Optimization of the Heat Dissipation Structure and Temperature Distribution in an Electric Vehicle Power Battery

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Abstract: In order to ensure that the lithium-ion battery pack keeps good working performance during the driving of electric vehicle, the heat generation mechanism and heat transfer characteristics of lithium-ion battery are analyzed. The power battery pack of electric vehicle is simulated by advanced vehicle simulator. The simulation results of battery pack current under typical cycle conditions and the heat source curve of lithium ion battery are obtained, which provide data for the simulation of heat source input of battery temperature field. On this basis, the flow field and temperature field of the original lithium-ion battery pack of electric vehicle are simulated by using computational fluid dynamics method. The influence of different air passage spacing and air inlet angle on the temperature field of lithium ion battery pack was analyzed. The optimization scheme of heat dissipation structure of lithium ion battery pack was put forward, and the numerical simulation analysis of the optimization scheme was carried out. The results show that the heat dissipation effect of the heat dissipation structure is obviously improved by choosing the appropriate air inlet and the combined air passage spacing, and it is beneficial to the uniformity of the temperature of the single battery. The maximum temperature of the battery pack is reduced by 3.8℃, and the temperature difference of the battery pack is reduced by 2.2℃.

Keywords: Electric vehicle, lithium-ion batter, temperature field, FLUENT.

1 Introduction

With the further popularization and use of electric vehicles, lithium-ion batteries have become the preferred batteries for electric vehicles because of their high energy ratio, high voltage characteristics and long service life. At the same time, power batteries are sensitive to temperature change. If lithium-ion batteries work in high temperature for a long time, their discharge capacity will increase correspondingly, but their aging degree will increase sharply, and their service life will also be seriously affected. When the temperature of lithium batteries exceeds a certain limit, there may even be the danger of expansion, leakage and explosion, which seriously affects daily life and personal safety. According to literature, the optimum operating temperature of lithium batteries is

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18~45℃, and the acceptable range of temperature difference should not be higher than 10℃.The importance of thermal management of battery packs temperature is an important factor affecting the safety, performance and life of lithium ion batteries. When the temperature is too high, the battery will accelerate aging; when the temperature is too low, the performance of the battery will obviously decline, but also accelerate aging; extreme high temperature will cause irreversible damage to the battery, and even damage the battery in serious cases. In addition, excessive temperature difference between single batteries will affect the consistency of batteries, thus reducing the performance and life of batteries. Therefore, thermal analysis of temperature field of lithium batteries is very important to promote the application of batteries in electric vehicles.

In this paper, the heat generation model and three-dimensional heat dissipation model of lithium-ion battery packs are established by using computational fluid dynamics (CFD) method. The temperature distribution law of battery pack is simulated and analyzed. The heat dissipation structure of battery pack is optimized. The influence of air passage spacing and air inlet angle on the temperature distribution of battery pack is discussed.

2 Heat transfer characteristics of lithium battery packs

2.1 Structural and thermophysical parameters of batteries

Batteries in working state generate Joule heat, polarization heat, electrochemical reaction heat and side reaction heat. The cooling environment of batteries is controlled by the thermal management system of batteries. In order to reduce the complexity of the calculation of temperature field, the performance parameters of batteries are calculated by the method in reference, the heat conduction is obtained by weighted average calculation along x, y and Z directions respectively. The specific heat capacity is calculated by weight method according to the specific heat mass of each substance in the battery. The density is simplified as the ratio of the mass of the battery to the volume of the battery. The structure parameters and thermophysical properties of the cell are shown in Tab. 1.

Table 1: Structural parameters and thermophysical properties of single cell batteries

Parameter	Numerical value
X-direction thermal conductivity/W/(m.K)	0.9
Y-direction thermal conductivity/W/(m.K)	2.7
Z-direction thermal conductivity/W/(m.K)	2.7
Density/kg/m^3	3000
Specific heat capacity/J/(kg.k)	1100
Cell length/mm	140
Cell width/mm	70
Cell height/mm	220
Cell voltage/V	3.2
Cell capacity/Ah	100

2.2 Heat dissipation model of battery pack

In reference, the thermal model of batteries is used to study the thermal management of batteries. The essence of the thermal model of batteries is the energy conservation equation of each cell in batteries. It is assumed that the dielectrics of the materials that make up the battery are uniform and the density is the same; the specific heat of the same material is the same value and the heat transfer coefficients are the same in all directions; the current density is uniform in all parts of the battery when the battery is charged or discharged. Based on the above assumptions, a three-dimensional unsteady heat transfer model in rectangular coordinates of battery packs can be obtained.

$$\rho C_{\mathrm{p}} \frac{\partial \theta}{\partial t} = \lambda_x \frac{\partial^2 \theta}{\partial x^2} + \lambda_y \frac{\partial^2 \theta}{\partial y^2} + \lambda_z \frac{\partial^2 \theta}{\partial z^2} + Q_z \tag{1}$$

where ρ is the density of heat transfer medium; C_P is specific heat; θ is temperature; t is time; λ_x , λ_y and λ_z are heat transfer coefficients along X, Y and Z directions; Q_z is calorific value.

The essence of calculating the temperature field inside the battery is the heat transfer differential equation shown in the solution Eq. (1). To solve the above equation, three key problems must be solved: (1) accurate expression of heat generation; (2) accurate acquisition of thermophysical parameters ρ ,C_P and λ ; (3) accurate determination of definite conditions (initial and boundary conditions).

2.3 Calorific value of battery pack

The calorific value of lithium battery is composed of reaction heat, polarization heat, joule heat and side reaction heat. Reaction heat is the heat generated by electrochemical reaction during charging and discharging, which is reversible. Joule heat is the heat generated by the work done by the internal resistance of the battery when lithium ions and electrons migrate between the positive and negative electrodes in the battery system. When lithium-ion batteries are working, the material on the cathode and cathode materials is not uniform due to the current action, which results in polarization phenomenon. The open-circuit voltage and the end voltage of batteries produce voltage drop, which results in polarization heat. Side reaction heat is the heat generated by the internal electrolyte and the decomposition of electrode materials when the battery is overheated or overcharged. Because the heat of side reaction is too small to be neglected compared with the other three parts, the heat of side reaction is generally not considered in practical calculation.

$$Q_1 = \frac{nmQI}{MF} \tag{2}$$

where Q_1 is reaction heat, n is the number of cells, m is the mass of the electrodes, Q is the algebraic sum of the heat generated by the electrochemical reaction, I is the current, M is the molar mass, F is the Faraday constant.

$$Q_2 = I^2 R_{\mathrm{p}} \tag{3}$$

where Q_2 is polarization heat; R_p is the polarized internal resistance.

$$Q_3 = I^2 R_e \tag{4}$$

where Q_3 is joule heat, R_e is Joule internal resistance.

The total calorific value of the battery $Q_z = Q_1 + Q_2 + Q_3$ (5)

When the temperature of lithium ion batteries reaches 70~80°C, the reaction heat accounts for a large proportion of the total heat produced by the batteries, and when the charge and discharge temperature is lower than the above temperature, the Joule heat accounts for a large proportion. Generally, the normal working temperature of lithium ion batteries is -20~65°C. Therefore, the calorific value of lithium ion batteries is mainly composed of polarization heat and Joule heat.

In addition to calculating the heat generation of lithium batteries as described above, there is a simpler theoretical analysis method. Assuming that the heat source inside the battery is stable and the heat generation is uniform, there is a model of the heat generation rate of the battery. The calculation equation is as follows:

$$\mathrm{q} = \frac{1}{V_b}\left(I^2 R_e + IT\frac{\partial U_{ocp}}{\partial T}\right) \tag{6}$$

where V_b is the volume of the battery, $\frac{\partial U_{ocp}}{\partial T}$ is the temperature coefficient, and its value is affected by chemical reaction.

3 Current variation of battery pack in electric vehicle

In order to obtain the current law of electric vehicle driving under typical operating conditions, the data of calorific value for subsequent analysis of temperature field of battery pack are provided. Based on ADVISOR software, this paper establishes the simulation model of the power performance of the electric vehicle, and simulates the power performance and driving mileage of the electric vehicle prototype. The simulation results are compared with the design objectives of the whole vehicle. The correctness and rationality of the simulation model are confirmed, and the current variation law of the battery pack when the electric vehicle is running is obtained by using the model.

3.1 Main technical parameters and design objectives of the vehicle

The main technical parameters of the electric vehicle provided by an automobile company are shown in Tab. 2. According to these parameters, the simulation model of the electric vehicle is established. The design objectives of electric vehicles are as follows:

1. Maximum gradient ≥20%;
2. Acceleration time: 0~50 km/h≤10 s, 0~80 km/h≤15 s;
3. Driving mileage≥160 km.

Table 2: Main technical parameters and design objectives of the vehicle

Name of parameter	Values	Name of parameter	Values
Vehicle quality(kg)	1500	Driving System Efficiency	0.9
Full load quality(kg)	1900	Distance between centroid and front axle(mm)	1300
Tire rolling radius(mm)	298	Windward area(m^2)	2.3
Wheelbase(mm)	2605	Drag coefficient	0.3
Centroid height(mm)	0.52	Rolling resistance coefficient	0.01

3.2 Simulation of electric vehicle cycle conditions

This paper chooses EUDC working condition among various test conditions provided by Advisor, because this condition is one of the typical test conditions of emission regulations in China. As shown in Fig. 1, the total mileage of the working condition is 10.93 km, including four urban cycle conditions and one suburban cycle condition. During the urban internal cycle test, 12 parking conditions are carried out, with the maximum speed not exceeding 50 km/h. After the urban cycle test is completed, the suburban cycle test is carried out, with the maximum speed reaching 120 km/h. At the end of the simulation test, the simulation results of battery pack current and the heat source change curves of battery pack can be obtained, as shown in Figs. 2 and 3.

As can be seen from Fig. 2, the change of current is similar to that of electric vehicle. During the four cycle test stages in city, the change of battery current is small, and the discharge current is below 50 A. In the suburban test stage, the maximum discharge current of battery group reaches 201 A. Comparing with the speed curve of EUDC, it can be seen that the discharge current of battery pack increases sharply when the vehicle runs at a higher speed.

From the variation curve of the battery heat source in Fig. 3, it can be seen that the heating rate of the battery pack also increases in the same period. In the urban cycle condition, the maximum heat generated by battery packs is only 1300 W/m3, but in the suburban test stage, the heat generated increases sharply, reaching a maximum of 24000 W/m3. It can be seen that under suburban conditions, the heating rate of battery packs is higher, and the requirements for heat dissipation system of battery packs are more stringent.

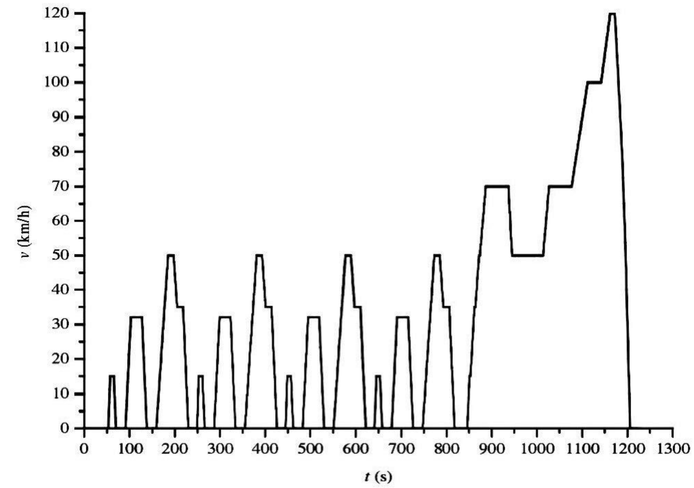


Figure 1: Vehicle speed change curve under EUDC conditions

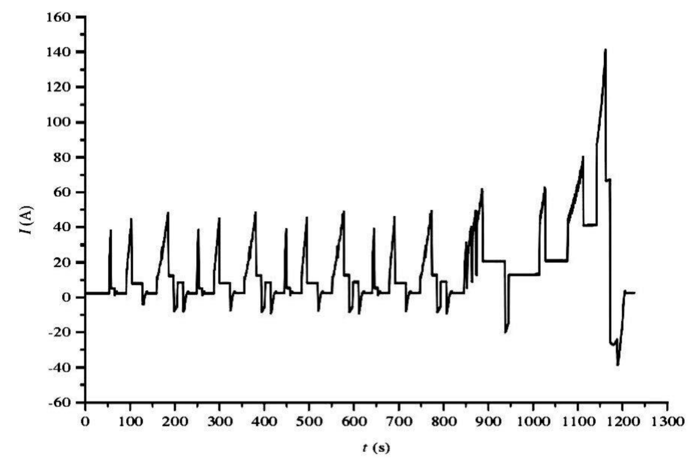


Figure 2: Simulation results of battery pack current under EUDC condition

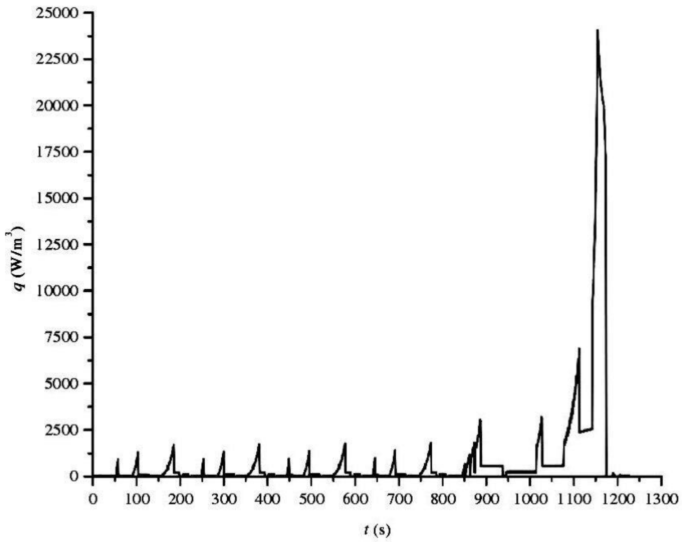


Figure 3: Change curve of battery heat source under EUDC conditions

4 Heat dissipation structure and temperature field simulation of battery pack

4.1 Heat dissipation structure

Parallel ventilation is used for heat dissipation, as shown in Fig. 4. This kind of heat dissipation structure is not only conducive to ensuring the heat dissipation effect of battery pack, but also conducive to the consistency of cell temperature. The angle between the bottom of the battery and the bottom of the bracket is defined as the angle of the air inlet. The preliminary design is 3°. The air passage, i.e., the distance between the battery and the bracket is set to 5 mm.

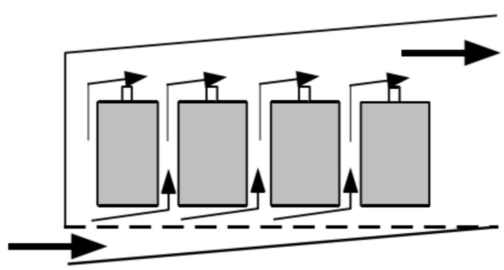


Figure 4: Parallel ventilation structure

4.2 Heat dissipation structure

During the operation of the vehicle, the battery pack generates heat, and the airtight air in the battery pack is heated and expanded. Convective heat transfer is formed between the airtight air and the battery pack. The heat is further transferred to the battery pack. During the driving of the vehicle, the battery pack also generates convective heat transfer with the incoming air. The heat transfer coefficient of the front end of the battery pack can be calculated by Eqs. (7) and (8).

$$\frac{hl}{K_{air}} = Num \tag{7}$$

$$Num = 0.0308 \times R_{ex}^{\frac{4}{5}} . P_{r}^{\frac{1}{3}} \tag{8}$$

where, L is geometric characteristic dimension, for flat plate, the geometric length is generally taken as the geometric characteristic dimension, and the coefficient of air thermal conductivity is *K*air=0.02624 when the air temperature is 300 K, which is Plante number; Pr=0.702, which is Reynolds number.

In ANSYS Fluent, the energy equation and turbulence model are selected, and the MSMD battery model is loaded. Define the conductive region and the positive and negative poles. The type of Velocity-inlet is set as the velocity inlet, which is 3 m/s in size and 25°C in initial temperature. Set the type of Outflow to Free Flow. The Outside-walls of the battery box is set as the adiabatic wall, and the Fluid-interface and the solid-interface contacted with the fluid domain are set as the coupled wall. The heat dissipation process of the whole battery pack is simulated by setting the step length to 1 s and the step number to 4000. The simulation results are shown in Fig. 5.

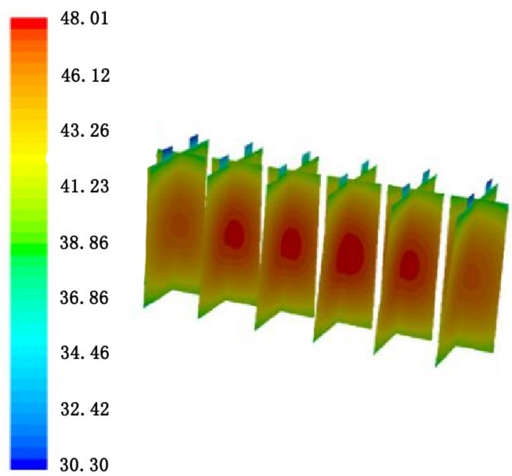


Figure 5: Cloud map of heat dissipation temperature distribution of battery pack

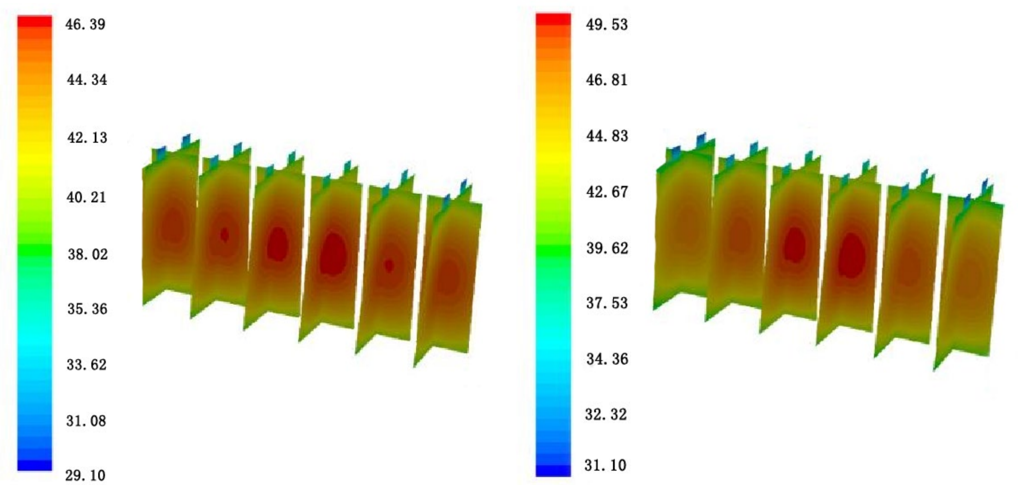
From the simulation diagram, it can be seen that the temperature of the intake side and the outlet side is lower, and the temperature of the battery in the middle position is higher. Because the condition of heat diffusion in the middle position of the battery is the most disadvantageous, and with the heat exchange between the air and the surface of the battery, the heat is taken away by the air, and the closer the air is to the outlet, the higher the temperature is. The maximum temperature of the battery pack is the fourth battery on the right side of the middle, the temperature is 48.01°C, the minimum temperature is 30.30°C, and the maximum temperature difference between single batteries is about 8°C. Although the maximum temperature is still within the operating temperature range of the battery, it is still in a high position, which is not the best operating temperature of the battery. And the temperature consistency of single battery is poor, which has a direct impact on the service life of the whole battery, so it is necessary to optimize the heat dissipation structure to improve the heat dissipation effect.

5 Optimization of heat dissipation structure of battery pack

5.1 Effect of structural parameters on heat dissipation

5.1.1 Effect of airflow channel spacing on battery temperature field

The distance between air passages is directly related to the resistance of air flow and the speed of heat diffusion of batteries. The battery spacing is set to 4 mm and 6 mm, respectively. The temperature field distribution of the battery pack is simulated for three times, and the nephogram is shown as (a) and (b) in Fig. 6.



(a) Air channel spacing is 4 mm (b) Air channel spacing is 6 mm

Figure 6: Cloud map of temperature field distribution with different air channel spacing

From the temperature distribution cloud of the battery pack, it can be seen that the larger the distance between air passages, the better the heat dissipation effect, and the lower the overall temperature of the battery pack. In the simulation of heat dissipation temperature field of galvanic battery pack, the air passage interval is 5 mm, and the maximum temperature is 48.0°C. In the simulation of the heat dissipation temperature field of the battery pack, when the air passage interval is 4 mm, the maximum temperature is 49.6°C, which is 1.6°C higher than that when the air passage interval is 5 mm. When the air passage interval is 6 mm, the maximum temperature is 46.4°C, which is 1.6°C lower than that when the air passage interval is 5 mm. It can be seen that the heat dissipation effect of battery pack is more and more remarkable with the increase of air passage interval. The heat dissipation structure can be optimized according to the volume of the whole battery box. As can be seen from the temperature distribution cloud of the battery pack, the highest temperature battery is located in the middle, and its heat dissipation needs to be further strengthened. Therefore, consider reducing the interval of air passage from the middle to both sides, and place the maximum interval in the middle of the highest temperature.

5.1.2 Effect of inlet angle on temperature field

The air inlet angle directly affects the pressure difference and velocity of the gas flow in the battery box and the heat dissipation effect of the heat dissipation structure of the battery pack. Comparing with the heat dissipation structure of the primary battery pack, the simulation of the heat dissipation temperature field of the battery pack is carried out by changing the angle of the tuyere to 6°. The simulation results are shown in Fig. 7. Comparing the temperature field simulation of the original heat dissipation structure with the inlet angle of 3°, shows that the maximum temperature of battery pack decreases with the increase of the inlet angle. When the inlet angle is 3°, the maximum temperature is 48.0℃, and when the inlet angle is 6°, the maximum temperature is 46.9℃. The difference between the two maximum temperatures is 1.1℃. It can be seen that the heat dissipation effect is obviously improved with the increase of the inlet angle. However, if the inlet angle is too large, serious reflux phenomenon may occur in the internal air flow, which is not conducive to the heat dissipation of the battery pack.

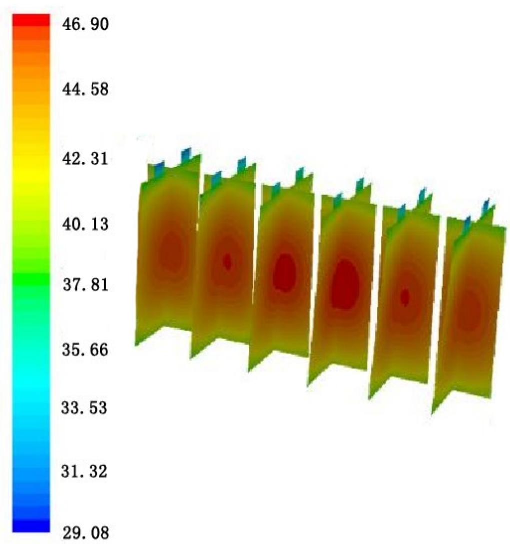


Figure 7: Cloud map of temperature field distribution with inlet angle 6°

5.2 Optimization of heat dissipation structure

According to the above research on the influence of air passage interval on the distribution of heat dissipation temperature field of batteries, it can be seen that with the increase of air passage interval, the better the heat dissipation effect is. However, the increase of air passage interval spacing will increase the volume of battery pack, which is not conducive to the layout of battery pack. At the same time, We found in the research results that the middle temperature of the battery pack is high. in order to improve the uniformity of cell temperature, the air passage interval is optimized to decrease from the middle to both sides, and the cell spacing from the intake to the outlet is 4 mm, 5 mm, 6 mm, 5 mm and 4 mm respectively. For each cell, the gas flow through the surface is uneven, but for the cells in the middle position, more cooling air can be exchanged. At the same time, in order to avoid the reflux phenomenon caused by too large angle, the angle of the tuyere is optimized to 6°.

The simulation results of the original heat dissipation structure and the simulation results of the heat dissipation temperature field of the battery pack after the optimization of the heat dissipation structure are shown in Figs. 5 and 8 respectively. The maximum temperature curve before and after optimization of heat dissipation structure is shown in Fig. 9. It can be seen from the simulation results of the original heat dissipation structure that the maximum temperature is located in the center of the fifth battery, the temperature is 48.0℃, and the maximum temperature difference of the single battery is 6.0℃. From the simulation results of optimized battery temperature field, it can be seen that the maximum temperature is 45.1℃, which is 2.9℃ lower than the original maximum temperature of heat dissipation, and the heat dissipation effect is obviously improved. The maximum temperature difference of single cell battery is 3.8℃, and the temperature difference is reduced by 2.2℃, which meets the requirement of temperature consistency of single cell battery.

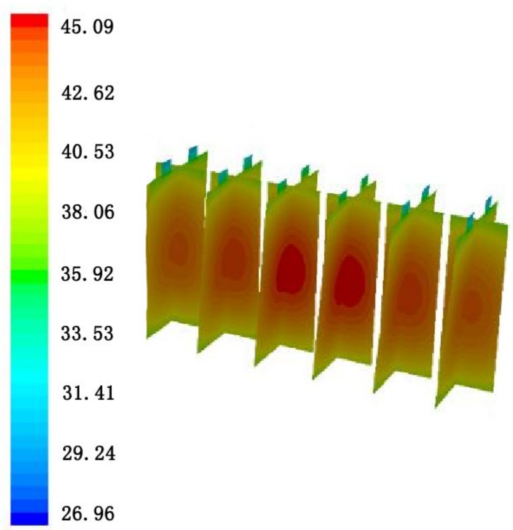


Figure 8: Simulation results of optimized temperature field

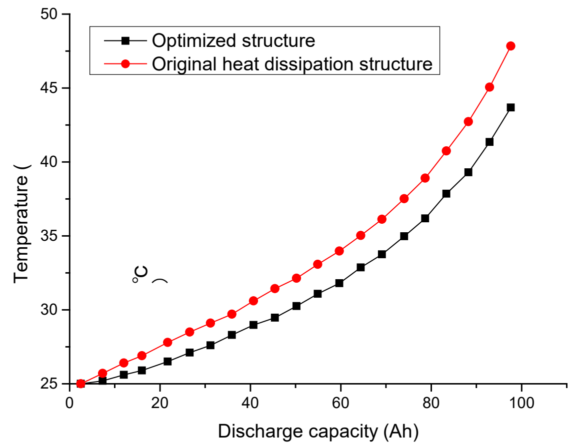


Figure 9: Maximum temperature curve before and after optimization of heat dissipation structure

6 Conclusions

In this paper, the simulation models of the main components and the whole vehicle of the electric vehicle are established by using the simulation software (ADVISOR), and the power performance and driving mileage of the whole vehicle are simulated. The simulation results show that the model is correct and reasonable. The current variation law of electric vehicle is obtained by using this model, and the temperature field of lithium ion battery pack is modeled and simulated by using computational fluid dynamics software FLUENT. The results show that the temperature rise of the original battery pack is high and the uniformity is poor, which affects the performance of the battery pack. Finally, an optimization scheme is proposed to change the distance between air passages and the angle of air intake. The results show that the heat dissipation effect of the heat dissipation structure is obviously improved by choosing the appropriate air inlet and the combination of air passage spacing, and it is conducive to the uniformity of cell temperature.

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