Dept. of Mech. Eng.
CUET

Mechanical Engineering Research Journal

Vol. 11, pp. 97–100, 2018

ISSN: 1990-5491

EFFECT OF DIFFERENT LAYER THICKNESS OF LITHIUM-ION BATTERY FOR THERMAL MANAGEMENT SYSTEM

A. M. Akram[1], B. Das[1], M. A. Rahman[1*], M. M. Rahman[1], F. A. Koly[1], M. A. M. Hossain[1] and S. Hossain[2]

[1]Department of Mechanical Engineering, Chittagong University of Engineering and Technology,
Chittagong 4349, Bangladesh.
[2]Department of unmanned vehicle Engineering, Sejong University, Seoul, South Korea

Abstract: Lithium-ion battery (LIB) is one of the dominant energy storage technologies. For lightweight gadget and electrifying transport, it has commissioned to equip as a vital potential origin. A requisite temperature condition is essential for lasting life, assurance, and peak yield of LIBs. Thermal management becomes more important fact at high discharge rate due to low discharge rate at low temperature. In this simulation, LIB considers as a layered structure of cathode, anode, separator, and electrolyte with different material properties. In addition, only convection way deposes heat from battery surface at 3C discharge rate through full discharge process. However, the thickness of each layer of electrode which has a huge effect on heat generation in the battery is studied in this paper. It is noted that reduction of temperature of positive electrode, negative electrode, pp-separator and electrolyte is observed to be 34.0507 to 31.5936 K during discharge operation.

Keywords: *Thickness, Thermal management, Electrodes, Lithium battery.*

1. INTRODUCTION

Electrochemical system has become one of the most fitting energy sources in the place of fossil fuels because of its high energy density, lifetime, CO_2 issue, and renewable energy in the perspective of global warming [1]. The Lithium-ion battery (LIB) is one of the most advanced electrochemical systems which is delivering more leading facilities such as light weight, life-cycle, 4V working voltage with a good range specific energy that is between 100 Wh/kg and 150 Wh/kg [1]. For this reason, electric vehicles (EVs), hybrid-electric vehicles (HEVs), civil aviation , portable electronic devices are utilizing LIB [2]. However, a good number explosion has been noticed in previous years because of uncontrollable reaction. For example, Moli produced several Li/ Li_yMoS_2 for cell phone application in Japan that produced first incidents in the form of flaming in 1988 and PowerBook 5300 manufactured by Apple in 1995 was exposed during testing by overcharged that caused pressure build up and venting [3].

Improvement of material and thermal runaway can increase the safety and stability of LIB. The thermal management system can be controlled by air flow, liquid flow, phase change material, heat pipe [4]. Although airflow is one of the popular thermal runaway systems giving the lowest operation cost for the battery pack cooling, but it has lower cooling performance [5]. Enhancement of life, high reliability, uniform temperature distribution of Li-ion battery will be gained by applying two directions independent airflow which is also decreases middle cell temperature [2]. Fixed and variable inlet air-flow decreases the temperature difference by 45% and 41% when the structure of Battery Thermal Management system is optimized [6]. Li-ion battery module will be also operated at its optimum temperature range by using the combination of 10 PPI aluminium foam having the porosity of 0.918 because of that has the highest thermal performance and the lowest pressure drop and of cooling air [5].

In addition, ideal battery simulation which gives the maximum temperature of 361.13K and the minimum temperature of 358.28K at 50% depth of discharge. An effective thermal management system must be ensuring that temperature is from 10 to 50 ˚C to maintain the health and life spam of Li-ion battery [7]. This paper represents a thermal simulation of the battery with respect to the different positive electrode, negative electrode, electrolyte, and separator layer thickness to find out the best dimension for each layer when battery produces lower

---

[*] **Corresponding author:** Email: arafat@cuet.ac.bd; Tel.: +88 31 714953; fax: +88 31 714910

temperature. It is noted that, the reduced thickness of the new battery exhibited minimum temperature difference which leads to minimize the material and operation cost.

2. MODEL DEVELOPMENT

2.1 Geometry

LIB can be modelled by cylindrical and sandwich shape. However, sandwich type is popular for thermal simulation since it is in easier construction and boundary condition application. Sandwich type model consists of seven layers as shown in Fig.1 with different thickness which is represented in the Table 1.

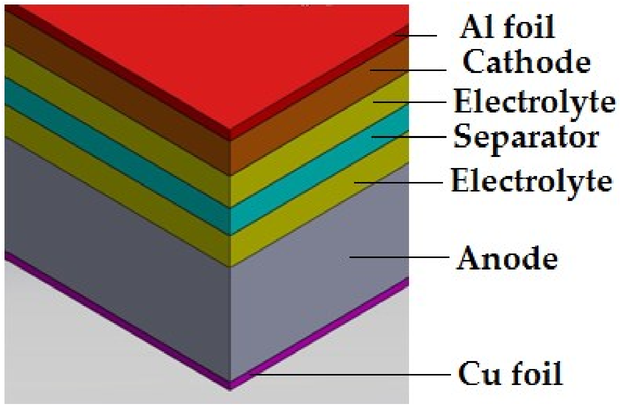

Fig. 1 Schematic diagram of a Sandwich type LIB.

Table 1 Dimensional information of Battery

Types	Remarks
Thickness of positive current collector (Al foil)	0.002 cm
Thickness of negative current collector (Cu foil)	0.0014 cm
Thickness of liquid electrolyte	0.01555 cm
Thickness of positive electrode ($LiCoO_2$)	0.014 cm
Thickness of negative electrode (Carbonaceous electrode)	0.0116 cm
Thickness of separator (PVDF)	0.0035 cm
Width of battery	10.0 cm
Length of battery	10. 0 cm

2.2 Thermal Model

Heat generation is generally produced by the reaction occurring between cathode (positive electrode) and electrolyte [2]. The formula given in Eq. (1) developed by Bernardi [8] is used to calculate the heat generation during discharge operation.

$$Q = \frac{I}{V}\left(E_{oc} - E - T\frac{dE_{oc}}{dT}\right) \quad (1)$$

Where I, V, E_{oc}, E, and T represent current density, total volume, open circuit potential, working voltage, and ambient temperature, respectively. It is noted that heat generation during discharge operation is simulated based on the parameters in Table 2.

2.3 Meshing

Meshing of the LIB is performed by ANSYS through mechanical meshing where number of edge division on both sides is 100 as shown in Fig. 2. Face meshing applied in every layer of the surface for rectangle structure mesh which gives 497021 nodes and 70000 elements.

Table 2 Simulation parameters of heat generation during discharge operation

Particulates	Remarks
Theoretical Capacity	185.3 Ah
Ambient Temperature	300 K
Initial Temperature	300K
$\frac{dE_{OC}}{dT}$	0.00022 VK^{-1}
Depth of Discharge Rate	3C

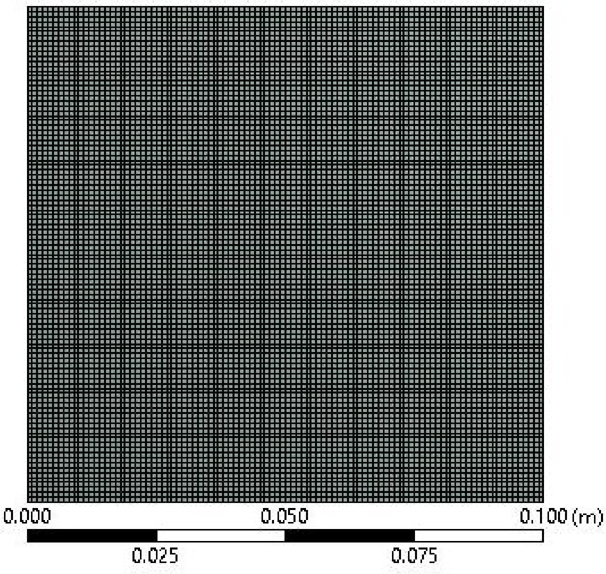

Fig. 2 Schematic of ANSYS Meshing.

2.4 Boundary Condition

Thermal and physical properties are shown in Table 3 which is used in simulation by using engineering data option through ANSYS. Thereafter, convection heat transfer co-efficient of 20 W/m^2 °C is applied in model setup step for the internal heat generation during discharge operation. This boundary condition is applied for both reference battery and modelled battery that uses the ambient temperature of 25 °C in 32 faces.

Table 3 Thermal and physical properties of each material used in the simulation of LIB

Material	Density (Kg/m^3)	Heat Capacity (J)	Thermal Conductivity (W/m°C)
Carbonaceous electrode	1347.33	1437.4	1.04
Al foil	2702	903	238
Cu foil	8933	385	398
Liquid Electrolyte	1129.95	2055	0.60
$LiCoO_2$	2328.5	1269.21	1.58
PP Separator	1008.98	1978.16	0.3344

3. RESULTS AND DISCUSSION

Figure 3 shows the variation of cell inside temperature of LIB with thickness of positive and negative electrodes. It is noted that for describing the thermal situation clearly, the maximum and minimum temperature of LIB was simulated at the surface of electrode with different shelve time. As shown in Fig. 3(a), thickness of positive electrode in the range of 0.004 to 0.01 cm exhibited low temperature difference (2.50 K) as compared to thickness of 0.01 to 0.024 cm. However, overall inside cell temperature increased with the increase in thickness of positive electrode. This phenomenon attributed to relative spatial distribution of several phases over the electrode, which changes during the charge/discharge process, might be related to this surface temperature distribution evolution [8]. In contrast, overall inside cell temperature of LIB reduced due to increase of thickness of negative electrode as shown in Fig. 3(b). This phenomenon of temperature drop could be attributed to the relative dominance of reversible and irreversible heat contributions. It is noted that endothermic entropy change is the result of phase change in the electrode material at a certain state of charge/discharge [9].

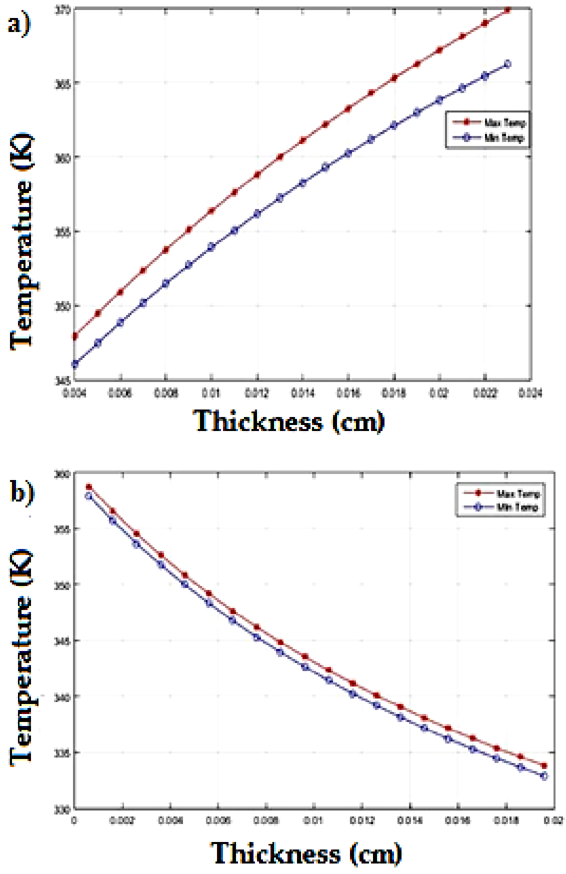

Fig. 3 Variation of temperature with thickness of (a) positive and (b) negative electrodes.

Figure 4 shows the variation of cell inside temperature of LIB with thickness of separator and electrolyte. It is noted that the primary function of a separator to prevent the physical contact between negative and positive electrode, while facilitating ion transport in the LIB cell. The inside temperature of the cell decreased due to the increased in thickness as shown in Fig. 4(a). This phenomenon could be attributed to the heat originating from short-circuit or side reactions became more difficult to dissipate through the cell [10]. Figure 4(b) shows the variation of temperature cell with the thickness of layer of electrolyte. The temperature difference increased with the increase in thickness of electrolyte. This was attributed to the reaction of electrolyte with the active materials of electrode led to generation of heat and gas [11].

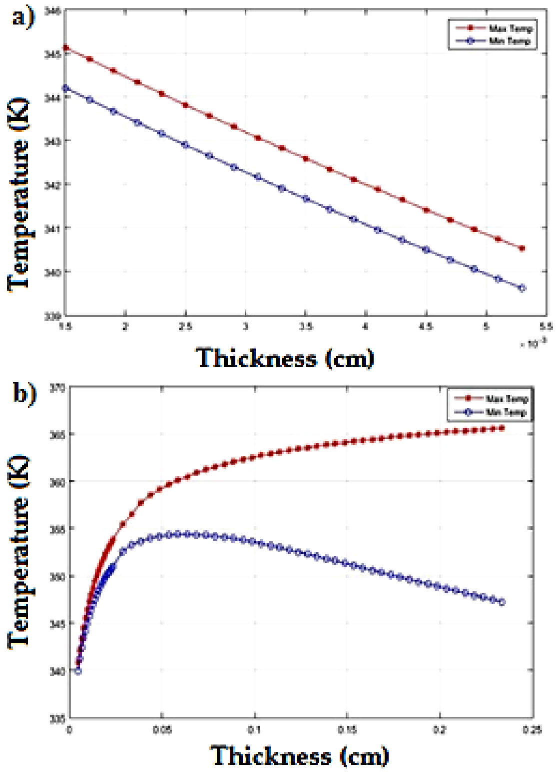

Fig. 4 Variation of temperature with thickness of (a) separator and (b) electrolytes.

Figure 5 shows the comparative study of original and modified battery. The modified battery is simulated using the data of Table 4. It is noted that the new battery with the data of Table 4 exhibited low heat generation compared to original battery.

Table 4 Dimensional information of modified battery

Parts of modified LIB	Dimension (cm)
Al- foil	0.002
Cu-foil	0.0014
Positive Electrode	0.0060
Negative Electrode	0.0186
PP-Separator	0.0047
Electrolyte	0.0055

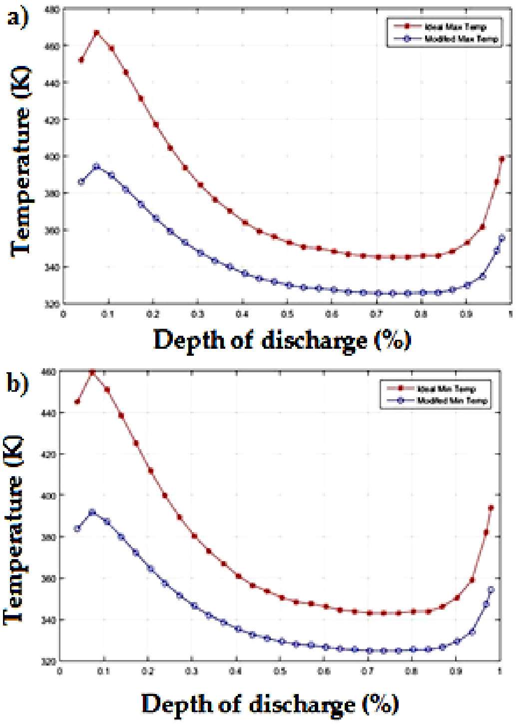

Fig. 5 Discharge operation of (a) original battery (b) modified battery.

4. CONCLUSION

Suitable thermal management is an important environmental requisite for Li-ion battery at high discharge rate due to various failures such as explosion, life cycle. The thickness of battery imposes an effective impact in thermal management because of its lower temperature. On the other hand, it requires the slight material having good thermal conductivity which minimizes production cost per battery and heat production. The air velocity with high convection co-efficient removes more heat over battery surface during whole discharge and charging process. It also creates the poor temperature difference between surrounding and surface which increases battery life cycle. In addition, the more accurate result can be achieved by applying radiation condition.

5. ACKNOWLEDGEMENTS

This research is financially supported by the Research and Extension (R & E), Chittagong University of Engineering and Technology (CUET) through the CUET-DRE Project "Nanoporous anode materials for high performance LIBs".

REFERENCES

[1] B. Scrosati and J. Garche, "Lithium batteries: status, prospects and future", Vol. 195, pp. 2419–2430, 2010.

[2] K. Yu, X. Yang, Y. Cheng and C. Li, "Thermal analysis and two-directional air flow thermal management for lithium-ion battery pack", Journal of Power Sources, Vol. 270, pp. 193–200, 2014.

[3] K. Chen, S. Wang, M. Song and L. Chen, "Structure optimization of parallel air-cooled battery thermal management system", Vol. 111, pp. 943–952, 2017.

[4] Q. Wang, B. Jiang, B. Li and Y. Yan. Wang et al., "A critical review of thermal management models and solutions of lithium-ion batteries for the development of pure electric vehicles", Renewable and Sustainable Energy Reviews, Vol. 64, pp. 106–128, 2016.

[5] L. H. Saw, M. C. Yew, M. K. Yew and W. T. Chong, "Numerical analyses on aluminum foams cooling plate for lithium-ion batteries", Energy Procedia, Vol. 105, pp. 4751–4756, 2017.

[6] S. K. Mohammadian, S. M. Rassoulinejad-Mousavi and Y. Zhang, "Thermal management improvement of an air-cooled high-power lithium-ion battery by embedding metal foam", Vol. 296, pp. 305–313, 2015.

[7] B. Mondal, C. F. Lopez and P. P. Mukherjee, "Exploring the efficacy of nanofluids for lithium-ion battery thermal management", Vol. 112, pp. 779–794, 2017.

[8] D. Robert, T. Douillard, A. Boulineau, G. Brunetti, P. Nowakowski, D. Venet, P. Bayle-Guillemaud and C. Cayron, "Multiscale phase mapping of LiFePO4-based electrodes by transmission electron microscopy and electron forward scattering diffraction", ACS nano, Vol. 7(12), pp. 10887–10894, 2013.

[9] K. Takano, Y. Saito, K. Kanari, K. Nozaki, K. Kato, A. Negishi and T. Kato, "Entropy change in lithium ion cells on charge and discharge", Journal of Applied Electrochemistry, Vol. 32(3), pp. 251–258, 2002.

[10] J. Xu, Y. Wu and S. Yin, "Investigation of effects of design parameters on the internal short-circuit in cylindrical lithium-ion batteries", RSC Advances, Vol. 7(24), pp. 14360–14371, 2017.

[11] E. P. Roth and C. J. Orendorff, "How electrolytes influence battery safety", The Electrochemical Society Interface, Vol. 21(2), pp. 45–49, 2012.