International Journal of Automotive Research, Vol. 8, No. 4, (2018), 2848-2853

Iran University of Science and Technology

International Journal of Automotive Engineering

Journal Homepage: ijae.iust.ac.ir

ISSN: 2008-9899

Role of phase change materials in creating uniform surface temperature on a lithium battery cell applicable in electric vehicles

S. Jenabi Haqparast1[1], G.R. Molaeimanesh [2*], S.M.Mousavi-Khoshdel[3]

[1] MSc student, School of Automotive Engineering, Iran University of Science and Technology

[2] Assistant Professor, School of Automotive Engineering, Iran University of Science and Technology

[3] Assistant Professor, School of Chemistry, Iran University of Science and Technology

ARTICLE INFO

Article history:
Received : 07 Aug 2018
Accepted: 5 Nov 2018
Published: 01 Dec 2018

Keywords:
Electric vehicles
Li-ion battery
Thermal management system
Phase change material (PCM)

ABSTRACT

With respect to limitations of fossil energy resources, different types of electric vehicles (EVs) are developed as suitable alternatives. Lithium-ion (Li-ion) battery cells play an extremely prominent role in EVs due to their unique features. But they require a suitable thermal management system (TMS) to maintain their surface temperature uniformity and avoid battery thermal runaways. In the current study a phase change material (PCM) based TMS is applied to a battery case in order to provide a uniform temperature distribution on a Li-ion battery cell surface. This PCM based TMS declines the final maximum temperature difference to (1/5) and (2/3) at 1 C and 2 C discharge rates respectively.

1 Introduction

Despite the fact that global fossil energy resources are coming to an end, fossil fuels still play an extremely important role in the transportation industry [1], which can result in some environmental problems such as global warming and air pollution [2, 3]. With respect to mentioned crises of fossil fuels ,which are caused by conventional vehicles, different types of EVs, such as hybrid electric vehicles (HEVs), plug-in HEVs, and fuel cell EVs are developed as suitable alternatives [4].

The Li-ion battery cells are very important part in EVs due to their high operating voltage, high power density, and long cycle life [5, 6]. The main drawback of mentioned batteries is that they generate a huge amount of heat during discharge because of ohmic and entropic heating [7]. Therefore, a TMS is necessary to provide adjusted temperature through a Li-ion battery system [8].

In the recent years, many researchers have experimentally and numerically investigated the methods of heat generation of Li-ion batteries [9] and also they have applied different kinds of TMSs to control the generated heat in this kind of batteries.

Li et al. [10] investigated the thermal performance of water cooling based TMS for lithium ion batteries in dynamic charging-discharging cycles. Wei and Agelin-Chaab [11] designed a simple air-cooling duct that utilizes enhanced water vaporization by convection to achieve an effective cooling.

Lu et al. [12] developed a three-dimensional model of a stagger-arranged battery pack to investigate the effects of cooling channel size and air supply strategy on the thermal behavior of battery pack. Xie et al. [13] researched the influences of three factors (the air-inlet angle, the air-outlet angle and the width of the air flow channel between battery cells) on the heat

---

* **G.R. Molaeimanesh**

Email Address: molaeimanesh@iust.ac.ir

https://doi.org/ 10.22068/ijae.8.4.2848

dissipation of a Lithium-ion battery pack in a forced air cooling battery TMS.

Feng et al. [14] used non-destructive temperature equipment and strain gauges to monitor the temperature of a lithium-ion battery pack with a heat pipe cooling device (HPCD). Mondal et al. [15] Examined the effects of vortex generators on the heat transfer performance of typical battery thermal management solutions.

One new technique in battery passive TMSs is using phase change materials (PCMs) as a heat absorber [16], However, PCMs have low thermal conductivities, which can restrict their application in the battery systems of EVs.

Adding carbon based additives, such as carbon fibers, carbon nanotubes, graphene, and graphite flakes to the pure PCM is a way to boost the thermal conductivity of PCM and increase the cooling performance of a passive TMS in creating a more uniform temperature distribution on a battery cell surface [17, 18].

Babapoor et al. [19] studied the effects of carbon fiber size and weight percent within the PCM on thermal performance. Experimental results have indicated that a mixture of PCM with 2-mm-long carbon fibers and mass percentage of 0.46% showed the best thermal performance for which the maximum temperature rise in the battery simulator can be reduced by up to 45%. Zou et al. [20] designed multi-walled carbon nanotubes (MWCNT)-based, graphene-based and MWCNT/graphene-based composite PCM to improve the performance of lithium-ion power battery thermal management system.

Mills and Al-Hallaj [21] designed and simulated a passive TMS for a Li-ion laptop battery pack. The problem of low thermal conductivity of the PCM was significantly improved by impregnating expanded graphite (EG) matrix with the PCM.

In the current research, in order to reach a uniform temperature distribution on the battery cell surface a composite is made by an organic PCM and graphite flakes.

2 Experimental

In this study, vegetable oil is used as an organic PCM, and to enhance the thermal conductivity of this organic PCM, graphite flakes are added and a vegetable oil / graphite flake composite is made. Thermo-physical properties of vegetable oil (PCM) and graphite flake (additives) are presented in Table.1 [22].

A LiFePO4 prismatic lithium battery cell with 1.05 Ah capacity is used as Li-ion battery in this experiment and four thermometers are placed on the surface of battery cell to record the surface temperatures, shown schematically in Figure. 1, then the battery cell is put in a plastic box and the gap between the cell and the plastic box is filled with the molten composite. Finally the plastic box is placed in a glass jar and the space between these two containers is filled with glass wool to achieve a well insulation. KimiaStat 126 battery analyzer device, shown in Figure. 2, is used to charge and discharge battery cell at 1 C and 2 C discharge rates.

Table 1: Thermo-physics properties of PCM and graphite flakes

Specification		**Value**
PCM	Heat capacity	1860 J/kg K
	Thermal conductivity	0.17 W/m K
	Melting temperature range	30-35 °C
Graphite	Molecular Weight	12.01 g/mol
	Particle size	<150 µ

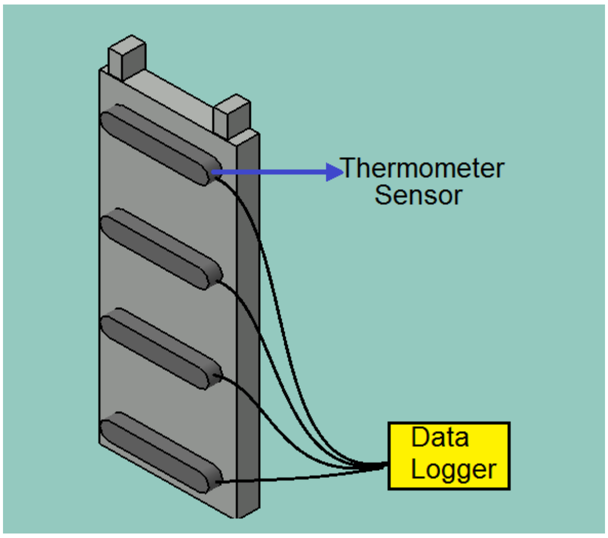

Figure 1. Schematic of battery cell and thermometers' positions

Figure 2. Battery setup and battery analyzer device

3 Results and discussion

As mentioned previously, surface temperatures are measured by four thermometers. The thermometers are placed on the vertical symmetry line of prismatic cell at four different elevations and data are saved in each two second.

3.1 Results at 1 C discharge rate

At first, in order to measure the temperature of the cell surface without applying any cooling system, no PCM is placed around the battery cell. Figure. 3 illustrates the maximum and minimum of temperatures on the battery cell surface in each moment. At the last moment of the experiment maximum and minimum temperatures of battery cell surface are 37.7 °C and 37.2 °C respectively.

In the next step, pure PCM is placed around the battery cell in the battery TMS case to reduce the temperature rise. From Figure. 4 it can be conducted that at the last moment of the experiment maximum and minimum temperatures of battery cell are 33.1 °C and 32.8 °C respectively.

Finally, the vegetable oil / graphite flake composite is replaced with pure PCM in the battery TMS case and the test carries out again. Figure. 5 shows how maximum and minimum temperatures of battery cell surface change during the discharging at 1 C discharge rate. At the last moment of the experiment, the maximum and minimum temperatures of battery cell surface are 31.1 °C and 31°C respectively.

This shows that maximum temperature difference at the last moment of experiment become one fifth in comparison with no TMS condition. And also the maximum temperature see a dramatically decrease and fall to 31.1 °C (in composite case) from 37.7 °C (in no TMS case).

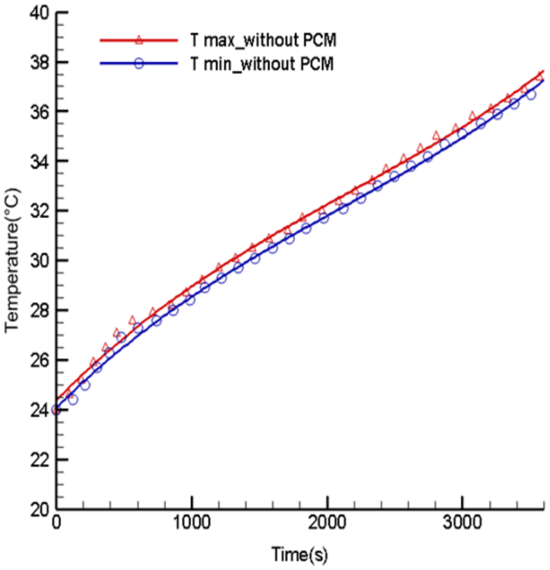

Figure 3. Temperature distribution at 1 C discharge rate without TMS

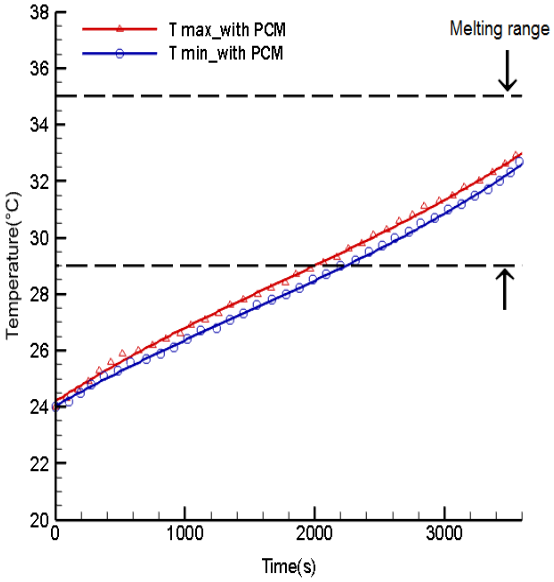

Figure 4. Temperature distribution at 1 C discharge rate after applying pure PCM

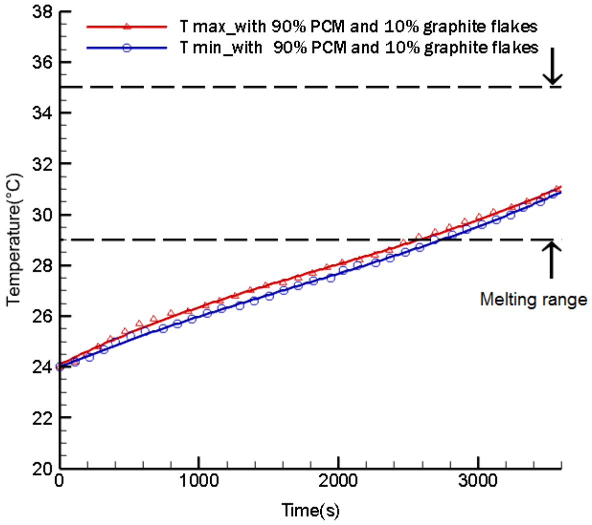

Figure 5. Temperature distribution at 1 C discharge rate after applying composite

In order to demonstrate temperature distribution on the battery cell surface at the last moment of the experiment, experimental data achieved from four thermometers are exported to COMSOL software and a schematic figure, Figure. 6, is obtained.

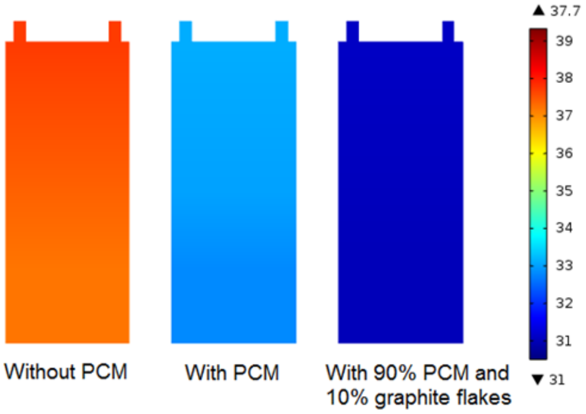

Figure 6. Final temperature distribution at 1 C discharge rate

3.2 Results at 2 C discharge rate

All pervious experiments which were discussed in last part at 1 C discharge rate, are carried out at 2 C discharge rate, and the results are presented in Figures. 7-10.

From Figure. 7 it can be conducted that when no PCM-based TMS is applied, at the last moment of the experiment, the maximum and minimum temperatures of battery cell are 48.1 °C and 46.3°C respectively.

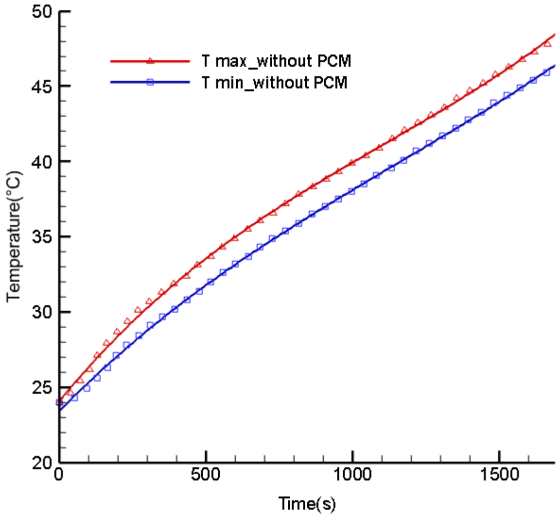

Figure 7. Temperature distribution at 2 C discharge rate without TMS

By adding pure PCM to the battery TMS case maximum and minimum temperatures of battery cell decrease to 38.2 °C and 36.6 °C respectively (Figure. 8).

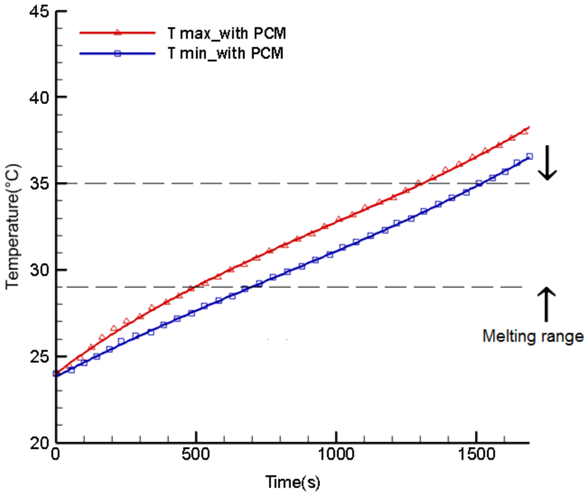

Figure 8. Temperature distribution at 2 C discharge rate after applying pure PCM

Maximum and minimum temperatures of battery cell surface after the presence of composite in the battery TMS declines to 36.2 °C and 35 °C respectively (Figure. 9). Again it is approved that using vegetable oil / graphite flake composite has a great effect on both temperature decrease and temperature uniformity of battery cell surface.

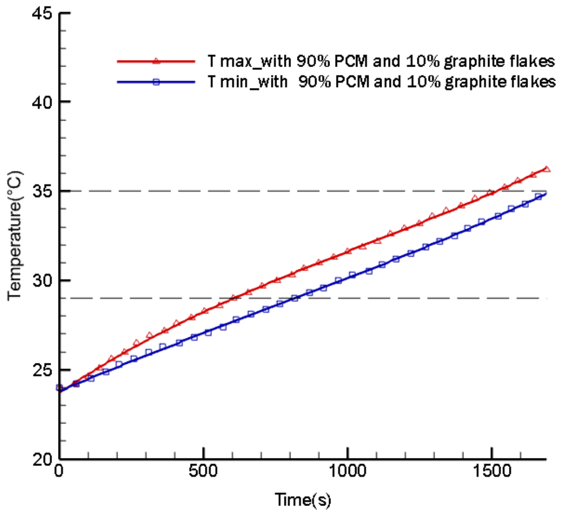

Figure 9. Temperature distribution at 2 C discharge rate after applying composite

Again, due to a better illustration of final temperature distribution on the battery cell surface, experimental data from four thermometers are exported to COMSOL software and a schematic figure, Figure. 10, is obtained. A considerable decrease in the temperature of battery cell surface and also a great increment in temperature uniformity from left battery cell (when no TMS is used) to the right one (applying introduced composite) is so clear in Figure. 10.

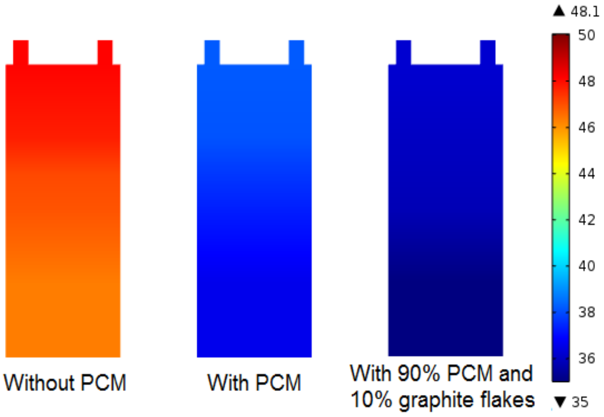

Figure 10. Final temperature distribution at 2 C discharge rate

4 Conclusion

In the current study, with the aim of achieving an acceptable temperature uniformity on a Li-ion battery cell surface, a completely passive PCM-based TMS is analyzed experimentally. In order to enhance the thermal effectiveness of the pure PCM (vegetable oil), graphite flakes are added and an effective composite is made. The following results can be concluded.

•At 1 C discharge rate, when no battery TMS is applied, the maximum and minimum temperatures at the last moment of the experiment rise to 37.7 °C and 37.2 °C respectively. These figures after placing pure PCM around the battery cell drop to 33.1 °C and 32.8 °C. Applying introduced composite make a greater reduction in the battery cell surface temperature, and the final battery cell temperatures increase to 31.1°C and 31°C in its maximum and minimum amounts. Also maximum final temperature difference after using introduced composite drops to one fifth in comparison with the condition which no TMS is applied.

•At 2 C discharge rate, generated heat increases, and when no battery TMS is used the final maximum and minimum temperatures reach 48.1°C and 46.3 °C respectively. The presence of pure PCM around the battery cell declines these amounts to 38.2 °C and 36.6 °C. The effectiveness of composite leads to a stronger reduction in the battery temperature rise and the final battery cell temperatures hit 36.2°C and 35°C in its maximum and minimum amounts. In this discharge rate, the maximum final temperature difference after applying introduced composite declines to two thirds in comparison with the condition when no TMS is used.

References

[1] A. Qasemian, P. Azarikhah, S. Jenabi Haqparast, Derivation of Specific Heat Rejection Correlation in an SI Engine; Experimental and Numerical Study, International Journal of Automotive Engineering, 8 (2018) 2679-2691.

[2] Z. Rao, Q. Wang, C. Huang, Investigation of the thermal performance of phase change material/mini-channel coupled battery thermal management system, Applied energy, 164 (2016) 659-669.

[3] Y. Deng, C. Feng, E. Jiaqiang, H. Zhu, J. Chen, M. Wen, H. Yin, Effects of different coolants and cooling strategies on the cooling performance of the power lithium ion battery system: A review, Applied Thermal Engineering, 142 (2018) 10-29.

[4] Z. Ling, J. Chen, X. Fang, Z. Zhang, T. Xu, X. Gao, S. Wang, Experimental and numerical investigation of the application of phase change materials in a simulative power batteries thermal management system, Applied energy, 121 (2014) 104-113.

[5] B. Scrosati, J. Garche, Lithium batteries: Status, prospects and future, Journal of Power Sources, 195 (2010) 2419-2430.

[6] Y. Saito, K. Kanari, K. Takano, Thermal studies of a lithium-ion battery, Journal of Power Sources, 68 (1997) 451-454.

[7] Y. Chen, J.W. Evans, Thermal analysis of lithium-ion batteries, Journal of the Electrochemical Society, 143 (1996) 2708-2712.

[8] S.A. Khateeb, S. Amiruddin, M. Farid, J.R. Selman, S. Al-Hallaj, Thermal management of Li-ion battery with phase change material for electric scooters: experimental validation, Journal of Power Sources, 142 (2005) 345-353.

[9] Y. Salami Ranjbaran, M.H. Shoajeefard, G.R. Molaeimanesh, Thermal behavior of a commercial prismatic Lithium-ion battery cell applied in electric vehicles, International Journal of Automotive Engineering, 8 (2018) 2700-2708.

[10] K. Li, J. Yan, H. Chen, Q. Wang, Water cooling based strategy for lithium ion battery pack dynamic cycling for thermal management system, Applied Thermal Engineering, 132 (2018) 575-585.

[11] Y. Wei, M. Agelin-Chaab, Experimental investigation of a novel hybrid cooling method for lithium-ion batteries, Applied Thermal Engineering, 136 (2018) 375-387.

[12] Z. Lu, X. Yu, L. Wei, Y. Qiu, L. Zhang, X. Meng, L. Jin, Parametric study of forced air cooling strategy for lithium-ion battery pack with staggered arrangement, Applied Thermal Engineering, 136 (2018) 28-40.

[13] J. Xie, Z. Ge, M. Zang, S. Wang, Structural optimization of lithium-ion battery pack with forced air cooling system, Applied Thermal Engineering, 126 (2017) 583-593.

[14] L. Feng, S. Zhou, Y. Li, Y. Wang, Q. Zhao, C. Luo, G. Wang, K. Yan, Experimental investigation of thermal and strain management for lithium-ion battery pack in heat pipe cooling, Journal of Energy Storage, 16 (2018) 84-92.

[15] B. Mondal, C.F. Lopez, A. Verma, P.P. Mukherjee, Vortex generators for active thermal management in lithium-ion battery systems, International Journal of Heat and Mass Transfer, 124 (2018) 800-815.

[16] S. Al-Hallaj, J.R. Selman, Thermal modeling of secondary lithium batteries for electric vehicle/hybrid electric vehicle applications, Journal of Power Sources, 110 (2002) 341-348.

[17] F. Samimi, A. Babapoor, M. Azizi, G. Karimi, Thermal management analysis of a Li-ion battery cell using phase change material loaded with carbon fibers, Energy, 96 (2016) 355-371.

[18] P. Goli, S. Legedza, A. Dhar, R. Salgado, J. Renteria, A.A. Balandin, Graphene-enhanced hybrid phase change materials for thermal management of Li-ion batteries, Journal of Power Sources, 248 (2014) 37-43.

[19] A. Babapoor, M. Azizi, G. Karimi, Thermal management of a Li-ion battery using carbon fiber-PCM composites, Applied Thermal Engineering, 82 (2015) 281-290.

[20] D. Zou, X. Ma, X. Liu, P. Zheng, Y. Hu, Thermal performance enhancement of composite phase change materials (PCM) using graphene and carbon nanotubes as additives for the potential application in lithium-ion power battery, International Journal of Heat and Mass Transfer, 120 (2018) 33-41.

[21] A. Mills, S. Al-Hallaj, Simulation of passive thermal management system for lithium-ion battery packs, Journal of Power Sources, 141 (2005) 307-315.

[22] a.J. LIPICO Technologies. Technical References - Vegetable Oil Properties. http://www.lipico.com/technical_references_palm_oil_properties.html /.