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Research Article

Temperature Field Analysis and Thermal Dissipation Structure Optimization of Lithium-ion Battery Pack in PEVs

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Abstract: Aimed to achieve good thermal stability of lithium batteries in electric vehicles under the conditions of high-power. This study established a three-dimensional, transient heat dissipation model for Lithium-ion battery package in the three-dimensional Cartesian coordinate system based on theoretical knowledge of thermodynamics and heat transfer. With the help of the numerical simulation theoretical of CFD, the flow and temperature field of force air cooling Lithium-ion battery pack was simulated with the heat source obtained from dynamic performance simulations of Pure Electric Vehicles (PEVs) under 15% climbing conditions. For the issues of high temperature rise and large temperature difference, optimal programs to improve the cooling effect of Lithium-ion battery pack were proposed. Simulation results indicate that the optimal measures make heat dissipation well and temperature distribution uniform, which satisfies the application requirement in PEVs.

Keywords: CFD, electric vehicles, lithium-ion battery, temperature field

INTRODUCTION

Today, global oil resources continue to decrease and the adverse impact to the environment caused by automobile exhaust is also increasingly evident. Governments and automobile manufacturers have recognized that energy conservation and emissions reduction are the main direction of the future automotive technology and they began to focus more on research and development of kinds of new energy vehicles. PEVs which embed with many high-techs and achieved zero-emission have become a hot field of new energy vehicles research. As a power source for electric vehicles, power battery's performances will directly affect the performance of electric vehicles (Xiao *et al*., 2012). Due to lithium-ion batteries have many advantages such as high voltage, high specific energy and specific power, long circulating life, low self-discharge, no memory effect and no pollutions, has gradually become ideal power source for electric vehicles and hybrid electric vehicles (Wang and Hu, 2008). It will produce a large amount of heat with frequently charge and discharge processes in Lithium ion batteries installed in PEVs, if the heat cannot be dissipated in time, it will cause heat accumulation and then lead to high temperature and uneven temperature among batteries, which will degrade battery performance and life expectancy, even arouse temperature thermal runaway (Keyser *et al*., 2011). So, it is needed to analyze characteristics of temperature field to ensure battery packs used in PEVs safely and efficiently.

CFD (Computational Fluid Dynamics) technology can accurately predict the temperature, velocity and pressure in the computational domain at any point; it can be convenient to research and compare kinds of programs in the structural design and the optimization of battery packs, so it has widely been applied in power battery analysis of flow and temperature field. Fei *et al*. (2012) and Li *et al*. (2011) had made simulation analysis to thermal performance of lithium battery pack cooling system under different discharge rates based on CFD, while they didn't consider vehicle's actual working conditions. Li *et al*. (2012) had simulated and analyzed temperature distribution difference of battery pack installed in city bus under low speed and different discharge currents, however, the research of battery temperature simulation analysis on pure electric passenger vehicles in high speed based on a variety of driving conditions is rare. Liu *et al*. (2012) had presented an approach to optimize the battery pack structure of natural air cooling under the uniform driving condition, while he didn't consider the situations that need the battery pack to heavy load discharge such as accelerating, climbing etc.

In this study, a dynamics simulation model of PEVs developed by a domestic car company under climbing condition is built based on Matlab/Simulink to obtain the discharge current, open circuit potentials and heating power of battery pack. We'll analyze the flow

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and temperature field distributions of battery pack with forced cooling systems by applying the CFD technique and verify the validity of simulate model through test. On the basis of analyzing influences on cooling performance, structure optimization schemes with good heat dissipation are given to solve issues of large temperature differences among modules caused by poor cooling effect and uneven flow in the premier cooling system.

LITERATURE REVIEW

Temperature field model of cell: The internal structure of Lithium-ion battery shown as Fig. 1a, the negative pole of battery will react with electrolyte on the solid-liquid interface and form a SEI (Solid Electrolyte Interface) membrane covering on the material surface of electrode in the process of charging and discharging. Due to a high number of the battery internal stack structure and the thickness of each layer is very small, the all internal heating layer of cell can be simplified into an integral part in accordance with the method of mass average. As shown in Fig. 1b, the battery temperature field model is simplified for two parts of the internal (heat source) and the battery housing (Johnson, 2002).

Heat generation of lithium-ion battery: The battery working states and heat generation rates are different with different driving conditions of vehicle. The battery heat generation and rates depend on the type, working status, SOC (State of Charge) and ambient temperature. Heat is generated in lithium-ion battery mainly consists of three parts: chemical reactions heat, polarization heat and Joule's heat (Zhang and Li, 2010). The chemical reactions heat can be represented as following equation:

$$Q_{Bat} = 0.0104QI \tag{1}$$

where,

Q : Algebraic sum of battery's positive and negative heat, kJ/mol

I : The discharge current, A

Polarization heat (Q_{Elec}) can be written as:

$$Q_{Elec} = I^2 R_{pd} \tag{2}$$

where,

R_{pd} = The polarization resistance, Ω, $R_{pd} = R_{td} - R_e$

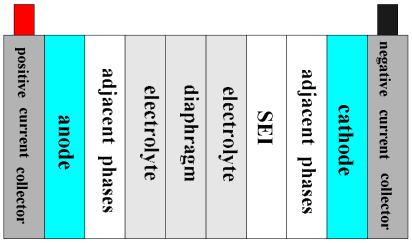
R_{td} = Battery's total resistance in discharging, Ω

R_e = The resistance during flow of electrons, Ω

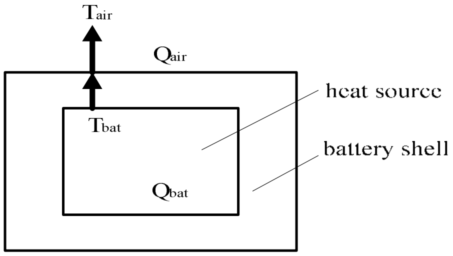
The following equation can express Joule's heat (Q_{Resi}) produced by the internal resistance:

$$Q_{Resi} = I^2 R_e \tag{3}$$

So, total heat generation (Q_{Sum}) of battery can be calculated with the following expression:



(a)



(b)

Fig. 1: Internal structure and temperature field model of cell
Q_{air} : Heat dissipates to cooling air from battery shell; T_{air} : Cooling air temperature; T_{bat} : Cell temperature; Q_{bat} : Heat generated from battery

$$Q_{Sum} = Q_{Bat} + Q_{Elec} + Q_{Resi} \tag{4}$$

Usually, the normal operating temperature of Lithium-ion battery is between -20 and 60°C, the chemical reaction heat will become the main heat when battery temperature exceeds 70°C. While Joule's heat will have a greater impact on the total amount of heat when battery works in normal operating temperature range and then the equation for heat calculating can be simplified as:

$$Q_{Sum} = I^2 R_{td} \tag{5}$$

3-D thermal model in Cartesian coordinates: Foreign investigators began to build and use battery thermal models to study issues of battery thermal management early (Chen *et al*., 2006). The essence of battery thermal model is energy balance on kinds of micro-units exist in battery. Following assumptions applied to simplify battery thermal model are proposed for convenience of analysis:

- Materials inside the battery have the uniform physical property and are isotropous.
- Internal radiation in battery can be neglected for it has little effect on the heat.
- Cell heat capacity and thermal conductivity are constants during operating.
- Heat generation in battery during charging and discharging is uniform.

Based on above assumptions, we analyze the heat generation in battery and external heat conduction process with the knowledge of thermodynamics and heat transfer theories and get the 3-D transient energy conservation equation of prismatic battery in Cartesian coordinates (Zhang *et al*., 2011):

$$\rho C_p \frac{\partial T}{\partial t} = \lambda_x \frac{\partial^2 T}{\partial x^2} + \lambda_y \frac{\partial^2 T}{\partial y^2} + \lambda_z \frac{\partial^2 T}{\partial z^2} + Q_v \qquad (6)$$

where,

ρ = Presents battery average density

C_p = Specific heat at constant pressure

T = The battery temperature

t = Presents the time

λ_x, λ_y, λ_z = Respectively heat conducting coefficients in x, y and z direction

Q_y = Unit volume heat generation rate

Here, the first term is micro-units thermodynamics energy in battery and the first three expressions of the right side are the increased energy of each microelement through the heat transfer in the unit time. Initial condition is:

$$T\ (x, y, z, 0) = T_0 \qquad (7)$$

where, T_0 stands for the battery initial temperature.

Boundary conditions can be given according to Newton's law of cooling:

$$-\lambda \frac{\partial T}{\partial x} = \alpha (T - T_\infty),\ x = 0,\ l \qquad (8)$$

$$-\lambda \frac{\partial T}{\partial y} = \alpha (T - T_\infty),\ y = 0,\ b \qquad (9)$$

$$-\lambda \frac{\partial T}{\partial x} = \alpha (T - T_\infty),\ z = 0,\ h \qquad (10)$$

where,

α = The heat transfer coefficient

T_∞ = Ambient temperature

l, b, h = Respectively the length, width and height of battery

Because λ_x, λ_y, λ_z are difficult to acquired through measurement, we can use material theory of series and parallel proposed by Chen *et al*. (2005) to estimate coefficients of thermal conductivity in each directions.

MODELING AND METHODS

Battery pack geometric model: In this study, the cathode material of lithium-ion used in EV is $LiFePO_4$, the cell has a nominal voltage of 3.2V, capacity of 60 Ah, the resistance is no more than 4 mΩ and has overall dimensions of 170×135×25.3 mm. The total voltage of the battery pack is 326 V and composed of 17 modules, each module contains 12 cells. Figure 2, shows the geometric model of the battery pack and the module number, the air enters into the battery system from an inlet where the fan is located and flows out through two outlets at side of pack. Figure 3, shows the single module in battery pack and the cooling duct inlet size between the adjacent two sells is 124.7×4 mm.

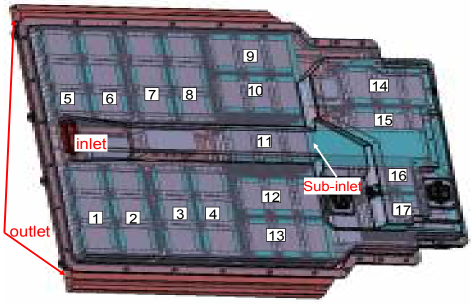


Fig. 2: Geometric of lithium-ion battery pack

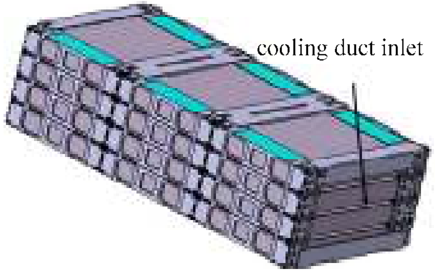


Fig. 3: Single module in pack

Vehicle dynamic model: The battery pack used in PEVs is not always discharged in the constant ratio during normal operation. Because the performance of the battery is seriously influenced by temperature and SOC, the discharge current of the battery pack will also change even though the PEVs study under some a constant condition. The heat generation and heat rates of the battery pack are inflected by its internal performance and external conditions. In order to get the real-time heating power of the battery pack discharged at large current, the driving dynamics model of PEVs with a certain speed in 15% slope is created and simulated, then we analyze the variation characteristics of open circuit potentials, discharging current, SOC and battery heat power, etc.

The drive power required of the PEVs for running on a certain slope with guaranteeing some a speed can be expressed as Huang *et al*. (2011):

$$P_e = \frac{v_a}{3600\eta_{tq}} \left(mgf \cos\alpha + \frac{C_D A v_a^2}{21.15} + mg \sin\alpha \right) \qquad (11)$$

where,

m = The completed vehicle mass, kg
A = Frontal area, m^2
f = The rolling resistance
α = The gradient
v_a = Represents the velocity, km/h
C_D = Automotive air drag coefficient
P_e = The motor output effective power, kW
η_{tq} = The mechanical efficiency of drive system

Lithium battery model: We establish the lithium-ion battery model in MATLAB/Simulink to obtain the heat input for battery thermal performance simulation of pack, which can estimate battery appearance parameter contain open circuit potentials, internal resistance, current, SOC, temperature and discharging power. The input of the model is mainly the request to driver motor power and output power battery pack can provide according to the voltage, current and SOC of cells.

Open circuit potentials and internal resistance module: The function of the model is to calculate voltage and internal resistance according to the SOC, temperature and motor power demand in real-time. The open circuit potentials of battery and internal resistance are related to the SOC and temperature. So in the model, we can get open circuit potentials and internal resistance by look up the table according the real-time temperature and SOC feedback.

Discharge current module: This module calculates discharge current and operating voltage in the equivalent circuit. In the battery modeling, the charge-discharge circuit can be equivalent to a loop which is made up of a voltage source and equivalent internal resistance (Tsang *et al*., 2010). Base on the equivalent circuit, the discharge current of battery pack can be calculated by the formula expressed as Eq. (12). The working voltage of battery doesn't exceed upper cutoff voltage, so it can be calculated according to Ohm's law:

$$I = \frac{Voc - \sqrt{Voc^2 - 4RP_{mc}}}{2R} \tag{12}$$

where,

I = The discharging current, A
Voc = The open circuit potentials, V
R = Equivalent resistance, Ω
P_{mc} = Motor power, kW

SOC module: The cell SOC is defined as the ratio of remaining battery capacity to rated capacity, expressed by percentage (0≤SOC≤100%). The remaining capacity of battery is calculated indirectly by the used capacity. In the period of *t*, battery discharge capacity can be obtained by current integration. The term SOC_{init} represents initial state of charge, so the battery capacity loss (C_{used}) after the period of *t* can be calculated by the formula as below:

$$C_{used} = (1 - SOC_{init})C_e + \int_t \frac{I(t)}{3600} dt \tag{13}$$

where, the C_e is rated capacity.

According to the Eq. (14), we can calculate the SOC of battery pack:

$$SOC = \frac{C_e - C_{used}}{C_e} \tag{14}$$

Thermal characteristics module: The main function of the module is to predict the operating temperature and provide temperature parameter for other sub-modules in real time according to thermal property of battery pack. Assume that most of the heat is produced by the battery resistance and the heat loose by the ways of convection heat transfer between battery's surface and surrounding air. When building the model, we use thermal properties of cell instead of the whole battery pack and ignore the heat concentration caused by the battery pack structure and model arrangement. The rate of heat q_{gen} can be calculated by the current which is obtained above according to Joule's laws, q_{bat_air} set for the comprehensive heat power between cell surface and the air, so the formula can be expressed as:

$$q_{bat\_air} = (T_{bat} - T_{air}) / R_{eff} \tag{15}$$

Assumed that the cell is an approximated isothermal body, so the temperature of battery T_{bat} is:

$$T_{bat} = T_0 + \int_t \frac{q_{gen} - q_{bat\_air}}{m_{bat} C_{p\_bat}} \tag{16}$$

where,

T_0 = Battery initial temperature, °C
m_{bat} = The battery mass, kg
C_{p_bat} = The heat capacity, J/kg·K

We create the battery pack simulation model according to the above mathematical formulas of several subsystems, as shown in Fig. 4.

Battery pack mesh model: Since the purpose of the simulation is to analyze the temperature distribution of the battery pack and the flow condition in pack, the internal mesh of the battery and cooling channels is generated. Cooling flow passage of battery module is relatively narrow, so to accelerate the convergence of the calculation and improve accuracy of simulation, the

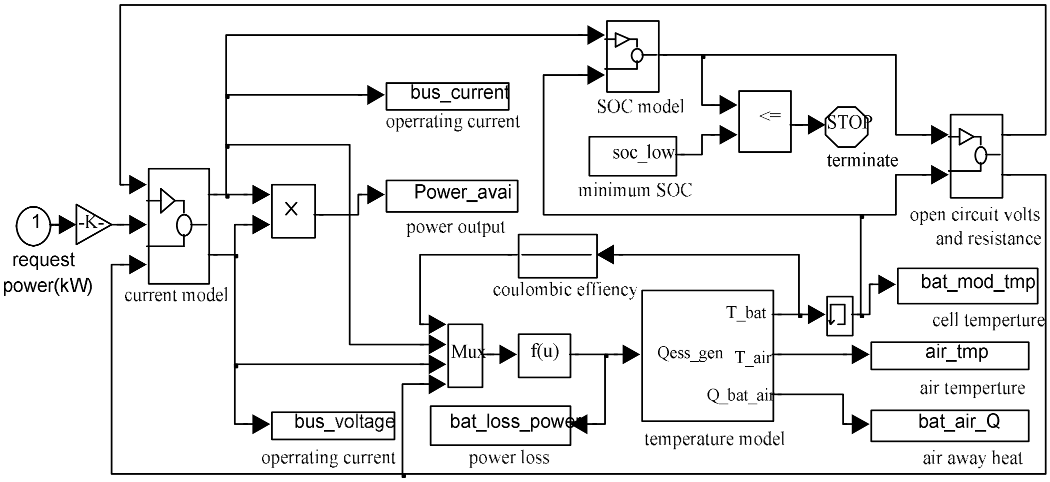


Fig. 4: Power battery simulation model

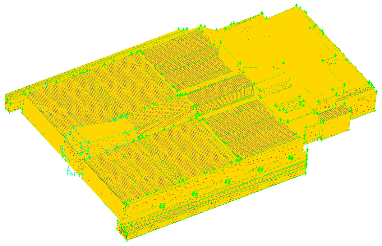


Fig. 5: Grid model of battery pack cooling system

boundary layer grid is divided at the junction interface of fluid-solid for mesh refinement. Above works can be done by the meshing method Gambit software provided, grid model is shown in Fig. 5, contains structured hexahedral mesh and unstructured tetrahedral mesh.

CFD governing equations: Since the cooling method of lithium battery pack is forced air cooling, the main physical issues about numerical calculation are the flow of cooling air and convective heat transfer between batteries and fluid. There exist fluid and temperature boundary layer at the junction of the air and batteries in fluid-solid coupling model, so turbulent Reynolds number is very low in the near-wall viscous layer. Therefore, it requires the use of a wall function near the wall when calculate the heat transfer between the fluid-solid with standard k-ε (k, ε denote the turbulent kinetic energy and dissipation rate of turbulent energy) model of high Reynolds number. The standard k-ε two-equation model has obtained extensive testing and successful application in scientific research and engineering with its high stability, economic and calculation accuracy. Here we select the standard k-ε turbulence model/wall-function method in the numerical simulation. The governing equations include continuity equation, momentum equation, energy equation, k-ε equations and turbulent viscosity (μ_t) formula.

Continuity equation, also known as mass conservation equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \tag{17}$$

where,

ρ = The fluid density
t = Time
u, v, w = The velocity components in the x, y and z directions

Momentum equation of the x, y and z directions:

$$\begin{cases}\dfrac{\partial(\rho u)}{\partial t}+div(\rho U u)=div(\mu_{eff}\, grad u)-\dfrac{\partial p}{\partial x}+S_u \\ \dfrac{\partial(\rho v)}{\partial t}+div(\rho U v)=div(\mu_{eff}\, grad v)-\dfrac{\partial p}{\partial y}+S_v \\ \dfrac{\partial(\rho w)}{\partial t}+div(\rho U w)=div(\mu_{eff}\, grad w)-\dfrac{\partial p}{\partial z}+S_w\end{cases} \tag{18}$$

where,

U = The fluid velocity
μ_{eff} = The equivalent turbulent viscosity, defined as $\mu_{eff} = \mu + \mu_t$, where μ is the viscosity of the fluid
μ_t = Related with assuming turbulent viscosity, turbulent kinetic energy and dissipation rate of k-ε equation, expression $\mu_t = C_\mu \rho k^2/\varepsilon$, C_μ is an empirical constant and taken as 0.09
p = The pressure
S_u, S_v, S_w = The source terms of x, y and z directions respectively

Energy equation:

Table 1: Material properties

Material name	Density (kg/m^3)	Capacity (J/kg/K)	Conductivity (W/m/K)
Air	1.293	1003.62	0.02603
Battery	3000	900	16.30000

$$\frac{\partial(\rho T)}{\partial t}+div\left(k_{eff}\rho UT\right)=div\left(\left(\frac{\mu}{\Pr}+\frac{\mu_t}{\sigma_T}\right)gradT\right)+S_h \tag{19}$$

where,

T = Gas temperature

k_{eff} = The effective thermal conductivity

S_h = The heat source of fluid

Pr = The turbulent Prandtl number

σ_T = The empirical constant values between 0.9-1.0

Standard *k*-ε turbulence model equation:

$$\begin{cases}\dfrac{\partial(\rho k)}{\partial t}+div(\rho Uk)=div\left[\left(\mu+\dfrac{\mu_t}{\sigma_k}\right)gradk\right]+G_k+\rho\varepsilon \\ \dfrac{\partial(\rho\varepsilon)}{\partial t}+div(\rho U\varepsilon)=div\left[\left(\mu+\dfrac{\mu_t}{\sigma_\varepsilon}\right)grad\,\varepsilon\right]+\dfrac{\varepsilon}{k}\left(C_{\varepsilon1}P_k-C_{\varepsilon2}\rho\varepsilon\right)\end{cases} \tag{20}$$

where, G_k is the turbulence product formed together of the fluid viscosity and buoyancy According to Launder (Sato, 2001) recommended values and experimental validation, empirical constants values: $C_{\varepsilon1} = 1.44$, $C_{\varepsilon2} = 1.92$, $\sigma_k = 1.0$, $\sigma_\varepsilon = 1.3$.

Initial conditions, boundary conditions and the numerical solver: The interface of batteries and the cooling air is set for coupled heat transfer boundary. Use the heat power calculated previously as the heat source of CFD simulation and load to the calculate model through the preparation of the UDF function. Battery pack with forced air cooling, inlet condition is the quality entrance and the flow rate into the battery pack the cooling fan provided is 270 m^3/h. Initial temperature of the simulation is taken as 25°C, outlet boundary condition is the pressure outlet and fluid domain is considered as homogeneous medium. The convective heats transfer occurs between the cooling air and the surface of the battery, so that the heat inside the battery pack can be dissipated. Table 1 summarizes material properties of the battery system.

Heat transfer process of the battery pack can be considered typical fluid-solid coupling, simple and effective method for solving such problem is constitute heat transfer of different regions into a uniform process, then the entire discrete and solver. The fluid and solid domain of cooling model coupled directly, so that used the same numerical methods and discrete rules to iterative. In order to improve the calculation accuracy, a discrete method of momentum and energy equations is selected 2-order upwind scheme and chose SIMPLE algorithm to solve pressure-velocity coupling (Patankar and Spalding, 2002).

SIMULATION RESULTS

Vehicle simulation results: The major parameter used in the simulation model of PEVs is provided in Table 2.

The simulation time is 30 min, uniform driving of PEVs is 30 km/h and the slope is 15%. Simulation results is shown in Fig. 6, which summarizes the changes of battery open circuit potentials, SOC, discharge current and heat generation calculated

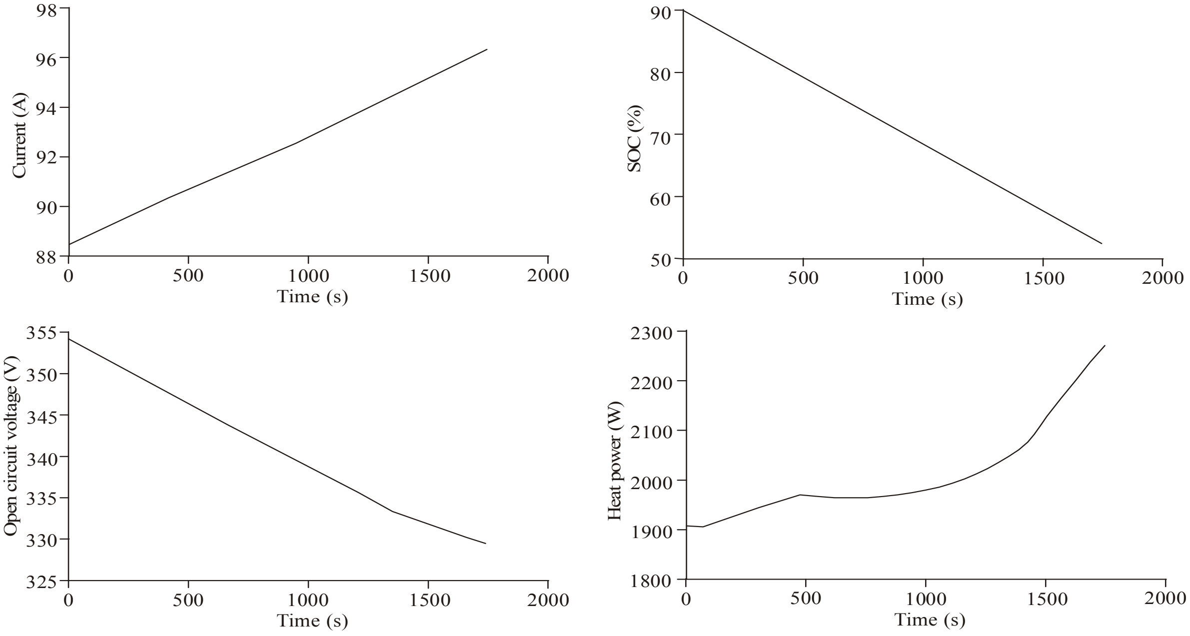


Fig. 6: Simulation results of climbing condition of slope 15%

Table 2: Input parameter of simulation

Parameter	Value
Front area (m^2)	2.30
Complete vehicle mass (kg)	1310
Rolling radius (mm)	282
Cell capacity (Ah)	120
Pack nominal voltage (V)	326
Discharge termination voltage (V)	2.00
Nominal power (kW)	21
Drag coefficient	0.35

according to the Eq. (3). As can be seen from the figure, although driving power does not change when the vehicle is climbing at a steady speed, open circuit potentials of battery pack decreases from 353.94 to 328.99 V, the discharge current increases from 88.54 to 96.38 A, the SOC reduces to 51.54% finally and also the rate of heat is changing. The temperature of battery pack is rising as the discharging and SOC is changing all time, which results in resistance increase and open-circuit voltage reduce, but the power demand for the vehicle keep the same, so discharge current increases gradually and the amount of heat also increases.

Thermal simulation results: Figure 7 shows the temperature distribution of battery module upper surface and Fig. 8 shows the under surface temperature distribution. As the narrow passage between the lower surface of the battery module and the housing, the cooling effect is poor and the temperature is significantly higher than the upper surface. Simultaneously, excessive air scatters from the top of battery modules results that the air doesn't cool battery and the temperature distribution is inconsistent. The internal flow field distribution of battery pack is presented in Fig. 9. As can be seen from the figure, the flow rate of cooling air in the middle is too larger and other regional significantly less, which causes uneven distribution of the flow field. From the temperature distribution of the battery pack we can see that the highest temperature appears in the middle surface of the

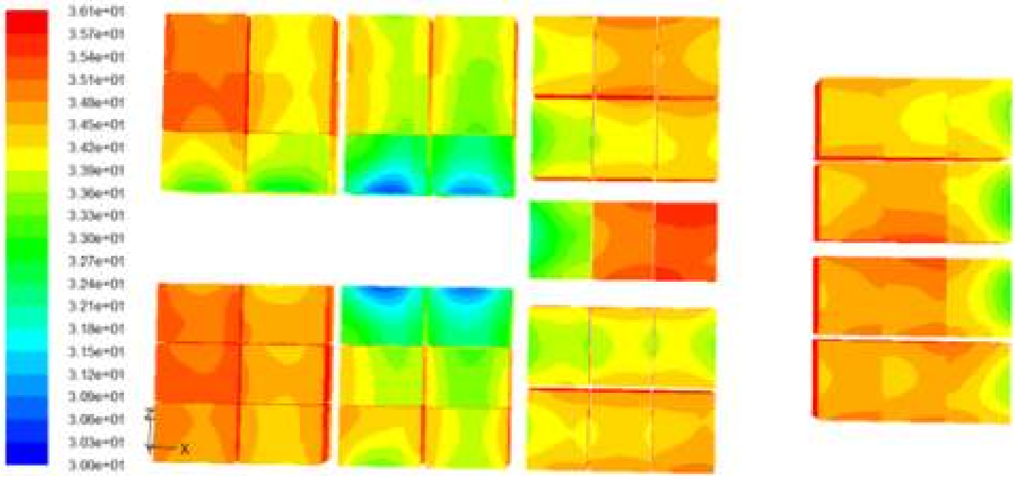


Fig. 7: Upper surface temperature of battery modules

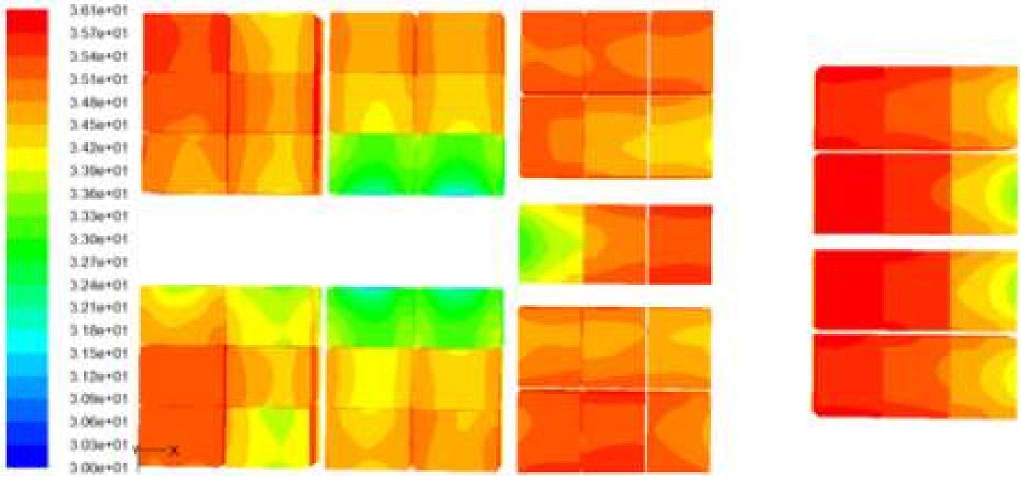


Fig. 8: Under surface temperature of battery modules

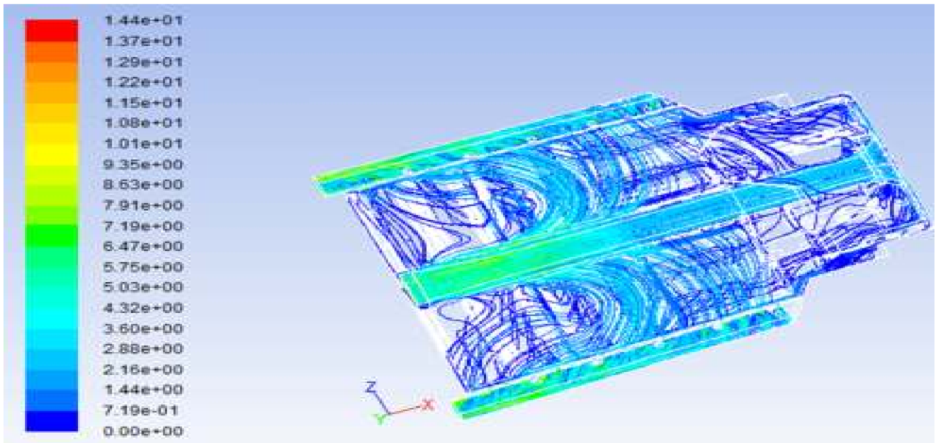


Fig. 9: Flow field distribution of the battery pack

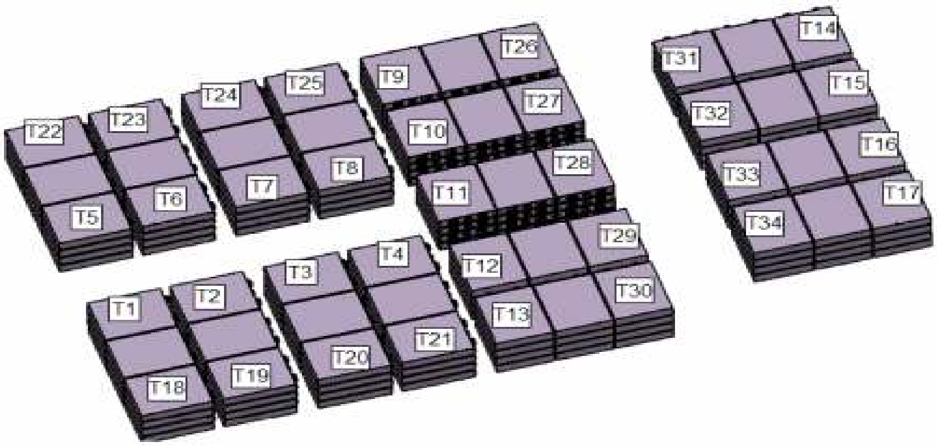


Fig. 10: Temperature sensor layout schemes

rear battery module, value of 36.2°C. The lowest temperature is 30.3°C appeared on the upper surface of vent, this is because the speed of air is larger and the heat transfer is more here. The maximum temperature rise of battery modules is 11.2°C and the internal temperature deviation is about 6°C. Although modules in the pack are symmetrically distributed, both sides of the flow distribution is not completely uniform and there is a temperature differences slightly, the reason is that there are two electrical boxes in the middle of pack and locate biased in favor of one side.

Temperature test results: To verify the reasonableness of the lithium pack thermal model and prove the correctness and reliability of simulation result, model tests have been carried out to investigate the performance of battery pack under climbing conditions of PEVs in the 15% slope. In order to accurately reflect the temperature uniformity of the battery and inspect the difference in temperature, the temperature sensor should be arranged in the highest and lowest temperature area of each module, as shown in Fig. 10.

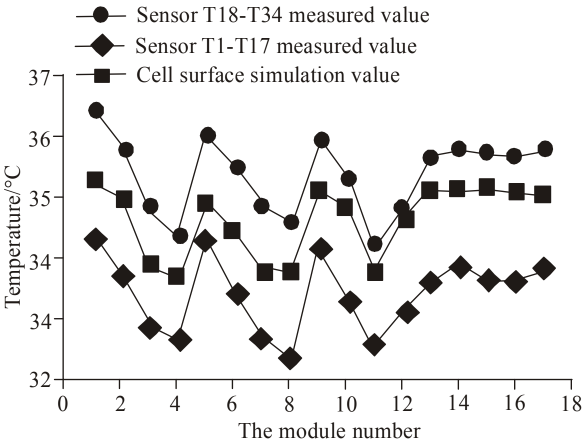


Fig. 11: Measured values and simulation results contrast

The temperature distribution of the each module measurement points is shown in Fig. 11 and is compared with the corresponding simulation results simultaneously. As can be seen from the figure, the simulated and measured value is more consistent with

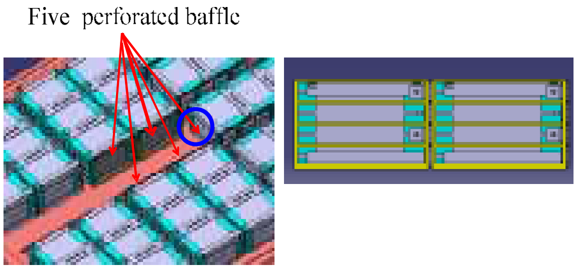


Fig. 12: Improved structure at the inlet of cooling channel

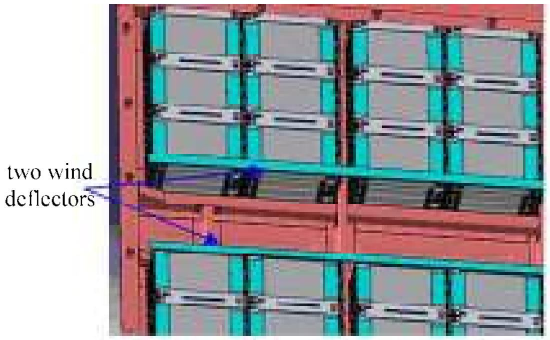


Fig. 13: Windshield at the top of module

the maximum temperature difference of 1.63°C and the battery temperature distribution shows the same trends, which indicate the reasonableness and accuracy of the lithium battery simulation model in this study. The measured temperature of the sensor T18-T34 is significantly higher than temperature sensor T1-T17, this is due to the sensor T18-T34 are located inlet of module and the sensor T1-T17 in the outlet. Air flow is heated gradually in cooling channels and the temperature is higher when it reaches the rear, so the convection heat transfer coefficient decreases and the temperature is lower at the air inlet compared with the outlet.

DISCUSSION AND OPTIMIZATION

Poor thermal performance of the original battery pack can be found through the above analysis and there are mainly some problems as following:

Problem 1: The gap between the battery module upper-lower surfaces and housing is varied, which results in uneven temperature distribution.

Problem 2: Flow field distribution of battery pack shows that the internal air flow is inconsistent and the excessive flow is on the air intake module.

Problem 3: Due to the gap between the module top and the box is too large, some air is lost without flow through the module.

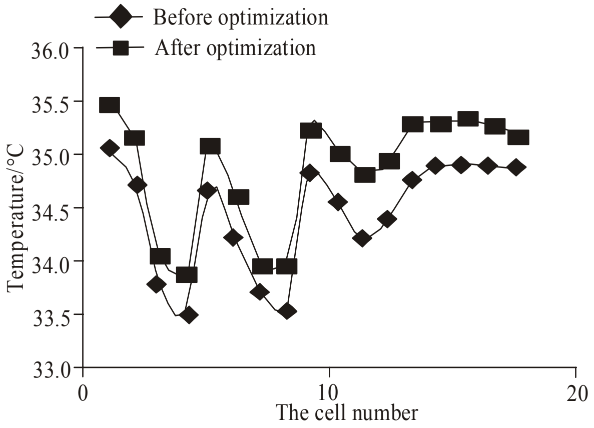


Fig. 14: Average temperature before and after optimization of each module

Therefore, it is necessary to optimize heat dissipation structure of the battery pack to guarantee the efficiency in the vehicle traveling.

Optimization schemes: Based on the simulation results of the original model we analyze thermal performance affect factors and propose following optimization schemes for heat dissipation unevenly: Change the cooling channel to increase the air flow between the box and the bottom of module; Add perforated baffle at the cooling air inlets of specific module to decrease the temperature difference among modules, as shown in Fig. 12; Plus two wind deflectors at the top of modules to reduce the loss of cooling air, shown in Fig. 13.

Optimization results: Once the optimized simulation mesh model of lithium battery pack has been done its temperature distribution as well as change situation is analyzed. Airflow is heated gradually in the module ventilation ducts and then heat away through the outlet, which has a cooling effect. After optimization, the highest temperature of the battery drops from 36.1 to 35.5°C and temperature difference reduces to 4.4°C, which meet the control requirements within 5°C and uniformity is improved, effectively increase the normal operation of the performance of the battery pack. The average surface temperature distribution of each module before and after optimization is shown in Fig. 14.

CONCLUSION

We established dynamic simulation model of PEVs under climbing conditions in MATLAB/Simulink to get the real-time thermal power of battery pack with PEVs running. Then we analyzed the variation of battery pack discharge current, open circuit potentials and SOC in the PEVs climbing process, which laid the foundation for the battery thermal performance simulation. A lithium-ion temperature field model was established based on the CFD theory and its numerical simulation was carried out. We obtained the maximum temperature rise, average temperature and the maximum temperature difference of modules. The simulation results and experimental data were more consistent which verified the reasonableness of the lithium pack thermal model.

The optimization measures of battery cooling structure were put forward and the simulation results showed that optimization strategy could greatly improve the normal operation performance of PEVs.

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