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Thermal Investigation of Changes in The Mass Flow Rate of The Lithium-Ion Battery Coolant

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Abstract

An electric battery is an energy storage device that has a high energy density, a long lifetime and has a high rate of charging and discharging the battery. The performance of the Lithium-Ion battery greatly affects the temperature of charging and discharging, so a cooling method is needed that is able to maintain the working temperature of the battery at (25 – 50^{0}C) conditions. In this study, the Computational Fluid Dynamics method was used to investigate the effect of Depth of Discharge (DOD) on the cooling performance of BTMS (Battery Thermal Management System) Liquid Cooling using ethylene-glycol as the working fluid to be flowed on the curved cooling tube. The results of this study indicated that the maximum temperature and temperature difference of the battery module decreased as the mass flow rate of the cooling fluid increased, the lowest temperature value occurred at the mass flow rate of 18×10-4kg·s-1 with a temperature value of 303.6 K. The maximum temperature of the battery module fluctuated as the DOD value increased.

Keywords: Battery Thermal Management System, Depth of Discharged, Li-Ion Battery.

1 Introduction

In recent years, energy resources from fossil in the world are very difficult to find it is because demand in the transportation sector will increase each year [1]. Many solutions that can overcome the demand for energy from fossil through government regulations, technology, and energy alternatives. One of the solutions to solve this problem is using electrical vehicle that is battery as its main energy source [2-4]. An electric vehicle is a modern transportation that can support conventional transportation, which is conducted by internal combustion engine. When use electrical vehicle, Lithium-ion is one of the types of electrical battery that has long durability of energy [5-6].

As a structure of lithium-ion battery, it consist of several parts of the propylene carbonate (PC) and spinal as electrolyte, cathode, and anode, which distribute Li ion and temperature exchange [7]. Thermal management as main issue nowadays that has repeatedly improved to control the temperature range at 20 ^{0}C - 40 ^{0}C [8]. Meanwhile, a uniform temperature of the battery is important to maintain durability, and it needs to keep the temperature at 5 K for each battery [8]. Zhang (2011) have investigated a cylindrical battery model using a Lithium-Ion battery on the behavior of heat generation. Based on his work, about 30% average of total heat generation, it is occurred because of the electrochemical reaction [7]. Bai (2017) has investigated battery thermal management system using PCM combined with liquid cooling. The experiment result showed that the mass flow rate of liquid cooling affects the temperature of battery module [9]. The previous study showed that it was still a lack of study to improve the cooling system of lithium-ion battery with a variety of BTMS (Battery Thermal Management System).

This study will offer a cooling system model using a cooling tube for a battery cooling system with ethylene glycol as a cooling fluid and the aim of study also will find the maximum temperature battery, temperature difference and contour of temperature distribution using computational fluid dynamic. Computational Fluid Dynamics (CFD) was employed to examine the influence of Depth of Discharge (DOD) on the cooling performance of a liquid-cooled Battery Thermal Management System (BTMS), where ethylene glycol served as the coolant circulating through a curved cooling tube.

2 Research Methods

This study focuses on a lithium-ion battery pack consisting of cylindrical 1650-type cells, as illustrated in Fig. 1. Cylindrical lithium-ion batteries are widely utilized in electric vehicle applications due to their high energy density, reliability, and relatively stable thermal performance. In the present configuration, the center-to-center distance between adjacent battery cells is set at 23 mm to provide sufficient spacing for thermal management components. A curved cooling tube with a thickness of 2 mm is integrated into the battery module to facilitate heat dissipation during operation. The geometric arrangement is designed to investigate the interaction between battery heat generation and the cooling system under different operating conditions.

The thermal management system analyzed in this study employs a liquid-cooling configuration using a single curved cooling tube model. The model represents a simplified battery module consisting of five cylindrical battery cells, as shown in Fig. 2, which is intended to emulate the cooling arrangement commonly found in electric vehicle battery packs. The cooling tube is positioned strategically to maximize heat transfer from the battery surfaces to the circulating coolant. By focusing on a five-cell module, the computational model can effectively capture the thermal behavior of the battery pack while maintaining reasonable computational costs. This approach enables a detailed investigation of cooling performance and temperature distribution within the battery module.

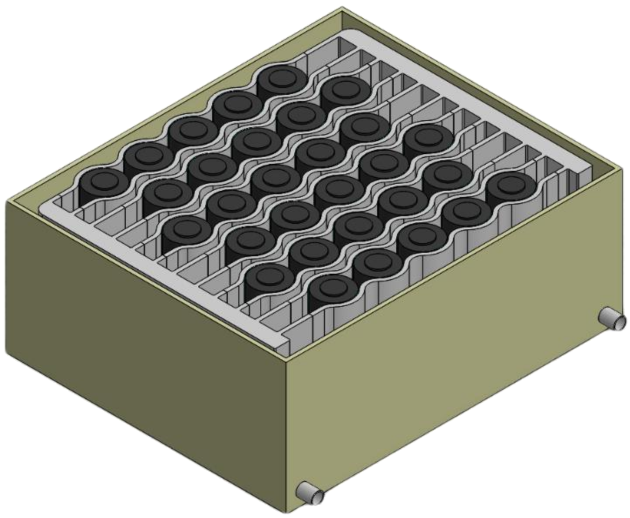

Figure 1. 3D visualization of cooling system for Lithium-Ion battery.

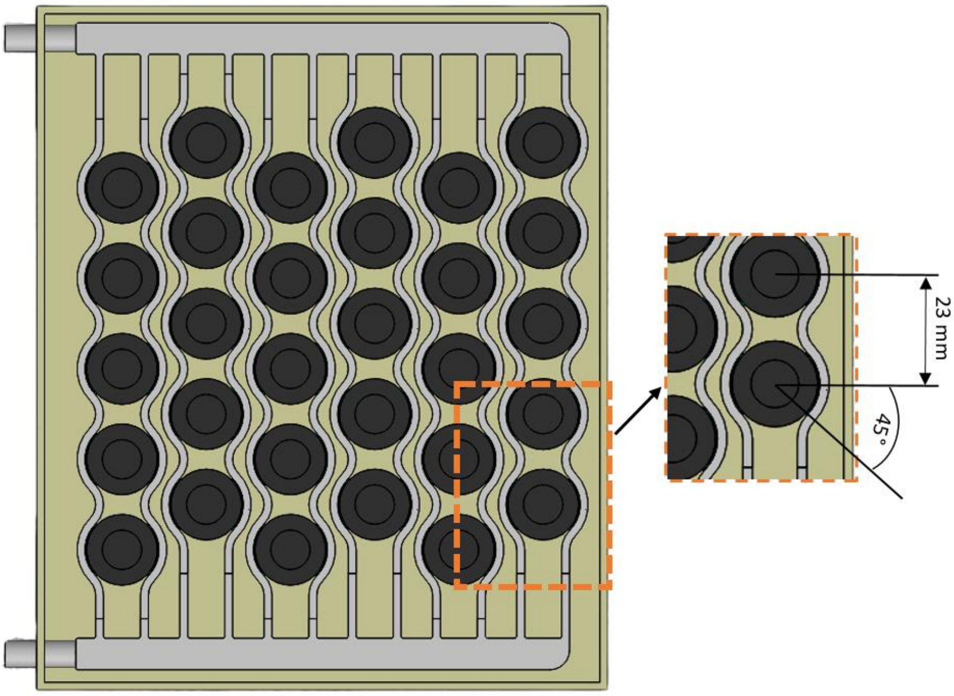

Figure 2. 3D visualization from top view for Lithium-Ion battery.

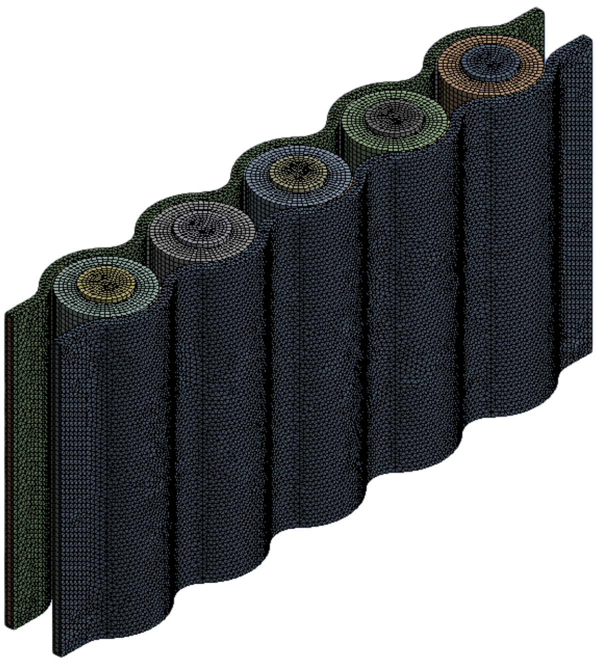

Figure 3. Meshing model for pack of lithium-ion battery.

To perform the numerical simulation, a three-dimensional mesh was generated using the mapped face meshing method with tetrahedral elements. An element size of 1 mm was selected to produce a structured and sufficiently refined mesh capable of accurately representing the complex geometry of both the battery cells and the curved cooling tube. The resulting mesh model is presented in Fig. 3. Furthermore, several boundary conditions were defined to accurately represent the physical system, including the battery cell, cooling pipe, positive tab zone, positive tab, negative tab zone, negative tab, fluid inlet, fluid outlet, and spacer components, as illustrated in Fig. 4. These boundary conditions were applied to ensure realistic simulation of heat generation, heat transfer, and coolant flow throughout the battery thermal management system.

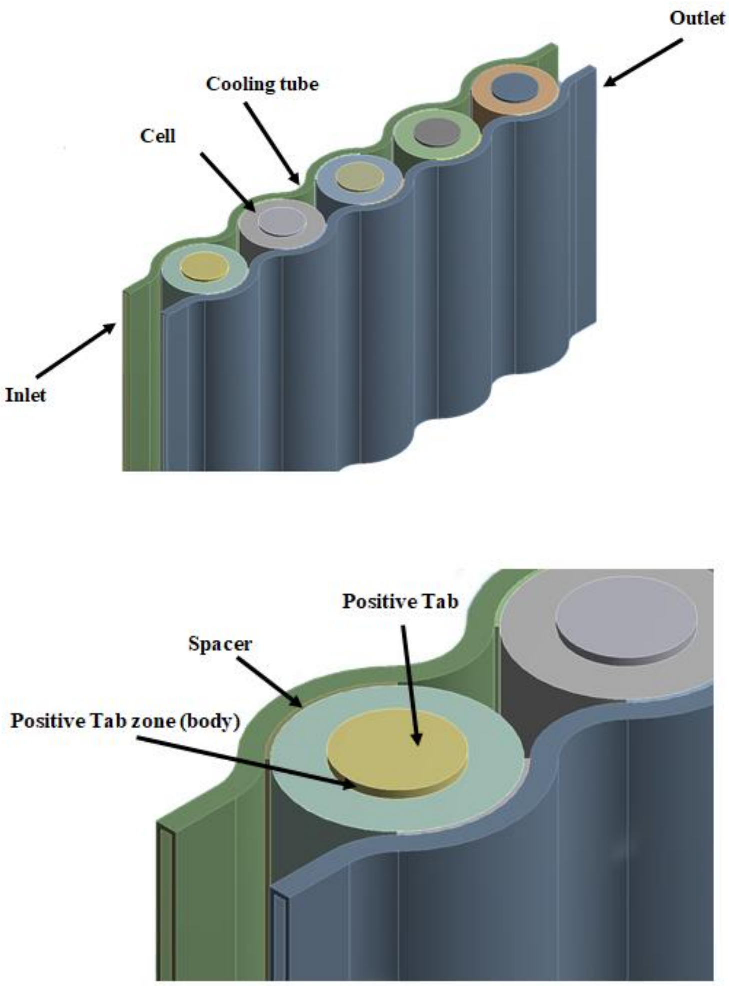

Figure 4. Boundary condition for Lithium-Ion battery.

3 Results and Discussion

Fig.5 shows that the maximum temperature of the battery module decreases as the Depth of Discharge (DOD) increases. However, at 90% DOD, a temperature rise occurs, followed by a decline again at 100% DOD. This behaviour is attributed to changes in the battery's entropy coefficient during the discharging process, which alternates between positive and negative values. As a result, both endothermic and exothermic reactions take place within the battery, causing the battery temperature to fluctuate[10]. Fig.5 further demonstrates that a higher coolant fluid mass flow rate leads to smaller temperature fluctuations in the battery module. This is because the mass flow rate has a direct influence on the heat transfer rate — the greater the mass flow rate of the fluid, the higher the rate of heat transfer that occurs [7].

Fig. 6 show that the temperature distribution for battery module with the varieties of mass flow rate of liquid cooling gradually increase as the coolant flow. In the fifth positive battery tab area, which is farthest from cooling tube inlet area and the lowest battery temperature located in the negative battery tab area, which is the nearest to the cooling tube inlet area.

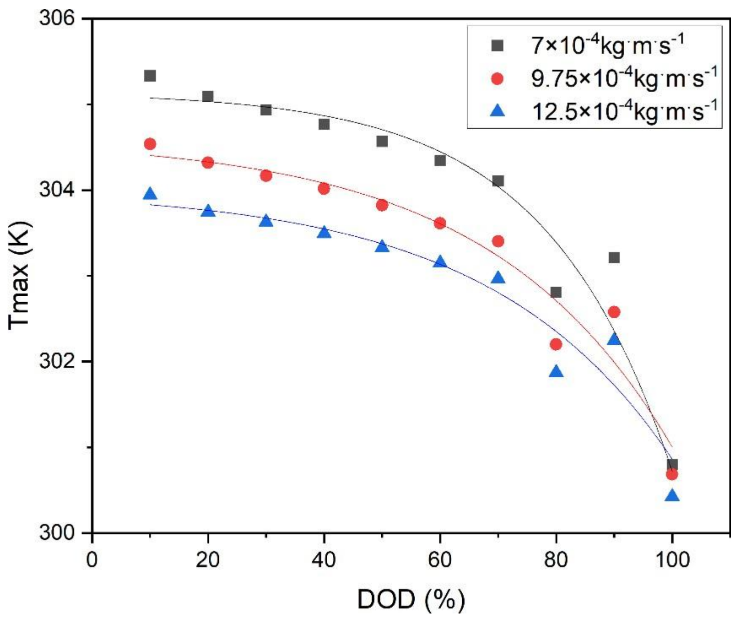

Figure 5. The correlation between Depth of Discharged versus Maximum Temperature on many differences of mass flow rates for the liquid cooling system

The uniform of temperature distribution is caused by the high thermal resistance of the battery cover and heat accumulation along the direction of the coolant stream of liquid cooling and the high temperature zone in the battery module shrinks as the mass flow rate of the coolant rises [2].

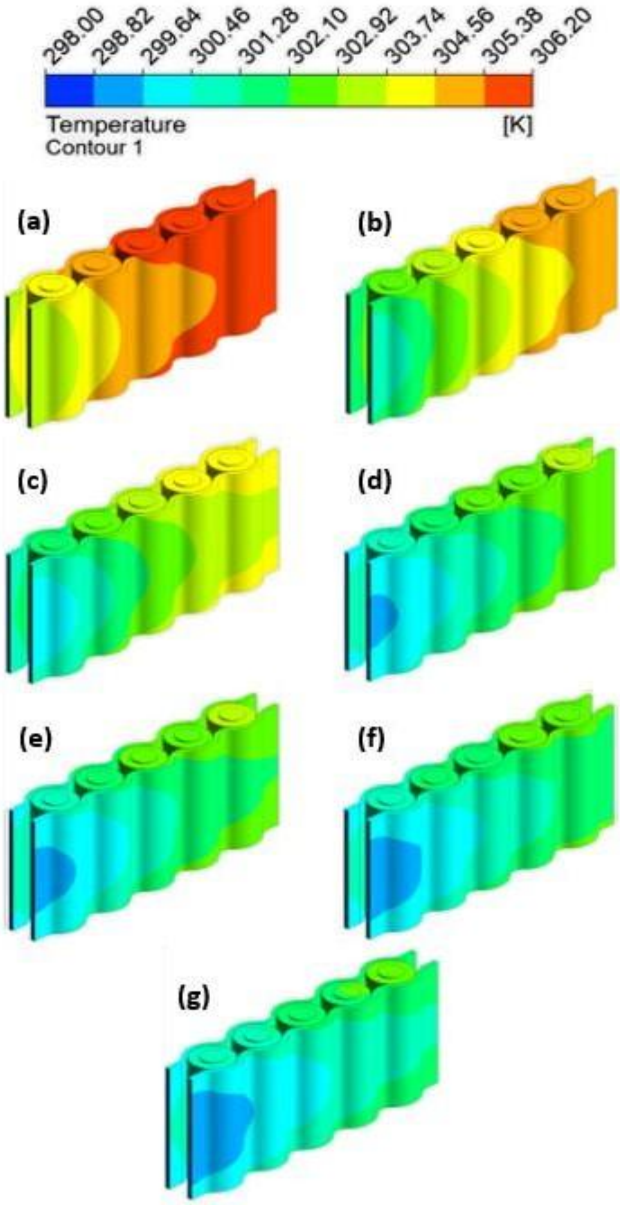

Figure 6. Isometric view of contour distribution temperature for the difference of mass flow rate liquid cooling for battery module

4 Conclusions

This study investigates the effect of mass flow rates for the liquid cooling system on battery module lithium-ion that the highest of mass flow rate able to keep battery temperature fixed at 20 ^{0}C – 40 ^{0}C where is at 300 K – 304 K. In addition, from the three-mass flow rate for liquid cooling that are different, it happened a uniform of temperature distribution for each lithium-ion battery.

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