DEVELOPMENT OF A NEW COOLING SYSTEM FOR LITHIUM-ION BATTERY OF ELECTRIC VEHICLE UTILIZING PHASE CHANGE MATERIAL AND HEAT PIPES

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ABSTRACT

The purpose of this study is to maintain the performance of lithium ion battery (LiB) of electric vehicle by controlling temperature of LiB. We verified the effectiveness of cooling system utilizing phase change material (PCM) and Heat pipes. Also, we compared cooling capacity by using improved thermal conductivity of PCM. This PCM was prepared by compounding carbon fiber to PCM. In the experiments, a battery was setup as a cooling object in series-connected four cells of laminating type LiB.

The experiments were conducted by repeating charge and discharge cycle at 1C (22A)-3C (66A). The experimental results showed that temperature rise of cooling by PCM and heat Pipes, PCM of improved thermal conductivity and heat Pipes were approximately same, but different from only by PCM. The PCM of improved thermal conductivity showed an equal effect in about 82% of utilization of PCM. The heating value when temperature rise of the LiB cells was maintained less than 45 degrees Celsius was calculated from thermal resistance. The heating value at cooling by PCM and Heat pipes, cooling by PCM of improved thermal conductivity and heat pipes were 195W and 204W, respectively. It was expected that higher cooling capacity was obtained by reducing thermal resistance between PCM of improved thermal conductivity and LiB cells or heat pipes from these results.

1. INTRODUCTION

In recent years, it is expected that electric vehicles require high-performance battery to use energy efficiently. Because electric vehicles can be driven by the battery power converted from new energy source such as wind or solar power. In addition, it is possible to regenerate the power as the chemical energy while the vehicle is driven. Therefore, the high-performance battery can make contributions in using the energy efficiently. Thus, high capacity and high output performance of LiB has been developed rapidly. However, it leads to risks of deterioration of the performance and thermal runaway for temperature rises in the LiB cells due to high heat generation in charging and discharging of the LiB. Ramadass et al [1] reported that the decline rate of the capacity of LiB was rapidly advanced at more than 45 degrees Celsius of operation temperature. From these points, optimization of the LiB characteristics and improvement of the temperature management are necessary to achieve high safety of the LiB.

In this study, we proposed a cooling system using heat pipes with Phase Change Material [2] [3] to manage bellow mentioned situations. In normal cases at low heat emission such as during ordinary driving, the temperature of the LiB should be kept under 45 degrees Celsius. In abnormal case such as thermal runaway, it should be intended to provide enough time until the passenger can be evacuated from the vehicle.

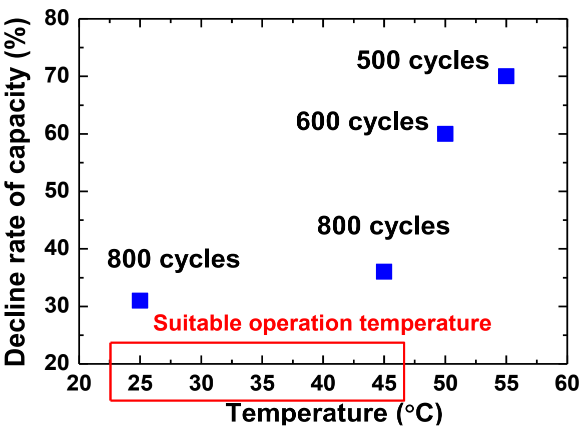
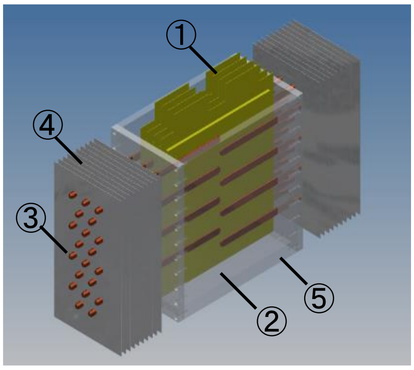


Fig. 1 Capacity fades analysis of lithium-ion battery at different operation temperatures [1].

2. EXPERIMENT

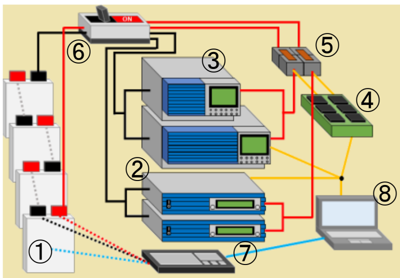
2.1 Experimental Apparatus

General view of the cooling system for LiB is shown in Fig. 2. This apparatus consists of four LiB cells, PCM, heat pipes, cooling fins and a housing case. In this cooling system, the four LiB cells were connected in series. One end of the heat pipes were inserted into between cells. Cooling fins were attached on the other end of heat pipes. The cooling fins were used as a heat sink. A gap in the case was filled with PCM. Laminated type of LiB cell with nominal capacity 22 Ah (positive electrode material: $LiFePO_4$, Negative electrode material: Artificial graphite) was used. The structure of experimental setup is shown in Fig. 3. The power supplies and electric loads were connected in parallel with LiB cells. The cycle of charge and discharge were controlled by personal computer (PC). The temperature and voltage of each LiB cell was collected by using a 20-channels data logger.



①LiB
②PCM
③Heat Pipe
④Fin
⑤Case

Fig. 2 Diagram of the cooling system for LiB cells

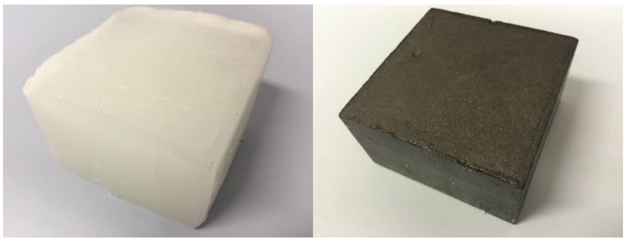


①LiB
②Power Supply
③Electric Load
④Relay Control Board
⑤Relay
⑥Breaker
⑦Logger
⑧PC

Fig. 3 Structure of the experimental setup[4]

2.2 Materials

In this study, two kinds of PCM were used. One is a RUBITHERM RT50 (RT50), and the other is a new material called as phase change composite (PCC). Pictures and physical property of these PCM are shown in Fig. 4 and Table 1, respectively. RT50 is organic material (a kind of paraffin). PCC is composite material that is produced by compounding carbon fiber to RT50 in order to improve thermal conductivity. The PCC has thermal conductivity of 8.6[W/m•K] whereas RT50 has that of 0.2[W/m•K].



(a) (b)

Fig. 4 Phase change material, (a) RUBITHERM RT50 (b) Phase change composite (PCC)

Table 1 Physical property of PCMs.

Typical Values	RT50	PCC
Thermal conductivity [W/(m·K)]	0.2	8.6
Density [kg/l]	0.76	1.2
Specific heat capacity [kJ/(kg·K)]	2	1.4
Melting temperature [℃]	45-51	45-51
Heat storage capacity [kJ/kg]	165	77.8
Mass used [kg]	0.73	0.60

2.3 Method

Table 2 shows experimental conditions. SOC (state of charge) of each LiB cell was set at 50%. LiB cells were repeatedly charged and discharged at cycle of 20 seconds intervals. Applied current (C-Rate) was adopted from 1C to 3C (C-Rate: xC is current value that constant current discharge from SOC100% completes in $1/x$ hour). Cooling capacity was compared between four cooling conditions; (1) use of heat pipes and PCC, (2) use of heat pipes and RT50, (3) use of only heat pipes, and (4) without cooling condition. Ambient temperature was set at around 25 degrees Celsius. Surface temperature of LiB cells was measured with type K thermocouple. Temperature variation of each cooling system between high temperature part and low temperature part of LiB cells was obtained. Thermal resistance of each cooling system was calculated using average value of temperature of LiB cells.

Table 2 Experimental conditions.

Class	Experimental conditions
SOC	50%
Charge and discharge condition	20 s
C-Rate	1C, 1.5C, 2C, 2.5C, 3C
Cooling condition	PCC+HP, PCM+HP, HP, without cooling
Ambient temperature	25±1℃

3. RESULTS AND DISCUSSION

The experimental results of each cooling conditions at 1C, 2C and 3C are shown in Fig. 5, 6 and 7, respectively. These figures show that the temperature rise is higher in order of without cooling by PCM and heat pipes, cooling by heat pipes, cooling by RT50 and heat pipes, cooling by PCC and heat pipes. The temperature of the LiB cells was maintained at less than 45 degrees Celsius at 1C-3C of charging and discharging by using both PCM and heat pipes. Temperature rise of cooling by RT50 and heat pipes, PCC and heat pipes are approximately same. The PCC showed an equal effect, but it contained only about 82% of the amount of RT 50.

The temperature variations of a steady state of the LiB cells regarding each cooling condition are shown in Fig. 8. This figure shows that the temperature variation of the LiB cells were almost similar in any cooling conditions. The temperature variation of LiB cells at 3C charging and discharging cycle were about 3 degrees Celsius. Thermal resistance of each cooling condition is given by Eq. (1)

$$\Delta T = T_{cell} - T_{amb} = R \cdot Q \qquad (1)$$

Where, T_{cell} ; the average value of temperature of LiB cells, T_{amb} ; ambient temperature, R ; the thermal resistance and Q ; the amount of the heating value of LiB cells. Fig. 9 shows that temperature rise of the LiB cells regarding each cooling conditions. The thermal resistance was calculated from the inclination R of ΔT and Q shown in Fig. 9. Table 3 shows calculated thermal resistance regarding each cooling condition. The heating value when temperature rise of the LiB cells was maintained at less than 45 degrees Celsius was calculated from thermal resistance as shown in Table 3. The heating value at cooling by heat pipes, cooling by RT50 and heat pipes, cooling by PCC and heat pipes are 166W, 195W and 204W, respectively.

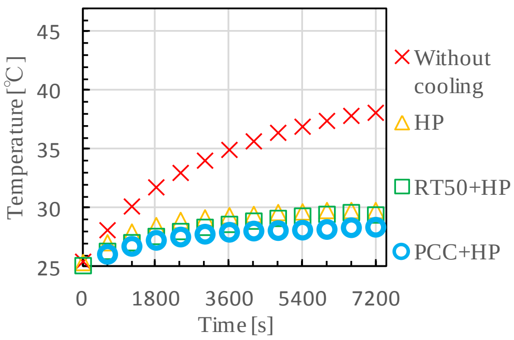


Fig. 5 Temperature change of the LiB cells at 1C

The PCC has low adhesion to LiB surface or heat pipe. Therefore, it tends to raise the contact thermal resistance between PCC and LiB surface or heat pipe. We expect that the thermal conductivity of constant thickness will be improved by applying thermally conductive grease inserted to the gap between the heat pipe and PCC.

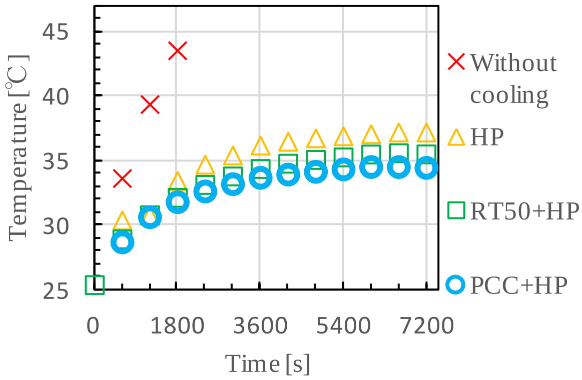


Fig. 6 Temperature change of the LiB cells at 2C

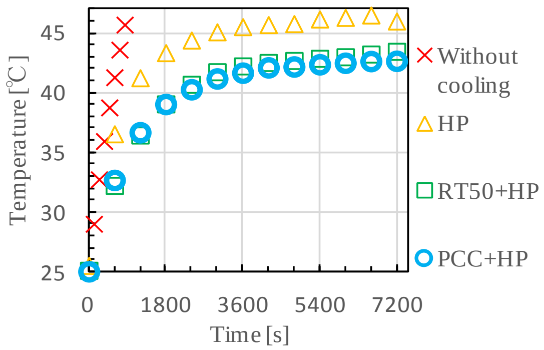


Fig. 7 Temperature change of the LiB cells at 3C

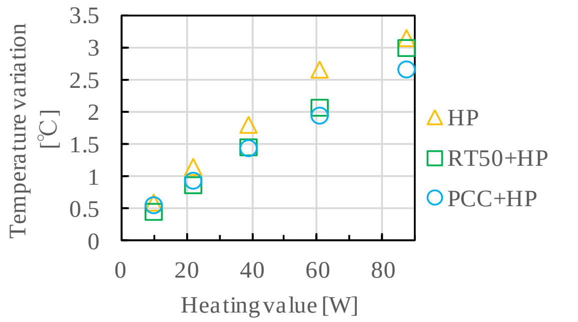


Fig. 8 Temperature variation in the LiB cells

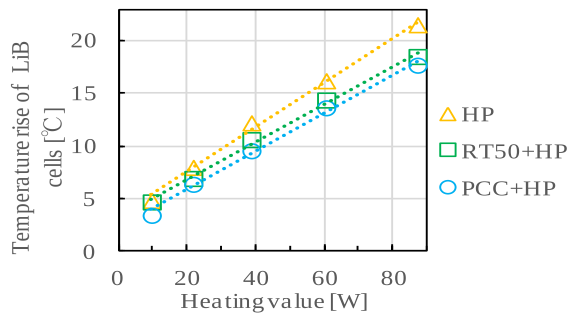


Fig. 9 Temperature rise of the LiB cells

Table 3 Thermal resistance

Cooling system	Thermal resistance [℃/W]
HP	0.27
HP+RT50	0.23
HP+PCC	0.22

4. CONCLUSION

In this study, we confirmed the effectiveness of the cooling system utilizing phase change material (PCM) and heat pipes to maintain the performance of lithium ion battery (LiB) of electric vehicle and it was also compared the cooling capacity of PCC by compounding carbon fiber with PCM in the cooling system. As the conclusion, following results can be stated.

1) Temperature change of the LiB cells at 3C charge and discharge cycle regarding cooling by RT50 and heat pipes, PCC and heat pipes were 18.5, 17.7 degrees Celsius, respectively.

2) The PCC showed an equal effect in about 82% of the amount of the RT 50.

3) The heating value when temperature rise of the LiB cells was maintained at 45 degrees Celsius or less at cooling by heat pipes, cooling by RT50 and heat pipes, cooling by PCC and heat pipes were estimated to be 166W, 195W and 204W, respectively.

In the next step, the effect of latent heat at melting point of PCM in high heating state of LiB cells such as short circuit within LiB cells will be investigated. It is thought that the improved thermal conductivity of PCM is useful for raising the cooling capability due to rapidly melting of PCM. We should also consider the possibility of increased thermal resistance between PCM and LiB cells or heat pipes.

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