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Research Paper

Numerical study on the thermal performance of a composite board in battery thermal management system

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HIGHLIGHTS

- One composite board with sandwich structure is designed for battery thermal management.
- Four working modes are compared under normal operating condition and thermal abuse condition.
- The composite board shows good heat dissipation capability and good heat-insulation capability.
- Increasing the latent heat of PCM can greatly improve the thermal performance of the composite board.

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ABSTRACT

One kind of composite board based battery thermal management system (BTMS) is proposed and a three-dimension battery thermal model is proposed in this work. The composite board consists of three parts with a sandwich structure, which contains a heat conducting shell, an insulation panel and phase change material (PCM). Then four different modes are compared in detail to verify the thermal performance of the composite board under normal operating condition and thermal abuse condition. The results show that the composite board can effectively improve the heat dissipation capability and the uniformity of the temperature, meanwhile it can enhance the heat-insulation capability of the battery pack to prevent the thermal runaway propagation. In addition, increasing the latent heat of PCM can greatly improve the thermal performance of the composite board, thus the PCM with a latent heat of 1125 kJ/kg and the phase change temperature between 303.15 K and 323.15 K are recommend to be used in the battery thermal management.

1. Introduction

Due to the dual pressure of resources and environment, many countries are developing electric vehicles (EVs) to replace traditional fuel vehicles, which have less environment pollution, lower noise and higher efficiency. Lithium ion battery is the dominate power source of the EVs by now. However, lithium ion battery that as the main driving energy of the electric vehicles still has some safety problems. There are many fire accidents of electric vehicles around the world. This is because that the battery will produce a lot of heat in the process of charging and discharging, if combined with the space constraint and time accumulation, leading to the temperature rise of the battery. When the temperature of single battery exceeds the normal working temperature, it is tend to thermal runaway, even it will spread to the whole battery pack and cause the fire of the vehicle. Several studies have shown that the optimum operating temperature range of lithium ion battery is from 293.15 K to 313.15 K [1], and Zhao et al. [2] mentioned that the lifetime of battery will be reduced by two months for each degree rise in temperature. Therefore, it is of great importance to design effective battery thermal management system (BTMS) in order to ensure the battery in the normal operating temperature range. In addition, enhancing the heat-insulating capability of the battery pack is also necessary, for it will effectively prevent the thermal runaway propagation between the batteries.

On the one hand, the battery thermal management system is essential to control the temperature of batteries in a normal operating temperature range and to decrease the temperature gradient

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in battery pack. The BTMS can be classified as air system, liquid system, and phase change material (PCM) system, and so on, according to the heat transfer medium. First of all, the air cooling method is the most simple and most commonly used method in reality. And the study of air based thermal management system is focused on the battery arrangement (i.e. aligned and staggered cell arrangements) [3], airflow rate, and airflow modes (i.e. two-directional air flow, reciprocating air flow) [4,5], and so on. However, the heat transfer coefficient of the air is low, and it is very difficult to satisfy the heat dissipation required at high discharge rate. Secondly, liquid based thermal management system is more effective than air system, for its higher heat transfer coefficient. Tesla motors [6] adopts the liquid cooling method, and the winding cooling tube is arranged between the battery, so the heat can be taken away through the liquid flow. But the liquid based system has a biggest drawback that is easy to leak causing the battery short circuit, and it needs additional power consumption. Thirdly, passive thermal management using PCM has attracted a lot of attention in recent years. Al Hallaj and Selman [7] first put forward that PCM can be applied to the battery thermal management, which can use its high latent heat to effectively reduce the maximum temperature and greatly improve the uniformity of temperature of the battery pack. The most commonly used phase change materials is paraffin, but its thermal conductivity coefficient is very low (about 0.2 W/m K). Then a lot of work have been done to increase the thermal conductivity coefficient of PCM through adding high heat conductivity materials such as expanded graphite, carbon fiber, graphene, aluminum foam, and copper foam [8–11], and so on. Besides, the development of composite thermal management system has become a new trend, such as the combination of PCM and liquid cooling, PCM and forced air convection, and PCM and heat pipe.

On the other hand, the heat-insulating capability of the battery pack is also of great importance to prevent the thermal runaway propagation. Berdichevsky et al. [12] presented that increasing heat conductive shell on the outside of battery to enhance the heat transfer between the battery and cooling medium, and placing insulation plate and metal plate between different cell layer, which

Table 1
Geometric size and thermo-physical parameters used in simulation.

Nomenclature	Parameters	Value
Battery length	L (mm)	70
Battery width	W (mm)	28
Battery height	H (mm)	134
Capacity of battery	C (Ah)	20
Internal resistance of battery	R (mΩ)	6
Entropy coefficient	dE/dT (mV/K)	−0.5 [19]
Thickness of composite board	d_1 (mm)	10
Thickness of heat conducting shell	d_2 (mm)	1
Thickness of Insulation panel	d_3 (mm)	2
Thickness of each PCM layer	d_{PCM} (mm)	3
Heat capacity of battery	C_b (J/(kg K))	1605 [20]
Specific heat of battery box	C_{p1} (J/(kg K))	900
Heat capacity of heat conducting shell	C_{p2} (J/(kg K))	385
Heat capacity of insulation panel	C_{p3} (J/(kg K))	800
Heat capacity of PCM (solid phase)	C_{PCMS} (J/(kg K))	2150 [21]
Heat capacity of PCM (liquid phase)	C_{PCML} (J/(kg K))	2180 [21]
Latent heat of phase change	L_{PCM} (J/kg)	225,000 [21]
Thermal conductivity of battery	k_b (W/(m K))	32 [20]
Thermal conductivity of battery box	k_1 (W/(m K))	238
Thermal conductivity of heat conducting shell	k_2 (W/(m K))	400
Thermal conductivity of insulation panel	k_3 (W/(m K))	0.1
Thermal conductivity of PCM (solid phase)	k_{PCMS} (W/(m K))	0.358 [21]
Thermal conductivity of PCM (liquid phase)	k_{PCML} (W/(m K))	0.152 [21]
Density of battery	ρ_b (kg/m^3)	2285 [20]
Density of battery box	ρ_1 (kg/m^3)	2700
Density of heat conducting shell	ρ_2 (kg/m^3)	8700
Density of insulation panel	ρ_3 (kg/m^3)	880
Density of PCM (solid phase)	ρ_{PCMS} (kg/m^3)	814 [21]
Density of PCM (liquid phase)	ρ_{PCML} (kg/m^3)	724 [21]
Ambient temperature	T_0 (K)	293.15
Phase change temperature of PCM	T_{PCM} (K)	303.15
Heat transfer coefficient of natural air convection	h_0 (W/(m^2 K))	10

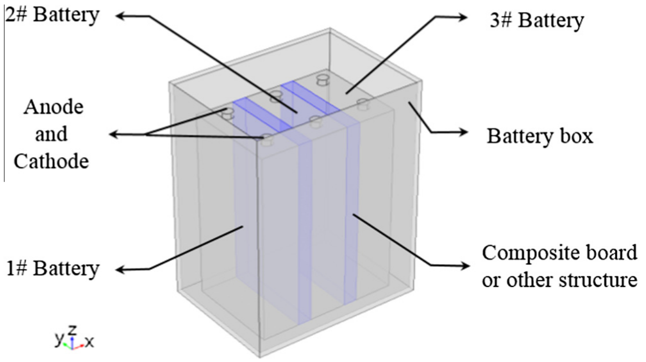
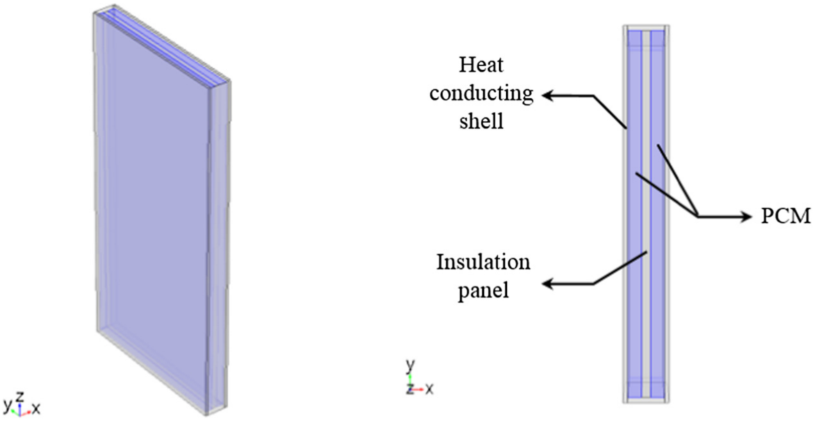


Fig. 1. The schematic of the Li-ion battery pack.



(a) The stereogram view (b) The vertical view

Fig. 2. The stereogram and vertical view of a composite board.