Cooling Simulation

As shown in Fig. 1, we proposed a Tesla valve channel cold plate cooling system in our previous study [10].

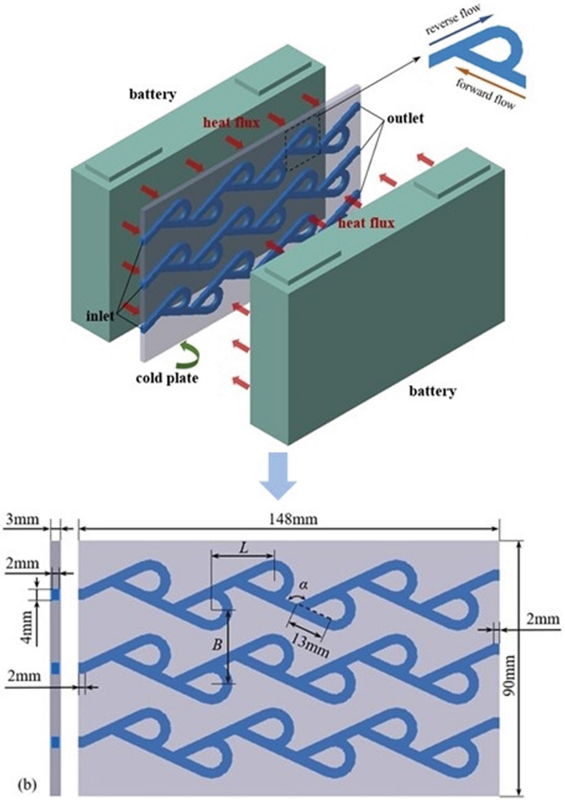

Fig. 1. Tesla microchannel cooling system

In [10] we obtained the optimal parameters of the cold plate by multi-objective optimization as were: Tesla valve angle α of 120°, Tesla valve spacing L of 23.1 mm, channel spacing B of 28 mm and coolant inlet velocity v of 0.83 m/s (Figs. 2 and 3).

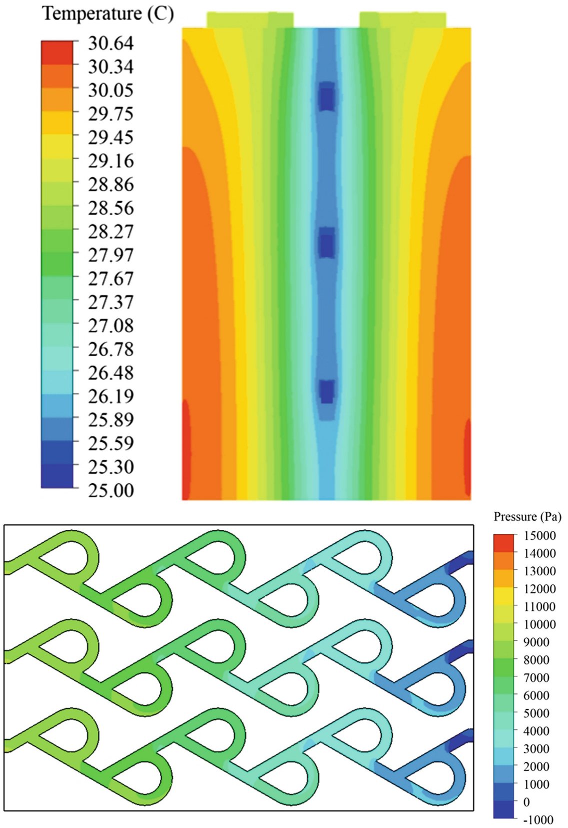

Fig. 2. The temperature and pressure diagram of the optimal cold plate

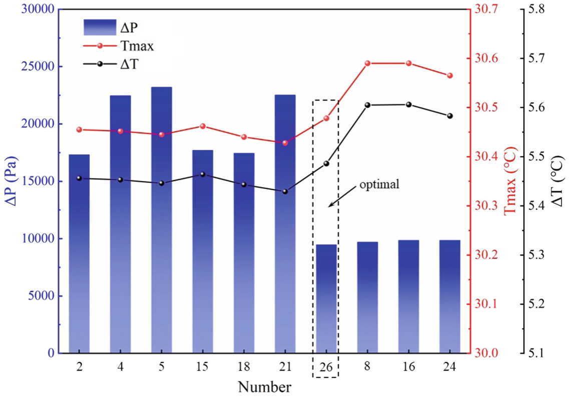

Fig. 3. Different simulation results

3 Battery Microchannel Cooling Experiments

As shown in Fig. 4 the designed Tesla valve channel cold plate was machined by milling. The material of the cold plate was aluminium and the internal channel structure parameters of the cold plate were consistent with the optimal channel parameters obtained by multi-objective optimization (Fig. 5).

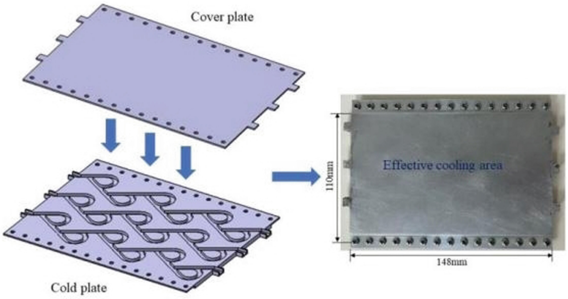

Fig. 4. Tesla valve channel cold plate 3D modelling.

Fig. 5. Battery liquid cooling system experiments.

The experimental results in Fig. 6 showed that the heat transfer performance of coolant flowing in the reverse direction was significantly better than in the forward direction. At the end of battery 3C discharge, the central temperature of the battery surface was basically maintained at around 30 °C when the coolant flowed in the reverse direction. There were still some deviations between the liquid cooling simulation and the experimental results, with a maximum error of 1.25 °C for forward flow and 1.04 °C for reverse flow. This was due to some factors, such as ignoring the influence of the thermal interface material, the inlet temperature of the coolant fluctuating to a certain extent, the existence of the diverter at the inlet, as well as the accuracy limitations of the instrumentation and the processing errors of the cold plate itself.

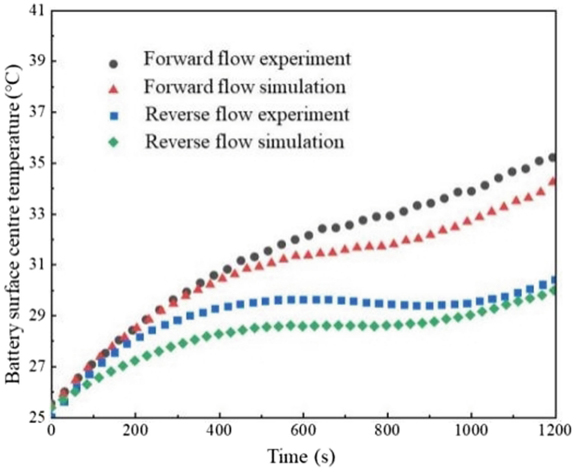

Fig. 6. Comparison of simulation and experimental results for liquid cooling under optimised conditions.

As can be seen from Fig. 7, the designed cold plate could significantly reduce the temperature of the battery and slow down the temperature rise of the battery. As the coolant flow rate increased, the surface central temperature of the battery gradually decreased and the cooling performance of the cold plate was gradually enhanced. But this did not mean that the larger the coolant flow rate the better, because when the coolant flow rate increased from 360 mL/min to 398 mL/min, the surface central temperature of the battery decreased by approximately 0.55 °C. It would consume more pump work when increasing the coolant flow, so the coolant flow rate was selected at 398 mL/min, i.e., the coolant inlet speed was about 0.83 m/s, which was basically consistent with the recommended results of multi-objective optimization.

Figure 8 showed that as the flow rate increased, the temperature difference decreased, but the degree of reduction gradually decreased. This indicated that increasing the flow rate also had limited improvement on the temperature uniformity of the whole battery liquid cooling unit. When the coolant flow rate was 398 mL/min, the maximum temperature difference was about 5.42 °C, which was basically consistent with the simulation results of the battery liquid cooling finite element model.

Figure 9 showed that a decrease in the coolant inlet temperature would cause a gradual decrease in the central cell surface temperature. In addition, as the coolant inlet temperature decreased, the earlier the central temperature changed into a steady state. Figure 10 showed that as the coolant inlet temperature decreased, the temperature difference of the battery liquid cooling unit became larger. When the inlet temperature was 20 °C, the maximum temperature difference reached 6.09 °C. When the inlet temperature was 28 °C, the temperature difference basically remained within 5 °C. This indicated that the coolant inlet temperature was not the lower the better. Too low coolant inlet temperature would make the temperature uniformity of the whole battery liquid cooling unit worse. Therefore the coolant inlet temperature should be selected in conjunction with the ambient temperature to avoid the uneven performance of the cold plate.

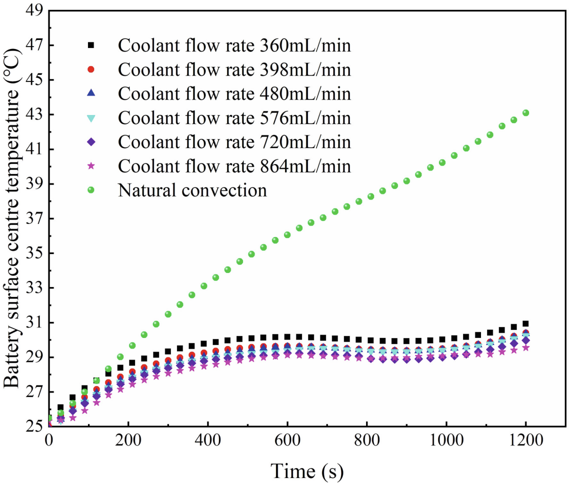

Fig. 7. Cell surface central temperature variation curve at different coolant flow rates.

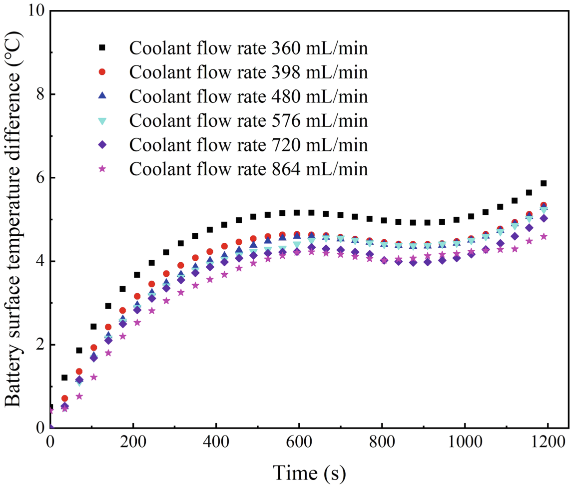

Fig. 8. Cell surface temperature variation at different coolant flow rates.

4 Conclusions

The experiment for the optimal cooling plate obtained by multi-objective optimization showed the relative error between the liquid cooling experiment and simulation were small. As the coolant inlet flow rate increased, the surface central temperature and temperature difference of the battery would decrease. When the flow rate exceeded 398mL/min, further increasing the flow rate would have limited improvement on the cooling effect and temperature uniformity of the battery. The decrease of the coolant inlet temperature would reduce the surface central temperature, but increase the temperature

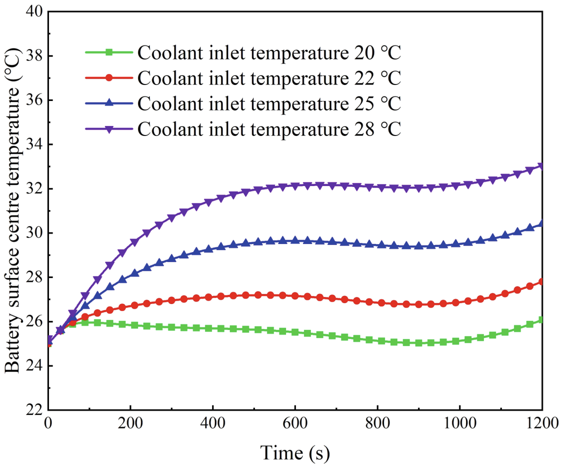

Fig. 9. Cell surface central temperature variation curve at different coolant temperature.

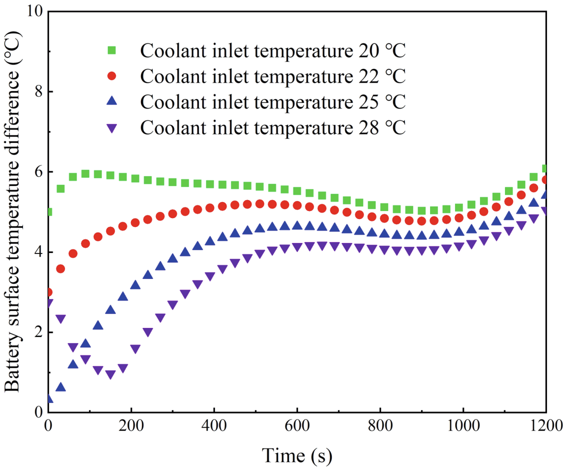

Fig. 10. Temperature difference variation at different coolant temperature.

difference of the liquid cooling unit. Therefore the coolant inlet temperature should be considered comprehensively to avoid uneven performance of the cold plate caused by too high or too low inlet temperature.

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