

Numerical modeling of Li-ion battery temperature control system at low initial temperature

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ABSTRACT

Li-ion battery temperature affects its performance, significantly and keeping its temperature in proper operational temperature is obligatory; so, this guaranties the performance, safety and life span of the battery. In this study, performance of the planar Li-ion battery temperature management system with 6 cells in cold weather (initial temperature -20°C) is investigated. Maximum temperature difference and average temperature of the battery cells are two main performance criterion of the temperature management system. Effects of mass flow rate, number of heating plates and flow arrangement consisting of parallel, counter and zig-zag flow arrangements on the performance criterion and also on the warm-up time are studied. Results show that increasing the fluid mass flow rate batteries reaches the proper temperature (20°C) faster and the temperature difference decreases. At constant mass rate, addition of heating plates decreases the warm-up time. Zig-zag flow arrangement has better performance in term of temperature difference criteria up to 8 times and reaches 2.1 degrees at the maximum value; but parallel flow warms up the batteries faster than the other flow arrangements.

KEYWORDS

Li-ion battery, temperature management, cold weather, operational temperature, flow arrangement.

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1. Introduction

Nowadays, li-ion batteries are widely used in portable devices such as mobile phones, lap-tops and electric vehicles (EVs). Batteries are the main source of these devices and directly affect on their performances. Li-ion batteries are more operative due to the more power density, efficacy and longer life span. Also; self-discharge and memory effect which lessens the battery life are lower in this kind of batteries. However, temperature of Li-ion battery directly influences its performance and this makes the Li-ion battery temperature management an important issue. The proper range of operative temperature of Li-ion batteries is between 20 °C and 40 °C . At temperatures lower than 20 °C performance suddenly drops due to the increment of electrolyte viscosity and internal resistance. Also, temperatures higher than 40 °C lowers the battery life and yields less battery cycles. Hence the Li-ion battery temperature management is important [1-4].

Many investigations are performed in order to maintain the Li-ion batteries temperature in the proper range. Qian et al. [5] have studied micro-channels for Li-ion battery pack cooling and showed that this method can decrease the batteries average temperature by 5 degrees. Chen et al. [6] optimized a temperature control system for a battery pack including 24 Li-ion batteries and decreased the pack temperature by 4 degrees. Phase change material application showed the similar result for cooling cases [7]. Direct contact between the batteries and the coolant fluid has been investigated by Patil et al. [8] for a 50V battery pack. They showed that the direct contact cooling can reduces the battery temperature by 9.3 percent more than indirect cooling. Fan et al. [9] performed an investigation on Li-ion batteries heating so they can reach the proper operative temperature in very cold weather. Results showed that higher mass flow rate influences the temperature difference more than average temperature.

Li-ion batteries need both heating and cooling systems based on the operational circumstances. Previous researches are mainly focused on the cooling of the Li-ion batteries. Hence; this in this study Li-ion battery pack heating for the batteries in extremely low initial temperatures is investigated to prevent battery life decrement and more uniform temperature distribution in them. For this purpose, a 3D model has performed with CFD software FLUENT and effects of heating plates number, mass flow rate and three flow arrangements consist of parallel, counter and zig-zag flows on the average temperature and the maximum temperature difference of the batteries are investigated. Silicon paste is applied between the batteries and the heating plates in order to reduce the contact resistance.

2. Governing equations and methodology

A planar Li-ion battery pack temperature management system is investigated in this literature. heating Fluid enters in the plates and warm-ups the batteries in low initial temperature (-20°C) in contact with heating plates. Figure 1 displays the three-dimensional model consisting of a single Li-ion battery cell and the pack with 6 Li-ion batteries and various numbers of heating plates which is performed and numerically solved by CFD software fluent. This investigation focuses on maintain the batteries temperature in their proper operational temperature which is 20 °C to 40 °C.

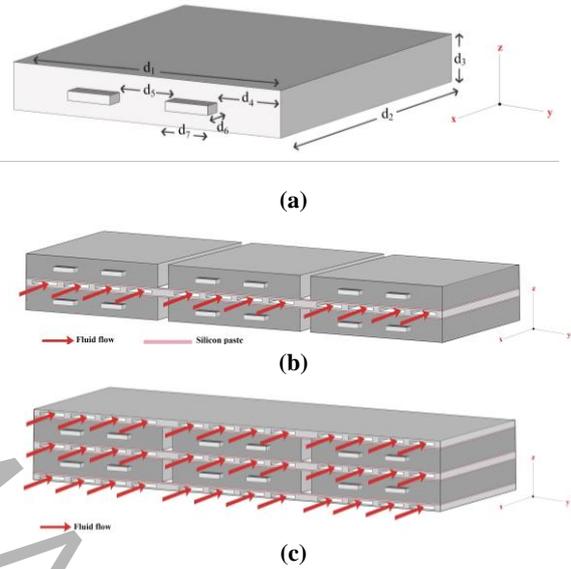


Figure 1: a) single cell li-ion, b) with a single heater plate, c) with three parallel flow

Nonlinear governing equations consisting conservations of mass, momentum and energy are developed under time transient circumstances. The fluid flow is always laminar (Reynold less than 2300) and single phase. The heat generation in the batteries is derived by the $q_s = I^2 R_t / V$. Where R_t is total resistance, V is voltage and I is the current generated by the battery.

A structured grid is considered for the study with 135944 computational cells that makes the study independent from the grid size. Problem is solved for constant C rate and 40°C flow temperature up to 1800s.

3. Results and discussion

Results showed that the battery pack is unable get to proper temperature range without external heat source after 1800 seconds with 0.01C discharge rate which is shown in figure 5. With insertion of one heating plate batteries could get the proper range in about 300s with 0.0012kg/s but the temperature difference exceeds 5 degrees in this case. This issue is shown in figure 6.

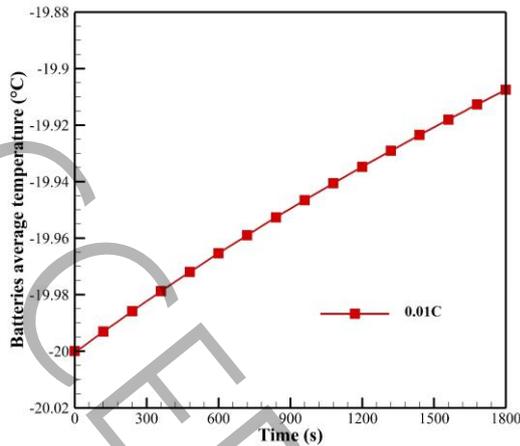
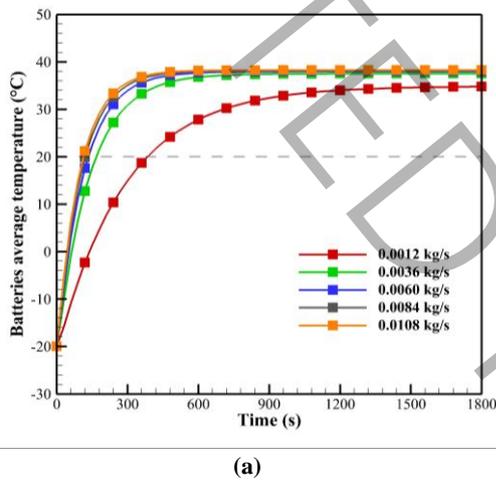
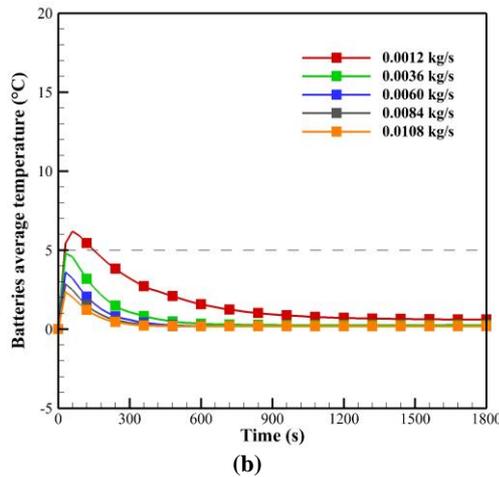


Figure 5: batteries average temperature without external heat source.



(a)



(b)

Figure 6: variation of a) batteries average temperature, b) maximum temperature difference with mass flow rate in single heating plate

According to figure 6, more mass flow rate causes a more uniform temperature distribution due to the lower temperature difference in cells. Also, this has less effect on the warm-up time. Adding more plates lowers the warm-up time but in short times it causes a non-uniform temperature distribution which is maintained by changing the fluid flow arrangement.

4. Conclusion

This investigation performed a study on Li-ion batteries in low initial temperature in order to increase battery life time. A 24V battery pack consist of 6 Li-ion cells at -20°C initial temperature is considered for this literature. Results showed that:

1. Warm-up time and temperature difference decrease with the increase of mass flow rate due to the higher convective heat transfer coefficient.
2. Changing the fluid flow pattern has negligible effect on the warm-up time but it seriously affects on the temperature distribution.
3. The zig-zag flow arrangement is better for battery warming, of its application limitations are ignored.

5. References

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