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Thermal analysis of electric vehicle battery pack cooling system using ethylene glycol

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ABSTRACT: *Power batteries generate a large amount of heat during the charging and discharging processes, which significantly affects operational safety and service life. An efficient cooling system is crucial for battery performance. A cooling channel for an electric vehicle battery pack with 72 battery cells using liquid water containing different types of ethylene glycol is proposed in this study. Various volume concentrations are analyzed their influence on the thermal cooling efficiency of the battery pack based on the maximum temperature and maximum temperature difference as two objective functions. The results indicate that using pure water enhances the heat transfer process compared to water-glycol. The study results are the theoretical basis for selecting coolant for electric vehicle battery cooling systems.*

KEYWORDS*: Lithium-ion battery, cooling channel, ethylen glycol, maximum temperature, temperature difference*

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I. INTRODUCTION

Lithium-ion batteries are the best option for electric vehicles (EVs) and hybrid electric vehicles (HEVs) due to several advantages. Compared to lead-acid batteries or nicklemetal hydride batteries, it has more energy density, longer cycle life, lower self-discharge rate, and greater efficiency [1]. It is also known that the performances (e.g., the cycle life [2], discharge capacity, voltage platform, etc.) of lithium-ion batteries are greatly affected by the operating temperature. The optimum operating temperature range of lithium-ion batteries is 15–35◦C, and the maximum temperature difference in the battery pack should not exceed 5 ◦C [3]. Therefore, the usage of an efficient battery thermal management system (BTMS) is an important condition to ensure the performance and safety of power batteries. Currently, commonly used BTMS are mainly based on aircooled, liquid-cooled, and phase-change materials. Liquid-cooled BTMS has a higher heat transfer coefficient, and itscooling efficiency is higher. However, liquid-cooled systems are also usually more complex and can have leakage problems. The PCM based approach is a new type of battery thermal management solution. It can effectively control the battery pack temperature in the optimal operating temperature range and ensure excellent temperature uniformity. However, it also has the problems of poor structural strength, leakage of melting material, and low thermal conductivity [4]. The liquid cooling method is the most widely used BTMS method nowadays. Depending on whether the battery pack is in direct contact with the coolant or not, the liquid cooling systems can be divided into two modes: direct contact and indirect contact. Compared with indirect contact BTMS, the cooling performance of direct contact BTMS is slightly better, but indirect contact BTMS is more suitable for practical applications [5]. As one of the emerging cooling technologies in recent years, direct liquid cooling, which is also called immersion cooling, has attracted considerable attention for electronic devices and in the EV industry [6]. In this system, the battery is submerged into a non-conductive dielectric fluid, thus making direct contact with the cell. This unique way of cooling brings several advantages. Firstly, immersion cooling has the potential to provide the best pack and cell temperature uniformity among all the cooling methods. This is because all battery surfaces are in the fluid, providing a homogeneous, high heat capacity thermal transport path for heat rejection. This direct contact with the cell surfaces further reduces the thermal contact resistances experienced in indirect cooling systems [7]. Immersion cooling simplifies the system design and reduces the system complexity [8]. Recent research in immersion cooling has mainly centred around performance analysis for single cells and battery packs. Nelson et al. [9] thermally modelled a 48-cell system with both direct cooling and air cooling. The result showed that direct cooling with silicone oil exhibited superior heat dissipation with the cell temperature rise only 2.5ºC, compared to air cooling which exhibited a 5.3ºC under the same load conditions. The similar conclusion on thermal performance comparison between direct silicone oil cooling and air cooling was also shown by Karimi et al. [10]. In other works, Kim and Pesaran [11] conducted a systematic single cell simulation comparison for three different thermal management systems including air cooling, indirect water/glycol jacket cooling, and direct mineral oil cooling. Among the three cooling methods, direct cooling demonstrated the lowest maximum cell surface temperature difference and the best heat transfer coefficient, especially with smaller cooling channel diameters and higher flow rates. Beyond water/glycol systems, authors have also proposed working fluids such as a pressurized saturated liquid ammonia. Here, Al-Zareer et al. [12] showed that a pressure of 9.0 bar with this liquid only covering 5% of the surface of the cell is adequate to maintain the battery temperature below 40ºC for high power charging and discharging cycles at a rate of 7.5C. The aim of this paper is to analyze the influences of various volume concentrations of liquid water containing different types of ethylene glycol on the thermal cooling efficiency of the battery pack. To achieve those goals, a cooling channel for an electric vehicle battery pack with 72 battery cells using liquid water containing different types of ethylene glycol is proposed to analyze their influence on the thermal cooling efficiency of the battery pack based on the maximum temperature and maximum temperature difference as two objective functions.

II. METHODOLOGIES

2.1. Geometry Models

The electric vehicle battery pack consists of 72 cylindrical 18650 Li-ion cells with the diameter and height of the cells being 18 mm and 65 mm, respectively. The geometric schematic of the cooling system using wavy channel is designed as shown in Fig 1. The battery cells are assumed to be simple solid blocks which is made of a material with orthotropic thermal conductivity while other properties are homogeneous. The thermophysical properties of materials used in this study are summarized in Table 1.

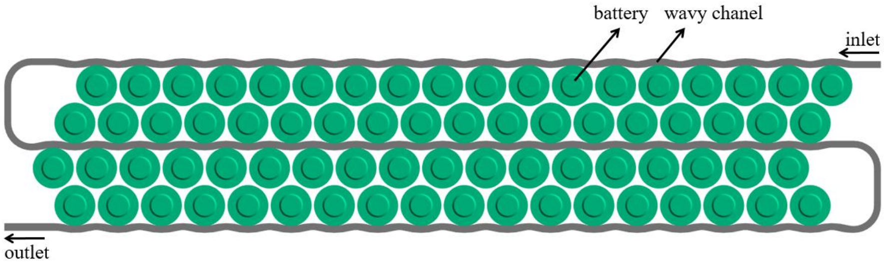

Fig. 1. The geometric model of battery pack

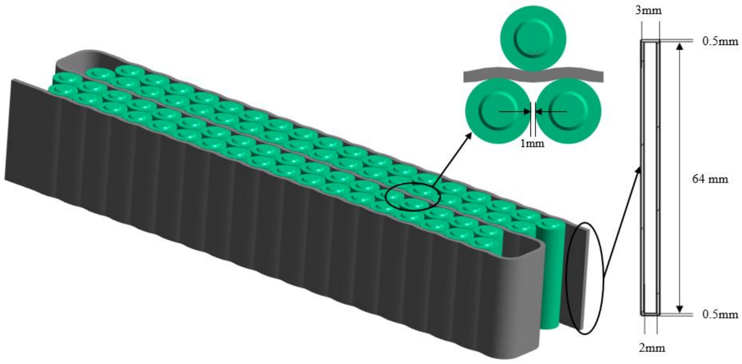

Fig. 2. Geometry parameters of battery pack

Table 1: Thermal physical parameters of ethylene glycol at different volume concentrations [14]

Material	Density (Kg/m^3)	Heat capacity C(J/KgK)	Thermal conductivity k (W/(mK))	Condensation point (℃)
Battery	1782	1010	15.8	-
Wavy channel	2719	871	202.4	-
0%	998.2	4185	0.65	0
40%	1039.6	3602	0.44	-22
50%	1052	3435	0.4	-38
60%	1063.7	3258	0.37	-48

2.2 Governing Equations

Coolant is assumed to be an incompressible fluid. Its continuity equation is expressed as:

$$\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}=0 \tag{1}$$

Its momentum equation is shown as:

$$\frac{\partial}{\partial t}\left(\rho_c \vec{v}_c\right)+\nabla.\left(\rho_c \vec{v}_c \vec{v}_c\right)=-\nabla p+\mu_c \nabla^2 \vec{v}_c \tag{2}$$

where $\vec{v}_c$ denotes the velocity vector of the coolant; where p denotes the static pressure of coolant, Pa.

Its energy equation is shown in equation:

$$\frac{\partial}{\partial t}\left(\rho_c C_{p,c} T_c\right)+\nabla.\left(\rho_c C_{p,c} T_c \vec{v}_c\right)=\nabla.\left(k_c \nabla T_c\right) \tag{3}$$

where $C_{p,\,c}$ is the specific heat capacity of coolant under constant pressure, J/(kg·K); k_w is the effective thermal conductivity, W/(m·K).

For the wavy channel, the heat transfer process is controlled by the heat transfer differential equation:

$$\rho C_p \frac{\partial T}{\partial t}=\nabla.(k \nabla T) \tag{4}$$

where ρ, C_p, and k denote the density of the corresponding material, kg/m^3, the constant pressure specific heat capacity, J/(kg·K), and the thermal conductivity, W/(m·K), respectively.

2.3 Initial and Boundary Conditions

The initial temperature is assumed to be the same with the ambient temperature, the ambient temperature is set at 30^{o}C. The inlet boundary condition is defined as a velocity inlet, while the outlet boundary condition is defined as a pressure outlet. The outer walls of the cell and colling channel are set as adiabatic. No-slip boundary condition is specified for the cold plate interface. Contact resistances between different regions are ignored. The laminar flow model is selected for the calculations. Ignore the convective heat exchange between the flowing coolant and the channel wall. The simulations are performed on the FLUENT 2023R2

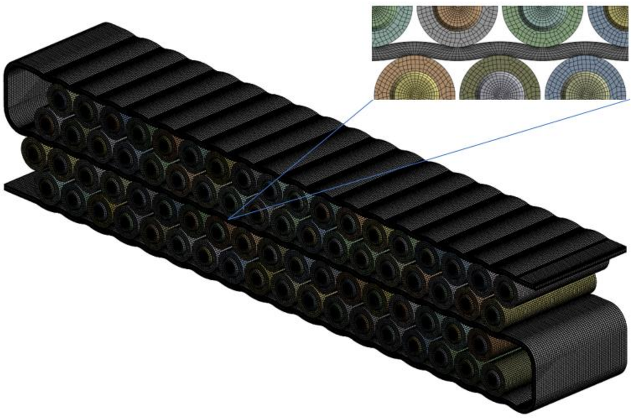

Fig. 3. The meshing result of battery pack

A mesh with 868,362 elements and 996,404 nodes was selected for the cooling system, the mesh metrics are provided in Table 2, the maximum skewness is 0.52, which is classified as 'good'.

III. RESULTS AND DISCUSSION

To explore the effectiveness of ethylene glycol, the performance of ethylene glycols with different volume concentrations is simulated at a 5C rate with an inlet velocity of 0.001 kg/s. As indicated in Fig. 4, pure water achieves better cooling performance than ethylene glycols, and their performance improves with decreasing volume concentrations. The maximum temperature (T_{max}) increases by 1.81°C, 2.40°C, and 3.03°C with 40%, 50%, and 60% ethylene glycol in comparison with pure water, respectively. Regarding the temperature difference (T_{diff}), although the effect of adding ethylene glycols is limited, a higher volume concentration slightly enhances the temperature difference under these conditions, with improvements of 1.04°C, 1.39°C, and 1.8°C, respectively.

At the initial stage, the maximum temperature and temperature difference increase rapidly until reaching a steady state after approximately 200 seconds for all case. The stable points occur at around 200 seconds and 700 seconds, respectively. Fig.4 shows that at a discharge rate of 5C, the maximum temperature and temperature difference inside the battery pack exceed the temperature limits of 35°C and 5°C, respectively, after approximately 200 seconds.

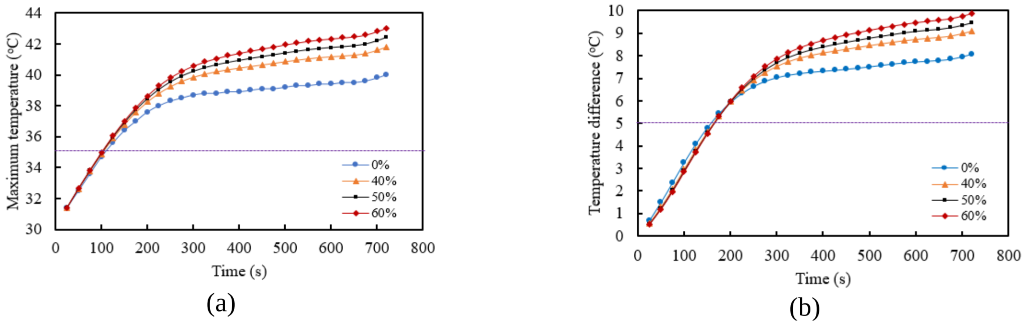

Fig 4. Maximum temperature (a) and temperature difference (b) for different volume fractions

IV. CONCLUSIONS

In this study, a cooling channel for an electric vehicle battery pack with 72 battery cells using liquid water containing different types of ethylene glycol was proposed to to analyze their influence on the thermal cooling efficiency of the battery pack based on the maximum temperature and maximum temperature difference as two objective functions. The obtained results showed that pure water achieved better cooling performance than ethylene glycols, and their performance improves with decreasing volume concentrations. In future study, the authors focus on analyzing the influence of other parameters of the cooling channel on the cooling efficiency of electric vehicle battery packs.

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