Experimental Study of Lithium-ion Battery Performance Based on Mini-channel Cooling Plate

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***Abstract*—Making efficient batteries is important nowadays. One potential problem that can hinder this is the thermal runaway that occurs in battery cells. There are various causes of thermal runaway, one of the most common is an increase in temperature that exceeds the optimal allowable limit. Additional cooling will be required in vehicles that use batteries. Battery Thermal Management System (BTMS) with mini-channel cooling plate is one of the methods often used to maintain battery performance. In this study, the performance of Lithium-ion batteries is affected by fluid flow velocity. The experimental process was carried out by charging and discharging with a C-rate of 1C. Cooling is done with ethylene glycol fluid with fluid velocity variations of 0.21 L/min; 0.42 L/min and 0.63 L/min. The results show that fluid flow velocity affects the final battery temperature and battery performance. The optimal fluid velocity is shown at 4.2 L/min. At this speed it can reduce the battery temperature by 6.7°C.**

***Keywords*—battery thermal management system (BTMS), mini-channel cooling plate, lithium-ion battery, c-rate, fluid velocity, ethylene glycol**

I. Introduction

Currently, the use of fossil fuels (petrol/diesel) is still common. However, their availability is limited and they cannot be renewed in a short time. In addition, its use produces exhaust emissions (carbon monoxide, carbon dioxide, hydrocarbons, nitrogen oxides and others). Electric vehicles can be an alternative to reduce the use of fossil fuels. Electric vehicles use energy storage in the form of rechargeable batteries. Generally the battery used is a Li-ion battery. Li-ion batteries are widely used due to its high energy density, relatively light weight, low self-discharge rate and long service life. Li-ion batteries work optimally at temperatures of 25-40°C and with differences between battery modules of less than 5°C [1]. Battery temperature can be controlled with the Battery Thermal Management System (BTMS). Controlling battery temperature can affect battery life, performance and safety [2].

According to the control strategy, BTMS is divided into active and passive cooling systems. While from the type of cooling, BTMS is divided into air cooling [3, 4], liquid cooling [5, 6] and Phase Change Material (PCM) cooling [7, 8]. Liquid cooling is most often used since liquid cooling has a good cooling speed. One of the liquid cooling that can be used is the mini-channel cooling plate [9, 10]. Mini-channel cooling plate was chosen because it has good cooling efficiency, compact design, flexibility and reduces pump power. Fluid flow velocity and type of cooling fluids can affect the performance of this cooling system. Inappropriate fluid flow velocity can result in less effective cooling and excessive energy consumption. The type of fluid also needs to be considered because it is the main medium for heat transfer [12]. One of the frequently used cooling fluids is ethylene glycol. Ethylene glycol was chosen because it has high thermal conductivity, low viscosity, relatively low cost and wide temperature range [13]. BTMS with mini-channel cooling plates can be applied to small and large battery packs. This BTMS also allows it to be applied to two-wheeled, four-wheeled or more electric vehicles. Therefore, further research needs to be conducted to utilized the 69pplication of BTMS.

Previous research on Li-ion batteries shows that heat generation can affect battery performance. At extreme temperatures it can cause thermal runway. To avoid this, Li-ion batteries need to be equipped with a cooling system. This paper will focus on optimizing BTMS by using a mini-channel cooling plate placed on the poles between battery packs.

II. Methods

The temperature of the battery will affect the performance and efficiency of the battery. Adding a BTMS with a mini-channel cooling plate will affect the battery temperature. The factor that will affect is the fluid flow velocity, the fluid flow is regulated by the power entering the pump. With various variations in fluid flow velocity, it can be observed that which fluid flow velocity is effective in the battery pack. This study aims to analyze the effect of fluid flow velocity on layered battery packs. Chroma Machine was utilized to collecting the data. The data collection process is carried out by the charge and discharge method with a C-rate of 1C. The temperature sensor is placed on each battery module. The results that will be observed are the difference in temperature and battery capacity before and after being cooled.

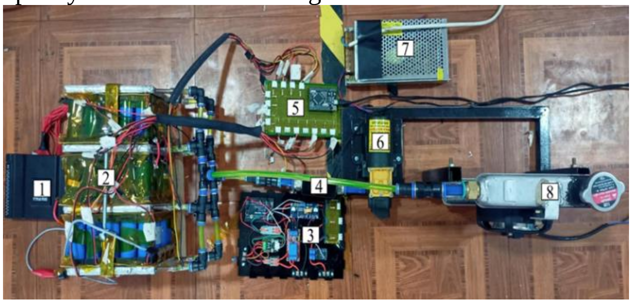

Fig. 1. Cooling schematic

Description:

1. Battery Management System (BMS)
2. Battery Pack
3. Controller and power sensor
4. Flowmeter
5. Temperature sensor
6. Pump
7. Power Supply Unit (PSU)
8. Radiator

The experimental process was conducted by using various inlet fluid flow velocities. With different set ups as follows:

1. With out Cooling
2. $v_1 = 0{,}21$ *L/min*
3. $v_2 = 0{,}42$ *L/min*
4. $v_3 = 0{,}63$ *L/min*

The specifications of the battery pack and cooling plate used in the data collection process are as shown in Table 1. The battery used during the test is a new battery and has the same capacity for each test. The charge and discharge process on the battery pack data changes the temperature and capacity of the battery. The process is car-ried out until the battery is empty and fully charged.

TABLE I. EXPERIMENTAL PROPERTIES

Battery type	LFP 48V 14Ah
Plate material	Aluminum Plate
Liquid type	Ethylene Glycol
C-rate	1C (14 Ampere)

Data collection was carried out by conducting several battery cycle tests with a chroma machine. Data collection is done by doing several speed variations. The test steps for the chroma are as follows:

III. RESULT AND DISCUSSION

The data experiments summarised in Table 2. Battery temperature greatly affects battery performance. When the battery is at a low temperature it does always have a good impact on battery performance.

TABLE II. EXPERIMENTAL PROPERTIES

Capacity (Ah)	CHARGE	DISCHARGE
WC	12.88	12.79
0.21L/min	12.88	12.86
0.42L/min	12.97	12.89
0.63L/min	12.89	12.89

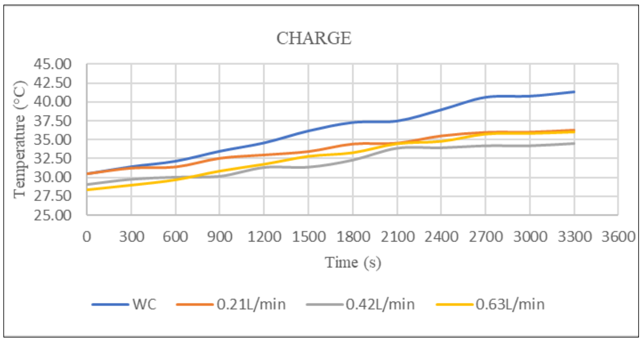

Fig. 2. 1C Charge Process Result

Fig. 3 1C charge process on the battery can change the temperature to 41.29˚C with a capacity of 12.88 Ah. The addition of coolant at a rate of 0.21 L/min can reduce the battery temperature to 36.27 ˚C with a battery capacity of 12.88 Ah. At the rate of 0.42 L/min can reduce the battery temperature to 34.50 ˚C with a battery capacity of 12.97 Ah. And at a rate of 0.63 L/min can reduce the battery tempera-ture to 36.07 ˚C. with a battery capacity of 12.89 Ah.

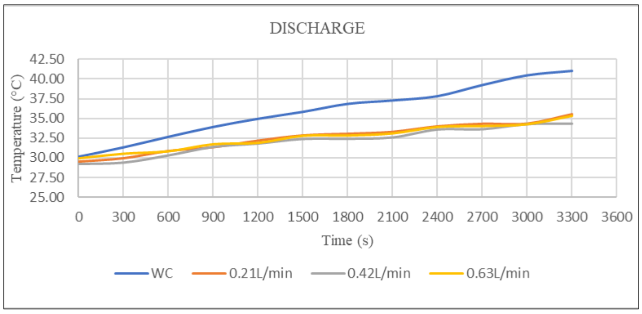

Fig. 3. 1C Charge Process Result

Fig. 4 1C discharge process on the battery can change the temperature to 41.01˚C with a capacity of 12.79 Ah. The addition of coolant at a rate of 0.21 L/min can reduce the battery temperature to 35.50 ˚C with a battery capacity of 12.86 Ah. At the rate of 0.42 L/min can reduce the battery temperature to 34.30 ˚C with a battery capacity of 12.89 Ah. And at a rate of 0.63 L/min can reduce the battery temperature to 35.30 ˚C. with a battery capacity of 12.89 Ah.

Higher C-rates accelerate the chemical reactions within the battery, leading to faster charging and discharging. This increased activity can cause excessive heat generation, which can degrade the battery's performance and lifespan. When a mini channel cooling plate is added, the heat of the battery can be transferred. The impact is that the battery temperature can be reduced and remains at its optimal temperature. Based on the experimental results, it is known that the addition of the cooling plate can reduce the temperature of the battery. A decrease in battery temperature has a good impact on battery performance. Besides, a good temperature can also reduce battery life.

IV. Conclusion

In this paper, the results show that the flow velocity affects the temperature and per-formance of the battery. The BTMS scheme with mini channel cooling plate can maintain the performance of lithium-ion battery. However, it must be considered which speed is selected to make the cooling process effective. The best fluid velocity of 0.42L/min can reduce the temperature by about 6.7°C. In order to improve the energy efficiency, it is also recommended to pay attention to the energy consumption of the active cooling support.

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References

[1] X. Wu, Z. Zhu, H. Zhang, S. Xu, Y. Fang, and Z. Yan, "Structural optimization of light-weight battery module based on hybrid liquid cooling with high latent heat PCM," Int. J. Heat Mass Transf., vol. 163, 2020, doi: 10.1016/j.ijheatmasstransfer.2020.120495.

[2] J. Li and H. Zhang, "Thermal characteristics of power battery module with composite phase change material and external liquid cooling," Int. J. Heat Mass Transf., vol. 156, 2020, doi: 10.1016/j.ijheatmasstransfer.2020.119820.

[3] R. Sabbah, R. Kizilel, J. R. Selman, and S. Al-Hallaj, "Active (air-cooled) vs. passive (phase change material) thermal management of high power lithium-ion packs: Limitation of temperature rise and uniformity of temperature distribution," J. Power Sources, vol. 182, no. 2, pp. 630–638, 2008, doi: 10.1016/j.jpowsour.2008.03.082.

[4] Z. Rao and S. Wang, "A review of power battery thermal energy management," Renew. Sustain. Energy Rev., vol. 15, no. 9, pp. 4554–4571, 2011, doi: 10.1016/j.rser.2011.07.096.

[5] K. Li, J. Yan, H. Chen, and Q. Wang, "Water cooling based strategy for lithium ion battery pack dynamic cycling for thermal management system," Appl. Therm. Eng., vol. 132, pp. 575–585, 2018, doi: 10.1016/j.applthermaleng.2017.12.131.

[6] C. Wang et al., "Liquid cooling based on thermal silica plate for battery thermal management system," Int. J. Energy Res., vol. 41, no. 15, pp. 2468–2479, 2017, doi: 10.1002/er.3801.

[7] R. Zhao, J. Gu, and J. Liu, "An experimental study of heat pipe thermal management system with wet cooling method for lithium ion batteries," J. Power Sources, vol. 273, pp. 1089–1097, 2015, doi: 10.1016/j.jpowsour.2014.10.007.

[8] F. Samimi, A. Babapoor, M. Azizi, and G. Karimi, "Thermal management analysis of a Li-ion battery cell using phase change material loaded with carbon fibers," Energy, vol. 96, pp. 355–371, 2016, doi: 10.1016/j.energy.2015.12.064.

[9] Q. Xia, Z. Wang, Y. Ren, B. Sun, D. Yang, and Q. Feng, "A reliability design method for a lithium-ion battery pack considering the thermal disequilibrium in electric vehicles," J. Power Sources, vol. 386, no. March, pp. 10–20, 2018, doi: 10.1016/j.jpowsour.2018.03.036.

[10] X. W. Tong, K. Somasundaram, E. Birgersson, A. S. Mujumdar, and C. Yap, "Thermo-electrochemical model for forced convection air cooling of a lithium-ion battery module," Appl. Therm. Eng., vol. 99, pp. 672–682, 2016, doi: 10.1016/j.applthermaleng.2016.01.050.

[11] X. M. Yang, G. Mathew, H. Nemati, M.A. Moghimi.: A novel approach for active cooling of a battery at cell level: Air-cooled mini-channel heat sink, enhanced with intermittent metal foam. J. Energy Storage, 2023.

[12] G. Marausna., Eric L, Bayu.A.: Heat Transfer Experiments on Electric Aircraft Battery Minichannels with Ethylene Glycol-Air Fluid. J. Energi, vol. 12, no May, 2022.

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