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Research Paper

Researches of composite phase change material cooling/resistance wire preheating coupling system of a designed 18650-type battery module

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HIGHLIGHTS

- An elongated battery module was designed.
- Battery module with CPCM cooling/resistance wire preheating coupling system and fins has good thermal performance.
- Infusion technology simplifies the process of production of thermal management system.
- Fins set on both sides to preventing CPCM from heat saturation.
- Temperature controlling and preheating performance of coupling system was effective.

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ABSTRACT

Nowadays, the battery thermal management system based on composite phase change materials (CPCM) is receiving increasing attention for researches. However, few researches were focused on the problems of molding CPCM battery module, cooling down CPCM after heat accumulation and preheating function of the CPCM thermal management system. In order to address these existent problems, an elongated battery module with CPCM cooling/resistance wire preheating coupling system and fins set on both sides of the shell was designed, and infusion technology was used to produce the coupling system due to the development of a kind of CPCM flowing after heated. Experimental results revealed that with the developed CPCM, the maximum temperature is still controlled below 45 °C and temperature difference is restricted within 5 °C although the battery module discharged at 5 C high rate in 40 °C high environment temperature. Moreover, the fins set on both sides of module can contribute to dissipating heat stored in CPCM efficiently, preventing CPCM from heat saturation. The CPCM cooling/resistance wire preheating coupling system not only prevents temperature from rising too high, but also preheats the batteries quickly in cold temperature. The inner center temperature of the batteries can be raised up 40 °C within 300 s with the coupling system.

1. Introduction

Lithium-ion (Li-ion) batteries have been widely deployed commercially in electric and hybrid electric vehicles [1,2], but safety, thermal runaway and poor low temperature performance limit their application, which are all related to battery thermal management [3–5]. The operating temperature of Li-ion batteries is closely related to their performance, capacity, lifespan and safety [6,7]. If Li-ion batteries, specially, large-scale battery packs discharge at large current in high environment temperature, the heat accumulated may overheat the battery, resulting in short lifespan, capacity and power reducing with cycling, and even thermal runaway in some extreme conditions [8,9]. Moreover, each battery in the pack will have different thermal environment if the pack is cycled without any thermal management system, therefore, batteries will undergo capacity fading at different rates, ultimately shorten the lifespan of the whole battery pack [10–13], thus it was necessary to keep the temperature difference within 5 °C [14,15].

What's more, in severe cold winter climates, preheating system should be adopted for insuring the battery operating normally, which prevents from the loss of usable energy and lithium depositing on the surface of negative electrodes in the form of dendrite

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Nomenclature

F	Faraday constant [96,485 C/mol]
E	battery's electromotive force [V]
ΔG	change in Gibbs's free energy [J]
N	moles of reactant for the whole battery [mol]
n	moles of the immigrating electrons [mol]
ΔS	entropy change [J/(K mol)]
Q_t	total heat generated of a battery [J]
Q_j	Joule heat [J]
Q_p	polarization heat [J]
m	the mass of composite phase change material [kg]
ρ	the density of composite phase change material [kg/m^3]
K	thermal conductivity [W/(m K)]
Δt	the mass of composite phase change material [kg]
γ	the latent heat of composite phase change material [J/kg]
R_o	the radius of the 18650-type battery [m]
$\partial E/\partial t$	temperature derivative of equilibrium potential [V/K]
C	specific heat capacity of the composite phase change material [J/(kg K)]
C_{cell}	the capacity of a battery pack or battery [A h]
r	the calculated thickness of the composite phase change material layer [m]
h	the height of the composite phase change material layer [m]
R_j	Joule internal resistance during discharge [Ω]
R_p	polarization internal resistance during discharge [Ω]
R	internal resistance [Ω]
T	temperature [K]
H	enthalpy [J]
I	electric current [A]
t	time [s]
q_t	heat generation rate [W]
Q_r	reaction heat [J]
Q_s	side reaction heat [J]
R_r	resistance of resistance wire
Q_E	energy consumption

Abbreviations

CPCM	composite phase change material
DSC	differential scanning calorimeter
SOC	state of charge

[16,17]. Considering the above-mentioned reasons, proper thermal management is necessary for battery module which cancool or preheat the pack to guarantee the module operating on appropriate temperature, therefore, to ensure the thermalstability and long-term durability of the lithium-ion batteries [18,19].

Composite phase change materials (CPCM) with great compactness, high energy efficiency and low maintenance have drawn great attention in recent years [20,21], representing better performance than conventional thermal management system under high discharge rates or other severe conditions [22]. Rao et al. [23] demonstrated that the efficiency of heat transfer can be enhanced by improving the thermal conductivity and lowering the melting point of the CPCM. Khateeb et al. [24] designed a battery module surrounded by CPCM made up with Al-foam and/or Al-fins, and the results revealed the effect of heat transfer improved manifestly. Until now much work has been focused on increasing the thermal conductivity of the CPCM using nanoparticle [25,26], Al-foam, copper foam, expanded graphite matrix, etc. [27,28], controlling temperature rising and improving the temperature uniformity of the battery module [29].

However, few researches were concentrated on the application of CPCM suffering from some serious problems. For example, it's very difficult to mold the battery module with CPCM thermal management system. Furthermore, CPCM thermal management system can obtain heat saturation easily during the battery charging and discharging process constantly. What's more, the research of preheating function for the current CPCM thermal management system is absent.

Towards the above-mentioned problems of the CPCM thermal management, the battery module was designed with thermal management system incorporating the composite phase change material cooling and the resistance wire preheating, this work has focused on designing an elongated battery module made by perfusion technique for producing easily. Meanwhile, fins were adopted to the module for enhancing CPCM heat dissipation, which can prevent the CPCM from heat saturation. Moreover, its cooling performance was measured experimentally, and furtherly the integrity performance of the CPCM cooling and the resistance wire preheating coupling system was researched.

2. Experimental setup

2.1. The battery module design

18650-type batteries were chosen to develop an elongated battery module with the CPCM cooling/resistance wire preheating coupling thermal management system and fins. To give full play to the fins to cool down the CPCM, the battery module was designed in strip form by reducing the batteries arranged along the width direction. There were three rows of batteries along the width direction of the designed battery module. The battery module and battery pack made of battery modules are shown in Fig. 1b and c.

There are holes at the bottom of the battery module shell. In the preparation of the battery module, batteries were located within the battery module shell in holes waiting for being winded with insulation resistance wires connected in parallel, as shown in Fig. 1a and b. With the purpose of making the CPCM thermal management system molded easily, perfusion technique was employed. Molten CPCM was poured into to the battery module shell finally. The CPCM flowed and filled the whole shell. After the CPCM cooling down, the CPCM and resistance wires fasten together, which formed a CPCM cooling/resistance wire preheating coupling system. Furtherly, the cooling and preheating performance of the coupling system were studied. The details of preheating experiment principle diagram are shown in Fig. 1d, which mainly includes the current control circuit and data acquisition system.

2.2. Heat generation calculation

The heat generation of the 18650-type battery during charging and discharging mainly consists four parts: Joule heat (Q_j) caused by the electrical resistance component, reaction heat (Q_r) by enthalpy change during electrochemical reactions, polarization heat (Q_p) by the electrochemical polarization and side reaction heat (Q_s). Among them, Q_j and Q_p can be expressed with Eq. (1) and Eq. (2).