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ARTICLE

Numerical Simulation of Thermal Management of Lithium Battery Based on Air Cooled Heat Dissipation

Zhenhua Li*

Sangdun New Energy Technology Co., Ltd., Xiangtan, Hunan, 411202, China

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ABSTRACT

In recent years, due to the rapid increase in the number of vehicles in the world, the traditional vehicles using gasoline or diesel as energy have led to serious air pollution and energy depletion. It is urgent to develop practical clean energy vehicles. The performance of electric vehicle depends on the power battery pack. The working temperature of the battery pack has a great impact on the performance of the battery, so it is necessary to carry out thermal management on the battery pack. Taking a lithium-ion battery as the research object, the temperature field of the battery pack in the charge and discharge state is simulated and analyzed by using CFD simulation software in the way of air cooled heat dissipation, so as to understand the influencing factors of uneven temperature field. At the same time, the development trend of battery temperature can be well predicted through simulation, so as to provide theoretical basis for the design of battery pack.

1. Introduction

Automobile is an important part of modern civilization. It not only promotes social development, but also causes increasingly serious energy crisis and environmental pollution. Severe energy and environmental challenges make the transformation of transportation energy become the main task faced by the automotive industry, and the electrification of automotive power system becomes an inevitable trend [1]. Battery pack is the only power source of pure electric vehicle. Its working performance is very important for electric vehicle, and the temperature of battery pack is also very important for the performance and service life of battery pack. The thermal management of battery pack directly affects the performance of the whole vehicle. If the temperature of the battery pack is too high and beyond the normal working range, the generation of irreversible substances in the battery pack will be accelerated. At the same time, due to the difference of working state of each battery unit, the temperature difference of the battery pack will be large, which will aggravate the difference of charge and discharge state of the battery pack, resulting in less cycle service life of the battery pack. When the temperature reaches the ignition point of the battery material, it will even cause the battery pack to catch fire; when the battery pack works at low temperature, dis-

*Corresponding Author:

Zhenhua Li,

Sangdun New Energy Technology Co., Ltd., Xiangtan, Hunan, 411202, China;

Email: 1957876517@qq.com

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charge efficiency of the battery pack will be reduced. The batteries of electric vehicles are connected in series. If the temperature of any single unit is too high or too low, it will affect the whole battery pack. If the battery pack is in the state of large temperature difference for a long time, the imbalance of battery capacity in the battery pack will affect the capacity of the whole battery pack. Therefore, thermal management must be carried out for the battery pack.

Simply changing the ventilation mode cannot achieve the best heat dissipation effect. In recent years, researchers all over the world have optimized the structure of the battery pack to improve the heat dissipation effect. In terms of air cooled heat dissipation, Anthony Jarrett et al. studied the heat dissipation plate structure of electric vehicle high-energy battery, and studied the use of air cooling to cool the battery pack, and optimized length and width of the cooling channel. CFD software is used for simulation to obtain the pressure drop and average temperature rise of cooling air, and then arbitrarily change the shape of cooling channel to compare the heat dissipation effect. The results show that any of the above designs can meet the requirements of fluid pressure drop and average temperature rise. By comparing the optimization results, they designed the cooling channel of the heat dissipation plate as a serpentine channel [2].

Kelly et al. conducted real vehicle test of power battery pack air cooling system based on Honda Insight and Toyota Prius. The experiment selected the working mode of the fan in real time according to the ambient temperature distribution of the battery in the battery pack. The experimental results show that the temperature difference between the battery cells of the two battery packs is small, and the ambient temperature of the battery pack is within the normal working temperature range of the battery pack. Khodadadi J.M. et al. studied the spacing between cells of the battery pack and the air inlet flow rate of the battery pack to optimize the maximum temperature and temperature uniformity of the battery pack, and compared the advantages and disadvantages in terms of heat dissipation effect and battery pack tightness through unilateral heat dissipation and bilateral heat dissipation experiments of the battery pack. Finally, a better heat dissipation model was obtained through mathematical analysis. Xu X.M. and He R. analyzed the influence of the inlet and outlet position of the battery pack and the battery layout on the battery heat dissipation effect, and studied the ventilation form of the battery pack through the battery pack heat dissipation experiment and software simulation analysis [3].

In this paper, the temperature rise characteristics of lithium-ion battery in charge and discharge state and the heat dissipation temperature field of battery pack in charge and discharge state are analyzed by combining theoretical analysis and simulation analysis, so as to ensure that the ambient temperature of battery pack is maintained in a certain range and improve the performance and safety of battery pack.

2. Temperature Field Simulation of Lithium Battery Pack

2.1 Establishment of Geometric Model of Battery Cell

The charging mode of power lithium battery generally adopts the mode of constant voltage and current limiting to avoid the battery exceeding the upper voltage limit. Under the condition of good control, the power lithium battery will not have side reactions during charging and discharging. Therefore, the internal reaction heat of power lithium battery have three parts: polarization heat Q_1, Joule heat and reaction heat Q_3. When the temperature of power lithium battery reaches 70 °C~ 80 °C, most of the total heat produced by the battery is reaction heat. When charging and discharging below the above temperature, most of the heat is Joule heat. Generally, the normal working temperature range of power lithium battery is –20 °C~ 65 °C. Therefore, the heat generation of power lithium battery during operation are mainly polarization heat and Joule heat Q_2 [4].

$$Q_a = Q_1 + Q_2 = I^2R_1 + I^2R_2 = I^2R_a \quad (1)$$

Where Q_a is the total calorific value of power lithium battery, J; I is the current during charging and discharging of power lithium battery, A; R_1 is the polarization internal resistance of power lithium battery, Ω; R_2 is the internal resistance when electrons flow in power lithium battery, Ω; R_a is the total internal resistance of power lithium battery during charging and discharging, Ω.

Heating power per unit volume of power lithium battery, that is body heat source:

$$q = Q_a/V = I^2R_a/V \quad (2)$$

Where V is the volume of power lithium battery, m^3.

Lithium ion battery will produce a lot of heat in the working process. If the battery is not dissipated timely and effectively, it will not only seriously affect the working performance and working cycle of the battery, but also cause spontaneous combustion or explosion of the battery. To load the cooling system on the battery to improve the working environment temperature of the battery pack, we must first understand the thermal behavior of the battery. Using the simulation software can effectively simulate the thermal behavior and temperature rise of the battery. In this paper, SolidWorks is used to establish the geometric model of the battery, and star CCM + is used to simulate and analyze the temperature field of the battery in the charge and discharge state. The main parameters of the battery are shown in Table 1.

Table 1. main performance parameters of lithium ion battery

battery type	soft pack lithium battery
nominal voltage/V	3.2
nominal capacity /Ah	10
internal resistance /mΩ	≈10
charging current /A	≤10
continuous discharge current /A	≤20
maximum discharge current /A	50
upper cut-off voltage /V	3.65±0.05
lower cut-off voltage /V	2.5
cycle life	≥2000
battery weight /g	275±5
size/mm	209×107×7.5

2.2 Battery Pack Modeling

Taking the soft packaged lithium battery for pure electric vehicle as the object for modeling, the modeling should not only truly reflect the heat dissipation of power single lithium battery, but also reasonably set the number of variables to simplify the subsequent calculation workload. The modeling is composed of 144 single cells, which are arranged in columns and rows, and the overall dimension of the single cell is 209 mm×107 mm×7.5 mm. The external dimension and shape of the model are consistent. There are three air inlet and outlet openings with the same size and shape. The spacing between modules and between modules and the inner wall of the box is 10 mm. The power lithium battery pack with two arrangement modes of column and row is meshed by ICEM software, and the fluid area grid is encrypted to generate unstructured grid. The geometric model of the generated grid is shown in Figure 1. The overall grid model of each power lithium battery pack has about 1.5 million grid units. Unsteady state calculation is carried out, and standard turbulence model is selected. In the treatment of wall function, the standard wall function with wall boundary conditions is provided by logarithmic correction method. The computational domain is divided into air fluid domain and battery solid domain. The heat transfer mode between battery surface and air is coupled heat transfer. The heating power of power lithium battery changes with working conditions. Convective heat transfer is conducted on the external surface of the box, and the convective heat transfer coefficient is 5 $W/(m^2 \cdot K)$; SIMPLE algorithm is selected for the coupled mode of pressure and velocity; The second-order upwind scheme is used for the discretization of momentum, energy and pressure equations; The number of iteration step is 5000.

To establish an effective battery thermal management system, it is necessary to understand the internal temperature distribution of the battery pack. Through simulation analysis, we can roughly understand the temperature field distribution in the battery pack, and then optimize the structure of the battery pack according to the analysis results, so as to gradually establish an effective battery pack heat dissipation system. The battery pack contains 12 battery modules, and three fans are used to extract air. The geometric modeling of the battery pack is carried out through SolidWorks. The model is shown in Figure 1.

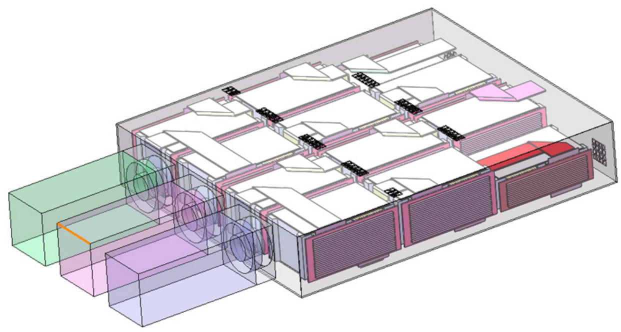

Figure 1. geometric model of battery pack

2.3 Battery Pack Simulation

When using star CCM + software for simulation calculation, the following assumptions are put forward for the whole simulation model: in the flow field inside the battery pack, the fluid is regarded as an incompressible ideal fluid without considering gravity and buoyancy; there is no relative sliding between the air and the battery and the inner wall of the pack; the inertial force of the fluid is ignored and the boundary pressure is zero, and ignore the thermal deformation of the whole system; the lithium battery is set as a constant heating source, and the air inlet is uniform air inlet conditions; radiation heat dissipation is not considered for the whole battery pack; it is assumed that the density and specific heat capacity of the single cell are constant; in the same direction, the thermal conductivity of the battery is not affected by SOC and temperature; when the battery is charged and discharged, the internal current density of the battery is uniform. See Table 2 for physical parameters of battery pack and Table 3 for fan parameters.

Table 2. material parameters of each part of the model

material	density kg/m^3	specific heat capacity $J/(kg*K)$	thermal conductivity $W/(m*K)$
aluminum alloy	913	2710	201
foamed silica gel	820	324	0.04
EVA foam	850	101	0.085
ABS+PC	1150	1300	0.24
coolant	1062	3305	0.418
battery cell	1933	1080	axial 0.66, radial 22.3
air	1.279	1006	0.024

Table 3. the parameters of fan system parameters

wind pressure (Pa)	375	250	187.5	150	125	0	speed (rpm)	size(mm)
air quantity (m/s)	0	0.02359	0.004719	0.07079	0.09439	0.11798	5000	140×140×51

2.4 Governing Equations of Computational Fluid Dynamics

In the process of fluid flow, three conservation laws are observed: the law of mass conservation, the law of momentum conservation and the law of energy conservation. In computational fluid dynamics [5,6], there should be: mass conservation equation, momentum conservation equation and energy conservation equation.

(1) Mass conservation equation

$$\frac{\partial\rho}{\partial t}+div(\rho U)=0 \tag{3}$$

Where ρ is the fluid density; U is the velocity vector.

(2) Momentum conservation equation

$$\frac{\partial(\rho u)}{\partial t}+div(\rho uU)=div(\mu grad u)-\frac{\partial p}{\partial x}+S_u \tag{4}$$

$$\frac{\partial(\rho v)}{\partial t}+div(\rho vU)=div(\mu grad v)-\frac{\partial p}{\partial y}+S_v \tag{5}$$

$$\frac{\partial(\rho w)}{\partial t}+div(\rho wU)=div(\mu grad w)-\frac{\partial p}{\partial z}+S_w \tag{6}$$

Where ρ is the fluid density; u, v, w are the velocity components of velocity vector U in x, y, z directions respectively; μ is hydrodynamic viscosity; S_u, S_v, S_w are the generalized source term of the momentum conservation equation.

(3) Energy conservation equation

$$\frac{\partial(\rho T)}{\partial t}+div(\rho UT)=div\left(\frac{k}{C_p}grad T\right)+S_T \tag{7}$$

Where k is the heat transfer coefficient of the fluid; C_p is the specific heat capacity of the fluid; S_T is viscous dissipation term.

(4) Differential equation of heat conduction in battery

$$\rho C\frac{\partial T}{\partial t}=\lambda_x\frac{\partial^2 T}{\partial x^2}+\lambda_y\frac{\partial^2 T}{\partial y^2}+\lambda_z\frac{\partial^2 T}{\partial z^2}+q \tag{8}$$

Where ρ is the cell micro cell density; C is the specific heat capacity of micro cell of battery; λ is the thermal conductivity of battery micro element; q is the heat generation rate of battery micro element.

2.5 Thermal Management Simulation Strategy

The working condition of discharge: under the ambient temperature of 25 °C, the initial temperature of the system is 25 °C, and the total current of the battery pack is 2000 A, discharging for 4S (the heating power of cell is 19040 W; the heating power of collecting current aluminum bar is 2252.5 W; the heating power of welding aluminum bar is 43 W; the heating power of aluminum lug is 726.8 W, and the heating power of copper plate is 1805.2 W); then stop for 1S, and a total cycle is 5S; the discharging lasts for 10 cycles while the fan remains on.

The working condition of charge: keep the fan on, the total current of the battery pack is 150 A, charging for 900S (the heating power of cell is 816 W; the heating power of collecting current aluminum bar is 12.7 W; the heating power of welding aluminum bar is 0.24 W; the heating power of aluminum lug is 4.1 W, and the heating power of copper plate is 10.2 W).

3. Analysis of Simulation Results

Using the third-party post-processing software, the high and low temperature curves of each monomer of power lithium battery shown in Figure 7 are obtained. Among them, 35 monitor is the maximum temperature curve of each monomer in column and row arrangement batteries, and 20 monitor is the minimum temperature curve of each monomer in column and row arrangement batteries. It can be seen from the curves in Figure 7 that the maximum temperature of monomers in column arrangement batteries is generally lower than that in row arrangement batteries. The maximum temperature change of each single cell in column arrangement batteries is relatively gentle, and the maximum temperature change of each single cell in row arrangement batteries is relatively rapid. The maximum temperature of 2 monitor to 11 monitor cells in column arrangement batteries decreases steadily, and the maximum temperature of 1 monitor and 12 monitor cells has a large temperature difference from their adjacent cells, but within the allowable temperature difference range. In the row arrangement batteries, the single battery of 1 monitor to 26 monitor are set as group I, and the single battery of 27 monitor to 46 monitor are set as group II. In each group of row arrangement batteries, the maximum temperature of each single cells presents the same arch distribution law, that is, the maximum temperature of 1 monitor to 26 monitor single cells presents a symmetrical distribution law. The maximum temperatures of 1 monitor and 6 monitor cells are almost the same and lower than those of 2 monitor to 5 monitor cells, and the maximum temperatures of 3 monitor and 4 monitor cells are slightly higher than those of 2 monitor and 5 monitor cells; Similarly, group II composed of 27 to 46 monitor single cells presents the same maximum temperature law. From the overall analysis of group I and group II, the maximum temperature of the single cell of group I is about 2.5 °C higher than that of the corresponding single cell of group II. According to the curve in Figure 7, the distribution law of the lowest temperature of each monomer in the two arrangement batteries of column and row is consistent with the distribution law of the highest temperature of each monomer in the two arrangement batteries of column and row. The maximum and minimum temperature curves of each monomer in column arrangement batteries are better than those in row arrangement batteries. That is, the column arrangement batteries are better in terms of maximum and minimum temperature. It can be seen from the temperature curve of each cell in the column arrangement batteries that the temperature difference between 1 monitor and 12 monitor cells is small, and the temperature difference between 2 to 11 monitor cells are large. In the column arrangement batteries, the temperature difference of 2 monitor single battery is the largest. It can be seen from the temperature curve of each cell in the row arrangement batteries that the temperature difference of each cell in group I and group II also presents an arch distribution law. The temperature difference of the single cells of group I is about 1 °C higher than that of the corresponding single cells of group II. In the row arrangement batteries, the temperature difference of 4 monitor single cells in the middle of group I is the largest.

The air cooling effect of heat dissipation of power lithium battery is closely related to the surface of single battery and the contact area of cold air. The single battery with large contact area between the column arrangement batteries and cold air are 1 monitor and 12 monitor, so they have good heat dissipation effect, low temperature and small temperature difference; In the row arrangement batteries, the single battery with large contact area with cold air are 1 monitor, 6 monitor, 7 monitor and 12 monitor, so they have good heat dissipation effect, low temperature and small temperature difference. The column arrangement batteries have good correlation between individual cells and small temperature change between cells, which is more conducive to ensure the temperature balance between individual cells.

The first discharge and charging cycle is completed, as shown in Figure 2. The maximum temperature of probe points is about 34.3 °C, and the minimum temperature of probe points is 30 °C, and the maximum temperature difference is 4.3 °C. The second discharge and charging cycle is completed, as shown in Figure 3. The maximum temperature of probe points is about 38.7 °C, and the minimum temperature of probe points is 31.7 °C, and the maximum temperature difference is 7 °C. The third discharge and charging cycle is completed, as shown in Figure 4. The maximum temperature of probe points is about 40.6 °C, and the minimum temperature of probe points is 32.4 °C, and the maximum temperature difference is 8.2 °C. The fourth discharge and charging cycle is completed, as shown in Figure 5. The maximum temperature of probe points is about 41.4 °C, and the minimum temperature of probe points is 32.6 °C, and the maximum temperature difference is 8.8 °C. The fifth discharge and charging cycle is completed, as shown in Figure 6. The maximum temperature of probe points is about 41.8 °C, and the minimum temperature of probe points is 32.7 °C, and the maximum temperature difference is 9.1 °C. During the whole working condition, as shown in Figure 7, the maximum temperature of all arranged probe points is 61.6 °C, and the maximum temperature difference is 9.1 °C, and the total time is 4750S.

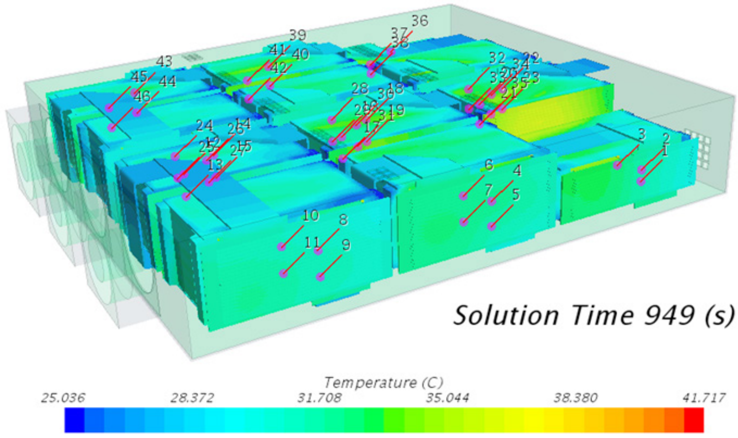

Figure 2. temperature distribution after the first discharge and charging cycle

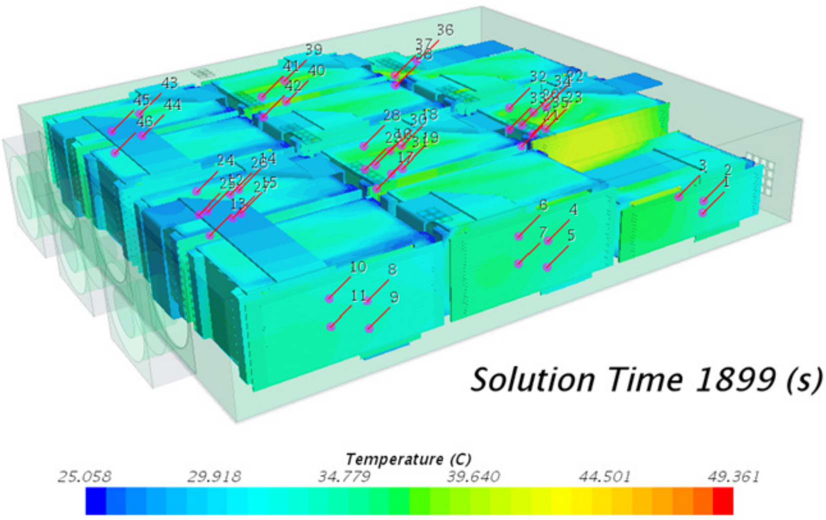

Figure 3. temperature distribution after the second discharge and charging cycle

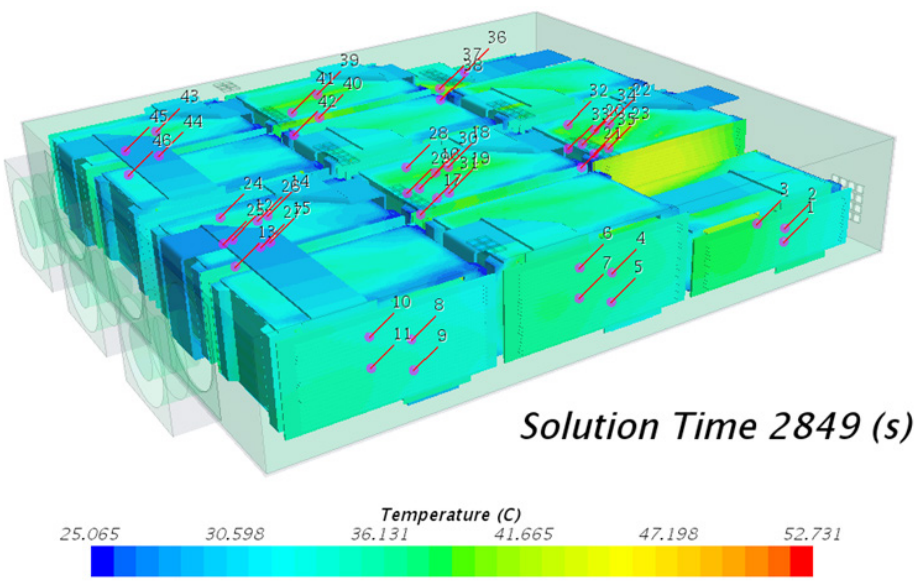

Figure 4. temperature distribution after the third discharge and charging cycle

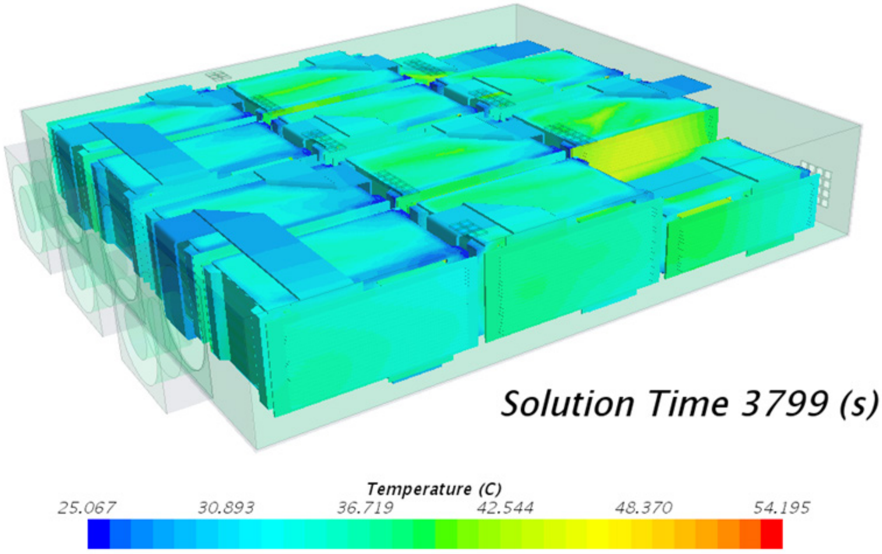

Figure 5. temperature distribution after the fourth discharge and charging cycle

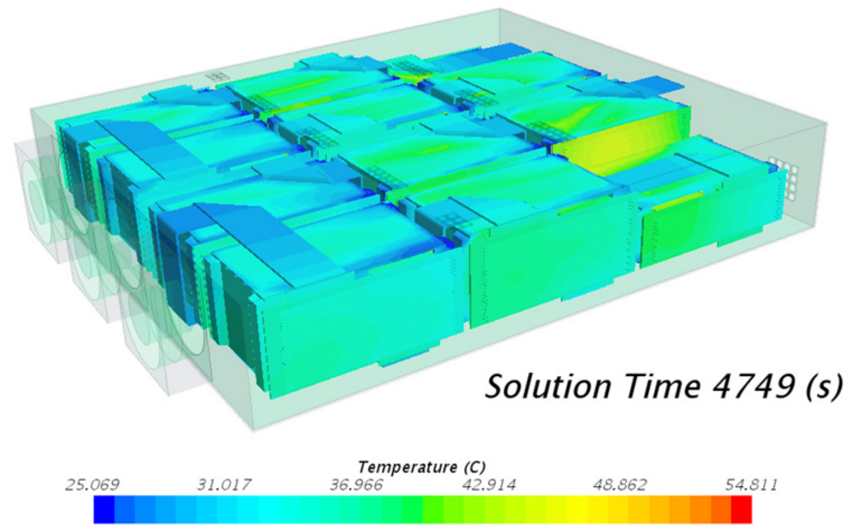

Figure 6. temperature distribution after the fifth discharge and charging cycle

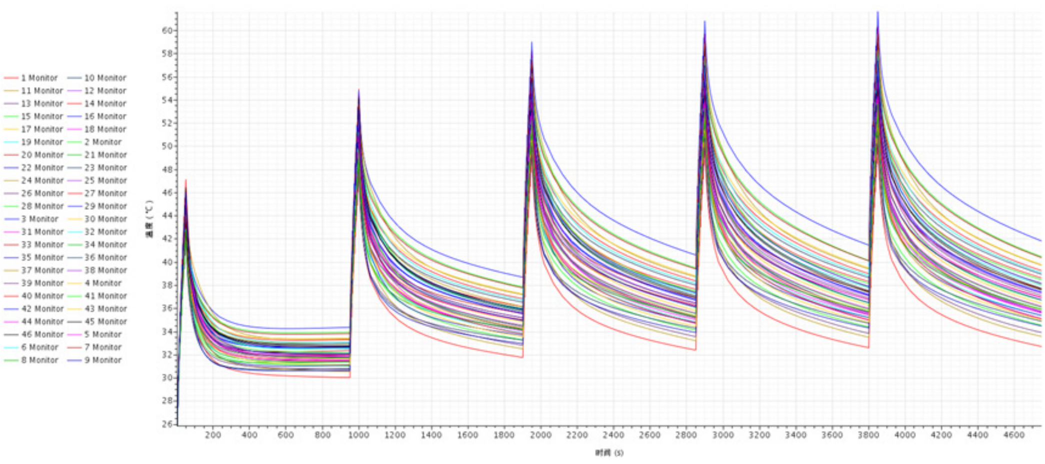

Figure 7. temperature variation curve of probe points with time

4. Conclusions

In order to optimize the heat dissipation system of electric bus power battery, the overall temperature distribution of the battery pack is understood through modeling and simulation of the battery pack, and the temperature difference and the maximum temperature are obtained. The conclusions are as follows:

(1) Through the simulation technology, the effectiveness of the thermal management control strategy of the air cooled system is verified, which can meet the heat dissipation requirements of the battery pack and prevent the thermal runaway of the soft packed lithium battery pack in the process of charge and discharge.

(2) When the battery pack is in the environment of 25 °C, the maximum temperature of the cooling system can be lower than 65 °C during the whole working condition, and the maximum temperature difference between all single batteries is within 10 °C.

Conflicts of Interest

The author declares that they have no conflicts of interest to report regarding the present study.

References

[1] Deng, Y., Yuan, Y., Zhang, X., 2015. An introduction of the application prospect of large capacity lithium battery in distributed energy storage system. Modern Machinery. (06), 83-86.

[2] Jarrett, A., Kim, I.Y., 2011. Design optimization of electric vehicle battery cooling plates for thermal performance. Journal of Power sources. 196(23), 10359-10368.

[3] Lei, Zh.G., Zhang, Ch.N., Lei, X.G., 2015. Research on thermal characteristics and thermal model of EVs lithium-ion battery. Advanced Technology of Electrical Engineering and Energy. 34(12), 59-63.

[4] Lu, Z., Meng, X.Z., Well, C., 2016. Thermal management of densely packed EV battery with forced air cooling strategies. Energy Procedia. 88, 682-688.

[5] Zhang, X., Wang, T., Xu, H.G., 2019. Simulation analysis of temperature of square power lithium-ion battery based on parallel air-cooling. Chinese Journal of Power Sources. 43(3), 426-428.

[6] Du, M.H., Zheng, X.W., Jiang, Zh.W., 2018. Analysis of influencing factors on heat dissipation performance on liquid-cooled of electric vehicle battery module. Guangdong Chemical Industry. 45(16), 48-50.