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Influence of the oblique fin arrangement on the fluid flow and thermal performance of liquid cold plate

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ABSTRACT

Electric vehicle (EV) is advancing as the transportation industry and the demand is expanding globally. The use of liquid cold plate (LCP) in EV battery is more effective in providing the desire temperature rather than using the conventional air cooling. The use of straight fins is being switched to oblique-shape fins to assist disruption of the thermal boundary layer development. The arrangement of fins in the LCP also will affect the performance of it cooling the battery. Three different arrangement of the oblique fin are developed to enhance the fluid flow and heat transfer performance. The LCP contains three arrangements of oblique fin namely as inline, incline and loureved. Experimental and numerical results reveal the good aggrement where the Nusselt number is enhanced with the louvered arrangement. Among three arrangements, loureved obtained the lowest surface temperature of the battery followed by inline and incline. It also found that Nusselt number increases as the Reynolds number increases. The LCP is able to maintain the average surface temperature of the battery below permitted working temperature of 50 °C. This shows that the present LCP with oblique fin could be a promising method for EV battery thermal management.

1. Introduction

With increasing concern on environmental issues, the automotive industry has been move towards sustainable vehicles such as Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV). Battery plays important role in development of electric vehicle. Recently, there is growing demand for lithium-ion (Li-ion) batteries in the production of electric vehicle. Compared to other batteries, Li-ion batteries have significant advantages such as high energy density, low self-discharge rate and long life cycle [1]. However, thermal issues of the Li-ion batteries has become a drawback issues. Li-ion batteries is very sensitive to temperature. Temperature affects the cycle life, efficiency, reliability and safety of the battery [2]. A large amount of heat is generated during charge and discharge process due to sensitive to temperature. Temperature affects the cycle life, efficiency, reliability and safety of the battery [2].

A large amount of heat is generated during charge and discharge process due to electrochemical reaction and resistance which will cause temperature rise of the battery. Thermal runaway may occur in the cell of the Li-ion battery pack if there is an extravagant rise in temperature of the battery pack.

There are different cooling method to maintain the Li-ion batteries at optimum temperature such as air cooling, liquid cooling and phase change material (PCM). Xie et al. [3] were optimized the structure of the air cooling by using the orthogonal design method. They found that with the optimization method, the maximum temperature and temperature different are reduced to 12.82% and

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Nomenclature

A	heated surface area, m^2
C_p	specific heat, kJ/kg K
D_h	hydraulic diameter, m
h	heat transfer coefficient, W/m^2 K
k	thermal conductivity, W/m K
Nu	Nusselt number, hD_h/κ
$\dot{m}$	mass flow rate, kg/s
R	thermal resistance, °C/W
Re	Reynolds number, $\rho u_i D_h/\mu$
T	temperature, K
Q	heat flux, W
$\vec{v}$	velocity vector

Acronyms

EV	electric vehicle
HEV	hybrid electric vehicle
PCM	phase change materials

Greek symbols

ρ	density, kg/m^3
μ	dynamic viscosity, N m/s
ν	fluid velocity, m^2/s

Subscripts

ave	average
i	inlet
o	outlet
f	fluid
e	ethylene glycol
c	cold plate
w	wall

29.72% respectively. Xu and He [4] were conducted a research on the heat dissipation performance of battery pack using forced air cooling. They concluded that thermal performances for longitudinal battery pack is better than horizontal battery pack. Kizilel et al. [5] were compared between the conventional air cooling method and the passive cooling method using phase change material (PCM). It was found that the passive cooling method using PCM can prevent the thermal runaway propagation. Kanargi et al. [6] carried out numerical and experimental study on heat transfer and fluid flow characteristics of an air-cooled oblique-finned heat sink. They found that the secondary flows, induced through the oblique channels of the oblique-finned heat sink, effectively disturbed and reinitialized the boundary layers on three walls of the oblique fins, reducing the thermal convective resistance for the entire range of air flow rates.

The temperature of the Li-on battery pack can be easily controlled at a temperature range of 20–55 °C [1]. Nonetheless, the local heat can increase abruptly in the case of a high power draws, high ambient temperatures or high power charging. Due to this, excess temperature can be propagated in the module of the battery pack and thermal runaway may occur. In order to maintain the temperature of the battery in a safe range, a dependable thermal management system is required. This system can also provide the battery to maintain safe operating temperature without the limiting the battery performance.

The liquid cooling system is a great cooling method for the battery with high energy density. However, the cost and the complexity of the system are determined to be the limitations for the system. Liquid cooling method can be divided into two: direct cooling and indirect cooling. Direct cooling involve direct contact of the liquid and the battery while indirect cooling uses tube that is injected around the battery. It is easier to conduct an indirect cooling with covers rather than to conduct direct cooling. Glycol solution is determined to be the most suitable coolant due to its low viscosity for indirect cooling system. Compared to using dielectric mineral oil as a coolant, the glycol solution does not limit the pumping power and it has a higher heat capacity for temperature changes inside the system. Glycol solution also have a higher thermal conductivity than oil as the battery module can achieve uniformity [1].

Panchal [7] was designed an apparatus using dual cold plates for Li-ion pouch cell undergoing various charge/discharges cycles with indirect liquid cooling system. An apparatus was designed to measure the surface temperature distribution, heat flux and heat generation from the battery. The results showed that the heat generation rate is significantly affected by the both discharge rate and boundary conditions.

Qian et al. [8] performed numerical investigation on thermal performance of Li-on battery using mini-channel cooling. The Li-on battery was designed in rectangular shape. The mini-channel is made of aluminium and water has been used as the cooling medium. They found that by increasing the number of channels will result in better cooling efficiency. Nevertheless, no significant effect on cooling efficiency when the channel number exceeds five. Besides, as the channel width increases the pressure drop was reduced up to 55%. Moreover, they revealed that the higher the inlet mass flow rate is, the more maximum temperature decreases.

Tong et al. [9] had performed a numerical investigation of watercooling for a Li-on battery pack. They suggested that the average temperature rise of the battery pack should reside around the operating line when considering the lifespan and the cost of the battery pack. Zhao et al. [10] proposed an optimum range of maximum and local temperature of the minichannel liquid cooling cylinder. By changing the effects of quantity of channels, mass flow rate, direction of flow and entrance size, the performance of heat dissipation were determined. The result revealed that temperature can be control below 40 °C at the inlet mass flow rate of 1 × 10–3 kg/s and by limiting the minichannel numbers to four. Additionally, it was found out that this method of cooling results in better circumstances compared to the free convection cooling.

Panchal et al. [11] carried out an experimental and simulation study of mini-channel cold plate for water cooled large sized prismatic lithium-ion battery. The study was conducted at two different discharge rate of 1 C and 2 C and different coolant operating temperature of 5 °C, 15 °C and 25 °C. They found that the temperature distribution within mini-channel cold plates increases as the discharge rates increase.

Huo et al. [12] designed a thermal management system for the EV battery referring to the minichannel liquid cooled plate. The