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Study On the Preheating Method of Lithium-Ion Battery for Electric Vehicles Operating in Cold Region

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Summary

Aiming at the problem of bad performance of lithium ion battery at low temperature, taking a battery pack as an example, using COMSOL (finite element simulation software), the temperature rising and thermal field distribution of the battery preheating with the electric heating film is simulated. Heating film covers the half of the two largest area of the battery is the optimal coverage through the research of 4 kinds of electric heating film covering forms. When the heating power is above 645W, the battery pack can be preheated from ambient temperature -10°C to 5°C in 5 minutes.

Keywords: power battery; low temperature preheating; heating power; thermal field

1 Introduction

With the increasing attention to environmental problems, the electric vehicle technology has developed rapidly. As the main energy source of electric vehicles, the performance of lithium-ion battery has received extensive attention. In order to make it more secure and reliable in high power applications, it is necessary to solve its thermal performance problems [1]. At present, domestic and international research on the thermal management of batteries mainly focus on the heat dissipation of batteries at high temperature. However, there is little research on the thermal management at low temperature. With the application range of electric vehicle increasing gradually, the problem of lithium ion batteries protruding in low temperature environment, it is necessary to pay attention to the pre-heating of lithium-ion battery at low temperatures [2]. The preheating method of the battery is mainly divided into two types: external heating and internal heating. Zhang et al. [3] use an alternating current with an amplitude of 7 A (2.25 C) and a frequency of 1 Hz to heat the lithium-ion battery, the battery can be heated from 20°C to 5°C within 15 min. No capacity loss is found and little damage to the battery health with this method. Song et al. [4] heated the battery by hot air, the heating effect is obvious, the mileage of electric vehicles has increased. But the structure is complex and the cost is high. Li et al. [5] use the external heating method, the battery is heated by heating band. The battery has the fastest heating rate in 15 to 20 minutes, after 60 minutes of heating, the charging capacity is about 97% of the maximum charge capacity at 25°C.

Aiming at the problem of bad performance of lithium ion battery at low temperature in this study, the battery is heated by an electric heating film, using COMSOL finite element simulation software, the temperature rising and thermal field distribution of the battery preheating with the electric heating film is simulated. In this paper, 4 kinds of electric heating film covering forms are proposed, the influence of heating film coverage area and heating power on the temperature rise and preheating time of the battery

was analyzed, the heating area and heating power of the heating film with better preheating effect are obtained.

2 Model building

2.1 Design of the battery pack structure

In this paper, COMSOL5.2a simulation platform is used for simulation research, a simple battery pack structure is adopted as the object of this study, as shown in Figure 1. The size of the battery pack is 500mm*200mm*150mm. The battery is 4 in series and 4 in parallel. The mesh of the model is Free tetrahedral, and the number of the mesh is 14857, the mesh is shown in Figure 2. The battery selects an 8Ah lithium-ion phosphate as the prototype of the battery. The size of the battery is 124mm*80mm*18.5mm. The heating film is attached to the center of the largest area of the battery on both sides. In this paper, 4 kinds of heating film cover form (cover form 1 to 4) are proposed, it is shown in Figure 3.

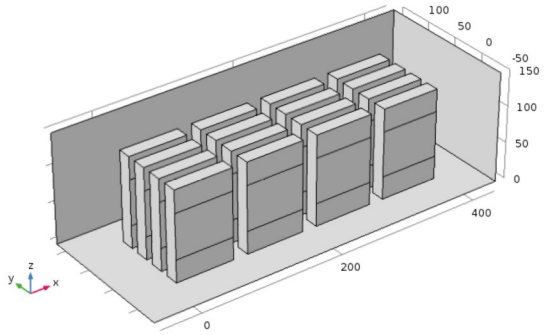


Figure 1 Battery package structure

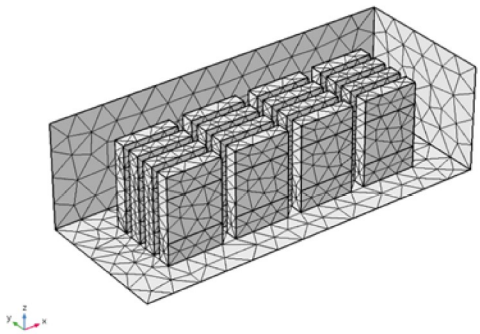
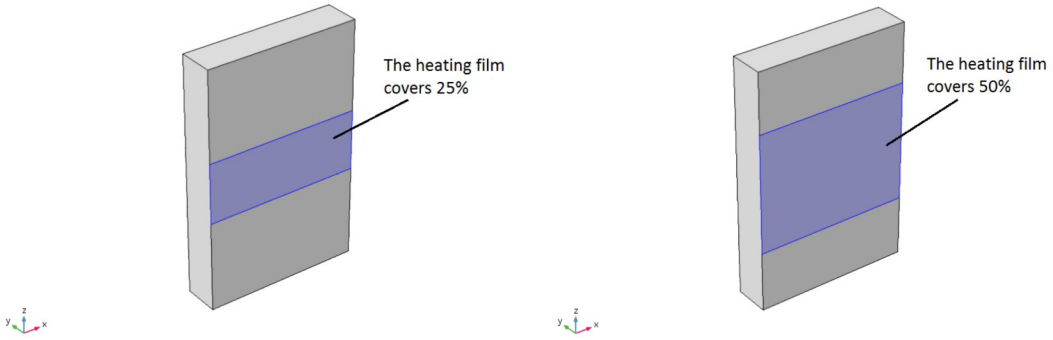
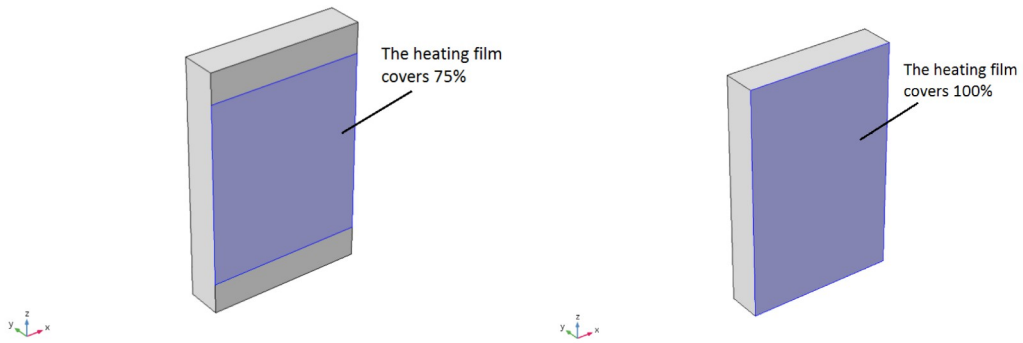


Figure 2 Mesh of battery pack



(a) Cover form 1 (b) Cover form 2



(c) Cover form 3 (d) Cover form 4

Figure 3 Heating film covering method

2.2 Thermal model building

In this paper, the transient heat conduction equation is used to simulate the heat transfer of the battery, used the finite element method to build the thermal model of the battery by COMSOL Multiphysics 5.2a (finite element simulation software).

Eq. (1) represents the internal energy conservation equation of the battery.

$$\rho C_p \frac{\partial T}{\partial t} = \lambda \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + q \tag{1}$$

where q is the total heat generation rate of the battery, ρ is the average cell density, C_p is the heat capacity, λ is thermal conductivity, T is temperature.

The heat exchange rate between the battery and the environment can be calculated by Eq. (2).

$$-\lambda \frac{\partial T}{\partial n}\Big|_r = h(T - T_s)\Big|_r \tag{2}$$

where h is the heat transfer coefficient, it is assumed that the battery is under natural convection, h is 7.17 W/m^2K [6], T_s is ambient temperature.

Surface heat flux density can be calculated by Eq. (3).

$$-\lambda \frac{\partial T}{\partial n}\Big|_r = q_h \tag{3}$$

where q_h is the heat flux provided by the heating film.

In order to calculate lumped heat parameters of the battery model, thermal-physical properties parameters of the battery are required. The thermal-physical properties parameters of lithium-ion battery materials is shown in Table 1.

Table 1 thermal-physical properties parameters of lithium-ion battery materials

material	k_i (W m^{-1} K^{-1})	ρ_i (kg m^{-3})	cp_i (J kg^{-1} K^{-1})
Separator [7]	0.334	1009	1978

Negative electrode	1.04 [8]	2500 [9]	641[7]
Positive electrode	1.48[10]	1500 [11]	800 [12]
Aluminium foil [13]	170	2770	875
Copper foil [13]	398	8933	385
Steel can [13]	14	7500	460

A lithium-ion battery is formed by placing a multilayer electrode and a diaphragm into the electrolyte in the form of a spiral structure; thus, the conductivity inside the battery is anisotropic [14]. In this study, the calculation methods of the average cell density, average density, and average heat capacity of the active material can be obtained by the method mentioned in the study of Du S L [15]. Assuming that the electrical conductivity is equal in the X and Y directions (λ_r) and can be obtained by Eq. (4).

$$\lambda_r = \frac{\sum \lambda_i l_i}{\sum l_i} \tag{4}$$

On the other hand, the conductivity in the Z direction(λ_a) can be obtained by Eq. (5).

$$\lambda_a = \frac{\sum l_i}{\sum \frac{l_i}{\lambda_i}} \tag{5}$$

The average density of active material (ρ) can be obtained by Eq. (6).

$$\rho = \frac{\sum L_i \rho_i}{\sum L_i} \tag{6}$$

The average heat capacity of active material (C_p) can be calculated by Eq. (7).

$$C_p = \frac{\sum L_i C_{p\,i}}{\sum L_i} \tag{7}$$

where λ_i is the material conductivity, $C_{p,i}$ is the material heat capacity, Li is the material thickness.

3 Results and analysis

In order to ensure that the battery can operate normally in low temperature environment, the battery pack needs to be pre-heated to 5°C [3]. The warm-up time of is also the focus of preheating, to make it easier for users to use electric cars, the preheat time is best from 5 minutes to 10 minutes. It is assumed that the ambient temperature is -10°C, the electric heating film is used to heat the battery, the influence of heating film coverage area and heating power on the temperature rise and preheating time of the battery was analysed, the heating area and heating power of the heating film with better preheating effect are obtained.

In this paper, the heating film covers 25%、 50%、 75%、 100% of the largest area of the battery (cover form 1 to 4)and the heating power is 500W、 550W、 600W、 650W are discussed. The temperature of the battery is simulated under these condition. The temperature rise of battery under different heating power and different heating film cover form is shown in Figure 4、 5、 6, respectively.

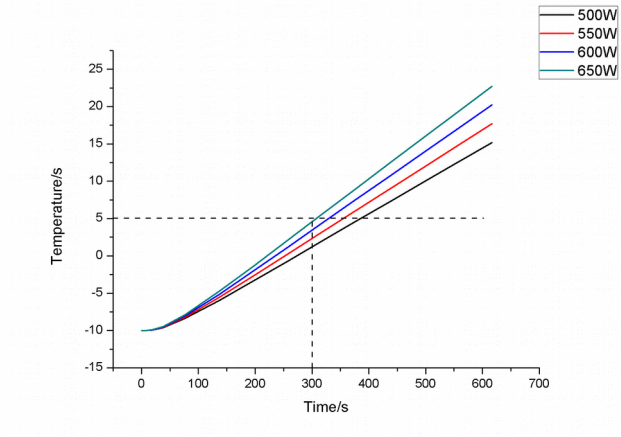


Figure 4 Temperature rise of cover form 1

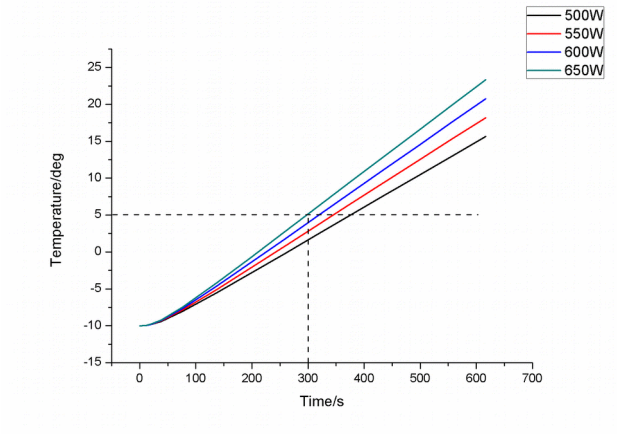


Figure 5 Temperature rise of cover form 2

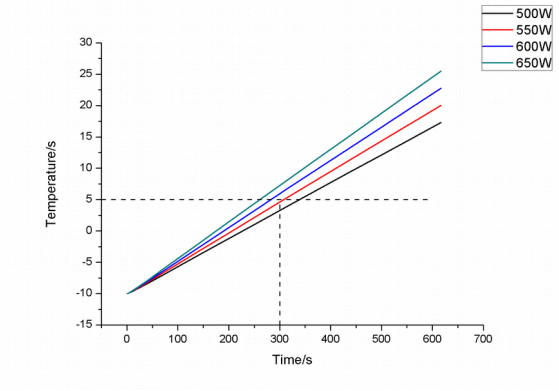


Figure 6 Temperature rise of cover form 3

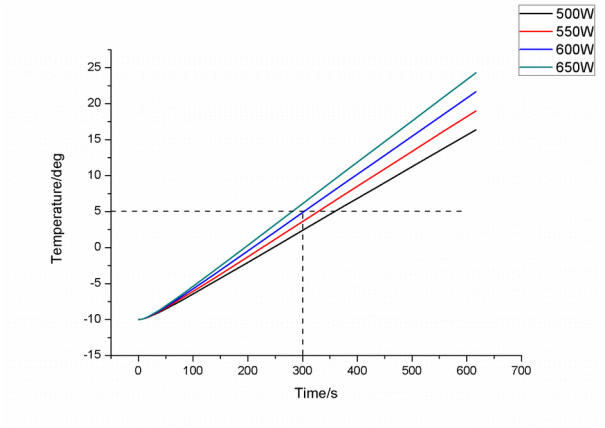


Figure 7 Temperature rise of cover form 4

It can be seen from the simulation results, when the heating film covers a certain area, the greater the heating power, the faster the temperature of the battery increases, the shorter the time that the battery temperature rises from -10°C to5°C.

To obtain the boundary power of the 4 kinds of heating film cover forms that can heated the battery from -10°C to 5°C in 5 minutes, 4 kinds of heating film cover forms are simulated and analysed. The boundary power curve is shown in Figure 8. It can be seen from figure 8, the heating power should be above 671W for cover form 1, the heating power should be above 645W for cover form 2, the heating power should be above 606W for cover form3, the heating power should be above 565.5W for cover form 4. With the increase of heating film coverage area, the heating power decrease which can heat the battery from -10°C to 5°C in 5 minutes. When designing a battery thermal management system, the heating power of the heating film should be above the boundary curve.

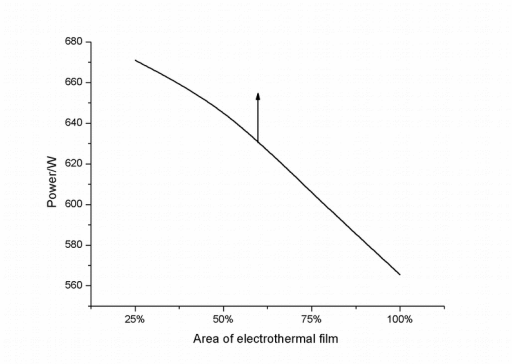


Figure 8 boundary power curve

Combined with the above analysis, the heating power decrease with the covering area of the heating film increase which heated the battery from -10°C to 5°C in 5 minutes. However, when designing a heating film, considering that cover of heating film will lead to poor heat dissipation in the normal operation of the battery. Owing to the two reasons above, the heating film covers 50% of the largest area of the battery is better, and the heating power should be above 645W. Figure 9 shows the thermal field distribution after preheating for 5 minutes when the heating film covers 50% of the largest area of the battery and the heating power is 645W. The thermal field distribution across the central axis of the battery package is shown in Figure 10. It can be seen from Figure 9, the temperature of the part that near the heating film is higher and the maximum temperature after preheating 5 minutes is at the centre of the battery pack, the temperature is 10.27°C. The minimum temperature after preheating 5 minutes is on the edge of the battery pack, the temperature is 5°C. It can be seen from Figure 10, the temperature of centre of the battery pack is higher than the edge.

4 conclusion

In this paper, using COMSOL finite element simulation software, the temperature rising and thermal field distribution of the battery preheating with the electric heating film is simulated and 4 kinds of electric heating film covering forms are proposed, the influence of heating film coverage area and heating power on the temperature rise and preheating time of the battery was analyzed, the heating area and heating power of the heating film with better preheating effect are obtained. The following conclusions are drawn:

1) The heating power decrease with the covering area of the heating film increase which heated the battery from -10°C to 5°C in 5 minutes.

2) the heating power should be above 671W for cover form 1, the heating power should be above 645W for cover form 2, the heating power should be above 606W for cover form3 and the heating power should be above 565.5W for cover form 4.

3) With the increase of heating film coverage area, the heating power decrease which can heat the battery from -10°C to 5°C in 5 minutes. When designing a battery thermal management system, the heating power of the heating film should be above the boundary curve.

4) The heating film covers 50% of the largest area of the battery is better, and the heating power should be above 645W.

Acknowledgments

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