Study on Heat Transfer Performance of a Liquid Cooling Power Battery

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Abstract. With the development of new energy vehicles, thermal management of power batteries has become a hot research topic. Power battery thermal management has a very important impact on battery life, safety, charging, and other performance. In this paper, the heat transfer performance of a cooling process is studied by establishing a three-dimensional thermal management model of power battery. The results showed that the proportion of heat in the battery taken directly from the coolant was 91.6%, and the proportion of heat absorbed and dissipated into the environment by the components outside the cell by heat transfer and so on was 8.6%.

1. Introduction
The Lithium-ion batteries are widely used in electric vehicles because of their high power and energy density, long cycle times and low self-discharge rates [1, 2]. In low-temperature environments, the battery exhibits a lower electrochemical reaction rate and capacity, and even loses the capacity of charge and discharge. If the electrochemical reaction heat, polarized heat and joule heat produced by the battery in the process of charge and discharge do not disperse effectively in time, the battery temperature will rise sharply. Meanwhile, the battery capacity may decrease due to the decomposition of SEI membrane at high temperature, and even occur the risk of thermal runaway [3, 4]. Nonuniform temperature distribution can also lead to voltage differences between single batteries, which results in the voltage of some individual cells reducing to cut-off voltage ahead of time, greatly reducing the efficiency and life of batteries [5]. Studies have shown that an increase in the temperature difference between the battery pack over 5°C will result in a 10% power decrease [6]. Therefore, for EV and HEV models, a suitable thermal management system is required to keep the battery temperature within the right range.

Thermal management focuses on analysis of liquid-cooled battery packs module or cell-level, and structural optimization of water-cooled plates and cooling channels. For example, the effects of different serpentine cooling channels, the cross-sectional shapes of different cooling plate channels, and the number of parallel coolant channels on the battery temperature have been investigated by relevant researchers [8, 9]. Zhao [10] et al. studied large liquid-cooled lithium-ion battery packs and found that shorter cooling channels can greatly reduce temperature unevenness.

The above research on the thermal management performance of battery pack sedation focuses on the effect of the optimization of water-cooled plate on the temperature field. Unlike these studies, this paper studies battery temperature field distribution, cooling path and thermal performance by establishing a three-dimensional thermal management model of power battery.
2. Power battery thermal model establishment

2.1. Power battery structure model.
The research object is an EV liquid cold battery package, including 14 module series, a box, lid, module and liquid cooling plate, as shown in Fig. 1. At the bottom of the module, the harmonica tube liquid-cooled plate is arranged and the harmonica tube cross-sectional shapes are as shown in Fig. 2. Each module has two NTC temperature sensors to characterize the temperature performance of the module, as shown in Fig. 3. In this paper, the output value of the temperature sensor NTC placement is used as a representation of the temperature of the battery. The battery heat transfer path is shown as Fig.4.

2.2. Power battery structure model

2.2.1. Three-dimensional thermal battery model. The aim of high temperature cooling heat management of power battery is to simulate the thermal heat generation of battery pack system. At the same time, due to the effects of the current, SOC, battery resistance, etc., the heat generation of the power battery is a typical three-dimensional unsteady thermal conduction process, so the thermal model of the square power battery is established as follows:
\[ \rho \frac{\partial T}{\partial t} = \lambda_x \frac{\partial^2 T}{\partial x^2} + \lambda_y \frac{\partial^2 T}{\partial y^2} + \lambda_z \frac{\partial^2 T}{\partial z^2} + Q \]  

Where \( \rho \) is battery density, \( T \) is battery temperature, \( Q \) is heat generation rate, \( \lambda_x, \lambda_y, \lambda_z \) represent heat conduction coefficient of battery in the x, y, z three coordinate directions. The left side of the formula is the energy increment of the battery per unit time, the first three items on the right are the energy increment caused by heat transfer in the unit time, and the fourth item on the right is the energy increment caused by heat production.

2.2.2. Battery heat generation analysis. When the battery pack is operating at high temperatures, the internal heat-producing components include the cells and the copper/aluminum row that acts as an electrical connection, including the copper/aluminum row within and between the modules. The heat generation inside the power battery is determined by the battery heat rate model established in the literature [16], which mainly consists of reversible heat and irreversible heat, and assumes that the heat production inside the battery is evenly distributed. The model is described as follows:

\[ Q_{\text{cell}} = I(U - E_O) + IT \frac{dE_O}{dT} \]  

Where \( I \) represents the charge and discharge current of battery pack, A; \( E_O \) is open voltage, V; \( U \) is operating voltage, V; \( T \) denotes battery temperature, K; \( \frac{dE_O}{dT} \) is temperature impact coefficient, mV/K; \( I(U - E) \) is joule heat. \( IT \frac{dE_O}{dT} \) is irreversible reaction heat.

The heat production of aluminum/copper rows is mainly joule heat generated when the current passes.

\[ Q_{\text{ele}} = I^2 R \]  

Where, \( I \) is the battery charge and discharge current, and \( R \) is the conductive resistance of aluminum row.

3. Numerical analysis of high temperature and high-speed conditions and test verification

3.1. Boundary conditions

The car had been immersed for more than 6 hours at an ambient temperature of 33 centigrade and be soaked until the battery temperature was close to the ambient temperature so as to begin the test. The vehicle was travelling at 120km/h & 3% slope and lasted 30min. At this point, the power requirement of battery's discharge is 75KW. The initial SOC of battery is adjusted to 95%. The cooling flow request is 10L/min. By the battery CAN signal data, the test data such as battery temperature and battery inlet water temperature can be read. Properties of cell is in table 1.

**Table 1. Properties of cell**

| Property | Capacity (Ah) | Weight (Kg) | Thermal conductivity (W/(mk)) | Specific Heat (J/(Kg K)) |
|----------|---------------|-------------|-------------------------------|-------------------------|
| Cell     | 180           | 2.6         | X/Y/Z: 2/25/25               | 960                     |

3.2. Comparison of numerical simulations and experiments

Numerical simulation has been conducted according to above boundary conditions. The temperature simulation results are shown in Fig. 5. Temperature simulation results and test results of the temperature sensor NTC placement are statistically shown in Fig.6. It can be seen from Fig. 6. The maximum temperature is 53.9 centigrade at the M8_NTC1. the temperature distribution trend of NTC location is basically consistent with the experiment. The temperature difference between simulation and test results at each NTC location is up to 1.4 centigrade.
Figure 5. Temperature distribution contour plot for battery pack

Figure 6. NTC position battery temperature (simulation versus test)

Figure 7. Heat transfer statistics for heat transfer paths in battery packs

Figure 7 shows the average heat transfer power of each heat transfer path of the battery pack. From the statistical results, it can be seen that the total heating power obtained by the cell is the heating power of the cell itself and the power from Busbar to the core (4715+164=4879W). The power lost by the cell
through each path is 3672W (3483+90+99). The cooling efficiency of the system is 75.3% (3672/4879*100%). Among them, the proportion of heat taken directly from coolant is 91.6% (3365/3672*100%), and the proportion of heat absorbed and dissipated into the environment by the components outside the cell by heat conduction and is 8.6%.

4. Conclusion
In this paper, the heat transfer performance of a cooling process is studied by establishing a three-dimensional thermal management model of power battery. The results are as follows:

(1) The display temperature sensor NTC position test and simulation results are basically consistent, the temperature difference is up to 1.4 centigrade, which shows that the predicted precision in this paper is acceptable.

(2) The proportion of heat in the battery pack that is taken directly by coolant is 91.6%, and the proportion of heat absorbed and dissipated into the environment by components outside the cell by heat transfer, etc., is 8.6%. Through this paper, a high-precision thermal management simulation analysis method of power battery can be obtained, which can effectively support the development of battery thermal management performance.

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