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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 guarantees the performance, safety, and life span of the battery. In this study, the performance of the planar Li-ion battery temperature management system with 6 cells in cold weather (initial temperature -20oC) is investigated. The maximum temperature difference and the average temperature of the battery cells are the two main performance criteria 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 by increasing the fluid mass flow rate batteries reach the proper temperature (20 oC) faster and the temperature difference decreases. At a constant mass rate, the addition of heating plates decreases the warm-up time. The zig-zag flow arrangement has better performance in terms 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.

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1- Introduction

Nowadays, Li-ion batteries are widely used in portable devices such as mobile phones, laptops, and Electric Vehicles (EVs). Batteries are the main source of these devices and directly affect their performances. Li-ion batteries are more operative due to their power density, efficacy, and longer life span. Also; self-discharge and memory effect which lessens the battery life are lower in this kind of battery. However, the temperature of the Li-ion battery directly influences its performance and this makes Li-ion battery temperature management an important issue. The proper range of operative temperature of Li-ion batteries is between $20^{o}C$ and $40^{o}C$. At temperatures lower than $20^{o}C$ performance suddenly drops due to the increment of electrolyte viscosity and internal resistance. Also, temperatures higher than $40^{o}C$ lowers the battery life and yield fewer battery cycles. Hence 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 a 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 direct contact cooling can reduce the battery temperature by 9.3 percent more than indirect cooling. Fan et al. [9] performed an investigation on Li-ion battery heating so they can reach the proper operative temperature in very cold weather. Results showed that a higher mass flow rate influences the temperature difference more than the average temperature.

Li-ion batteries need both heating and cooling systems based on operational circumstances. Previous research is mainly focused on the cooling of Li-ion batteries. Hence; 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 been performed with the Computational Fluid Dynamics (CFD) software FLUENT and the effects of heating plates number, mass flow rate, and three flow arrangements consisting 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 contact resistance.

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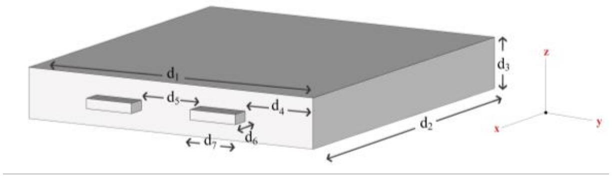

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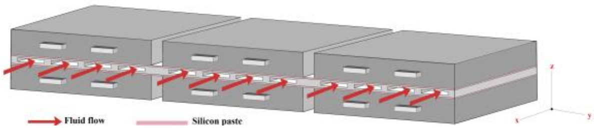

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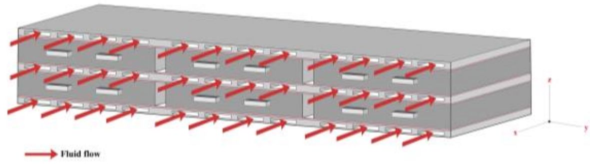


(c)

Fig. 1. a) single-cell Li-ion, b) with a single heater plate, c) with three parallel flow

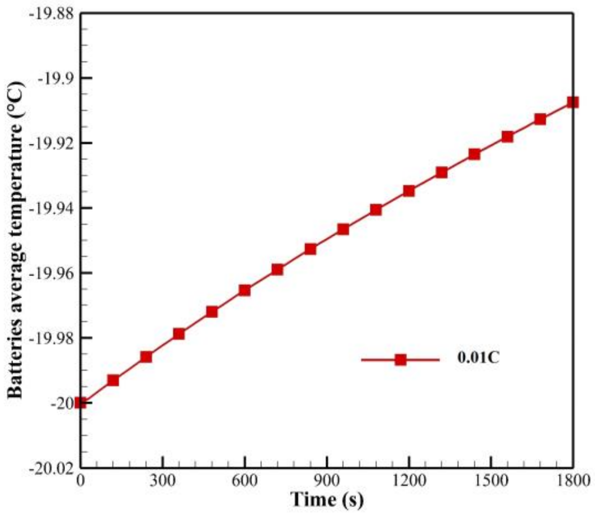


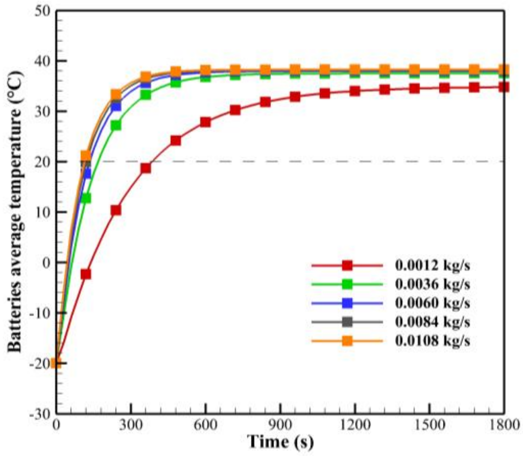
Fig. 2. Batteries' average temperature without an external heat source.

2- Governing Equations and Methodology

A planar Li-ion battery pack temperature management system is investigated in this literature. heating Fluid enters the plates and warm-ups the batteries at a low initial temperature (-20°C) in contact with the heating plates. Fig. 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 are performed and numerically solved by CFD software Fluent. This investigation focuses on maintaining the batteries' temperature at their proper operating temperature which is 20°C to 40°C.

Nonlinear governing equations consisting of 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 $q_s=I^2R_t/V$. 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 which makes the study independent from the grid size. The problem is solved for constant C rate and 40°C flow temperature up to 1800s.



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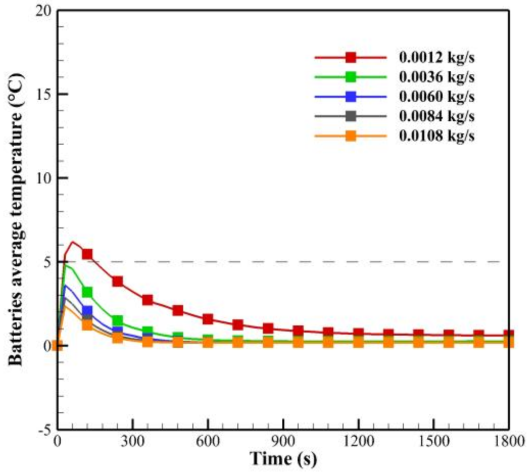

(b)

Fig. 3. Variation of a) batteries average temperature, b) maximum temperature difference with a mass flow rate in a single heating plate

3- Results and Discussion

Results showed that the battery pack is unable to get to the proper temperature range without an external heat source after 1800 seconds with a 0.01C discharge rate which is shown in Fig. 2. With the 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 Fig. 3.

According to Fig. 3, 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 temperatures in order to increase battery lifetime. A 24V battery pack consisting of 6 Li-ion cells at -20^{o}C initial temperature is considered for this literature. Results showed that:

Warm-up time and temperature difference decrease with the increase of mass flow rate due to the higher convective heat transfer coefficient.

Changing the fluid flow pattern has a negligible effect on the warm-up time but it seriously affects the temperature distribution.

The zig-zag flow arrangement is better for battery warming, of its application limitations, are ignored.

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