Energy Conversion and Management 126 (2016) 622–631

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Thermal performance of lithium-ion battery thermal management system by using mini-channel cooling

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ARTICLE INFO

Article history:
Received 15 May 2016
Received in revised form 19 August 2016
Accepted 21 August 2016

Keywords:
Mini-channel
Cold-plate
Battery thermal management
Lithium-ion battery pack

ABSTRACT

Thermal management is indispensable to lithium-ion battery pack especially within high power energy storage device and system. To investigate the thermal performance of lithium-ion battery pack, a type of liquid cooling method based on mini-channel cold-plate is used and the three-dimensional numerical model was established in this paper. The effects of number of channels, inlet mass flow rate, flow direction and width of channels on the thermal behaviors of the battery pack were analyzed. The results showed that the mini-channel cold-plate thermal management system provided good cooling efficiency in controlling the battery temperature at 5C discharge. A 5-channel cold-plate was enough and the temperature could be evidently reduced by increasing the inlet mass flow rate. Additionally, for the bad temperature uniformity in the design 1, design 2 was proposed and compared with the design 1. The maximum temperature and temperature difference decreased 13.3% and 43.3%, respectively. Temperature uniformity was significantly improved.

1. Introduction

The issues of energy shortage and environment pollution have provided opportunities for the development of pure electric vehicles (EVs) and hybrid electric vehicles (HEVs) [1]. Compared to conventional vehicles, EVs have the advantages of less noise, higher energy utilization and environment protection [2]. Power battery is the key to electric vehicles development. Various kinds of battery such as lead-acid battery, nickel-metal hydride (Ni-MH) battery and lithium-ion battery are available for electric vehicles [3]. Compared with other batteries, lithium-ion batteries have significant advantages such as higher power density, longer cycle life and lower self-discharge rate. Therefore, they are the advisable candidates for electric vehicles [4]. However, lithium-ion batteries are very sensitive to temperature. Temperature affects the cycle life, efficiency, reliability and safety of the battery [5]. During charge and discharge process, a large amount of heat is generated inside the battery due to electrochemical reaction and resistance, which will increase the temperature of the battery. Thermal runway, electrolyte fire and explosions can occur when the temperature is too high [6]. Lithium-ion batteries operate best at temperature between 25 °C and 40 °C. The desirable temperature distribution is less than 5 °C in a battery or from module to module [7]. As a result, efficient thermal management systems are highly necessary for lithium-ion batteries.

At present, battery thermal management system can be divided into three types: air cooling system, liquid cooling system and phase change material (PCM) based cooling system. The first two types can be further divided as active system and passive system. PCM based cooling system is usually passive [8].

PCM based cooling system is a new type of battery thermal management. It was first proposed to apply in battery thermal management by Al-Hallaj and Selman [9]. Javani et al. [10] investigated the effects of PCMs on square lithium-ion battery. They found PCMs could bring more uniform temperature distribution and keep battery in safe temperature range. In our previous work [11], PCM was employed to cool the ageing lithium iron phosphate ($LiFePO_4$) power battery. It was shown that the higher thermal conductivity and lower melting point of PCM was very beneficial to decrease the battery temperature. However, they still cannot be widely used limited by their very lower thermal conductivity [12].

In the aspect of air cooling, it is one of the widely used cooling system in electric vehicles due to its simple structure, low cost and easy maintenance. Air cooling system was employed in the Toyota Prius and Honda Insight, Nissan and GM also used forced air cooling system to cool batteries [13]. Zolot et al. [14] studied the temperature control performance of a forced air cooling system in Ni-MH batteries, it was shown that the maximum temperature was effectively reduced and temperature distribution was uniform.

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http://dx.doi.org/10.1016/j.enconman.2016.08.063
0196-8904/

Nomenclature

Q_{gen}	heat generation of the battery (W)
Q_r	electrochemical reaction heat (W)
Q_j	joule heat (W)
ρ	density (kg/m^3)
k	thermal conductivity (W/m K)
C_p	heat capacity (J/kg K)
I	discharge current (A)
n	number of electrons (mol)
F	Faraday constant, 96485 C/mol
ΔS	entropy change
E	open circuit voltage (V)
V	operating voltage (V)
T	temperature (K)

Subscripts

b	battery
c	cold-plate
j	joule
r	reaction
w	water
gen	generation

Acronyms

EVs	electric vehicles
HEVs	hybrid electric vehicles
PCM	phase change materials
UDF	user defined function
SOC	state of charge

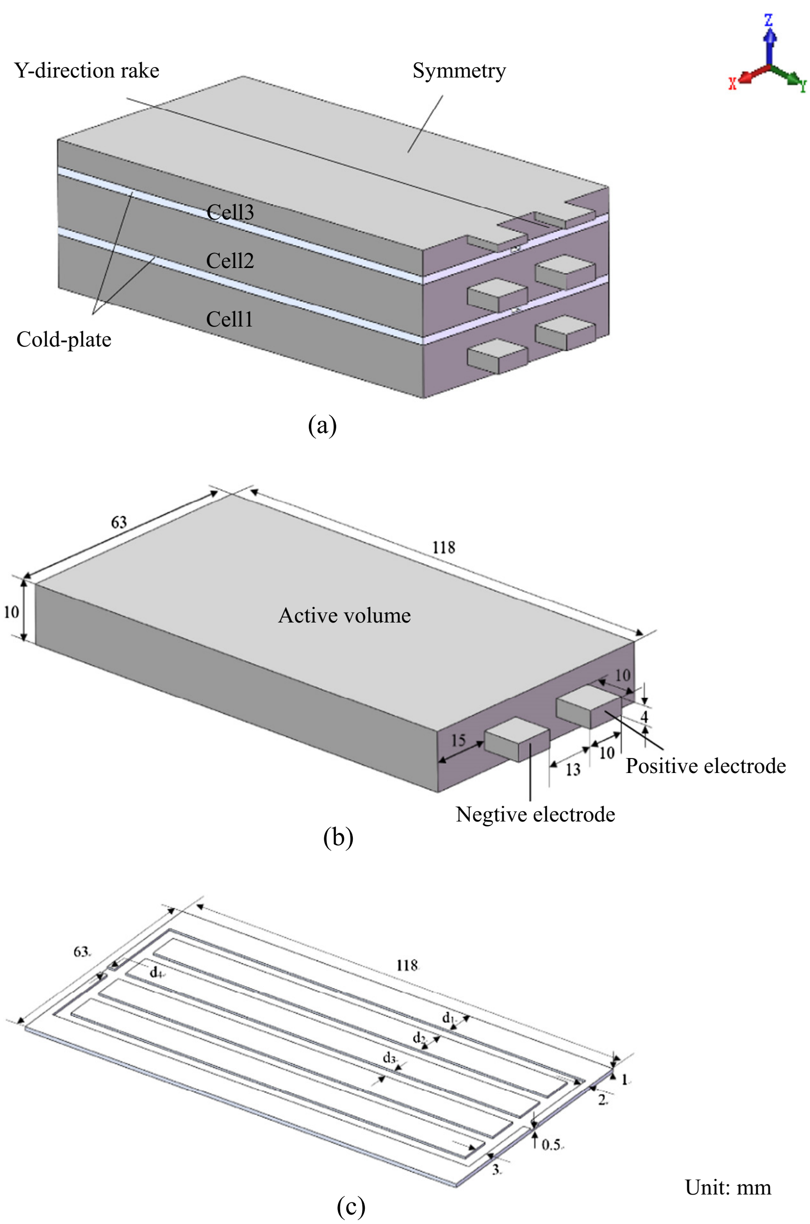

Fig. 1. Schematic of the cooling system: (a) design 1. (b) Single battery cell. (c) Half of cold-plate.