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Novel Thermal Management of A Lithium-Ion Battery: Internal Cooling Method

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Abstract -Transient thermal analysis of a prismatic Li-ion cell using internal cooling method has been carried out to introduce a novel method of Lithium Ion (Li-ion) battery pack thermal management. To serve this aim a three dimensional numerical simulation is done and results compared with those of for external cooling. Water and liquid electrolyte have been utilized as coolants for external and internal cooling, respectively. The effects of the two methods of cooling were studied on decreasing the temperature inside the battery and also temperature uniformity. The results indicated that at the same pumping power, using internal cooling not only decreases the bulk temperature inside the battery more than external cooling, but also decreases the standard deviation of the temperature field inside the battery significantly.

***Keywords*:** Internal cooling, Lithium-ion battery pack, Thermal management, Hybrid electric vehicles

1. Introduction

Due to the effects of internal resistance during operation, heat is generated inside the Li-ion cells. Heavy power demand of electric and hybrid electric vehicles requires that Li-ion packs couple in series and parallel combinations which leads to excessive rise in pack temperatures and causes to deteriorate the performance of the packs significantly (Bhatia, 2013).

According to importance of thermal management of Li-ion batteries many researchers conducted many experimental and numerical investigations to manage the thermal behaviour. Different types of thermal management systems can be classified as: (a) active cooling such as air or liquid cooling (Nelson et al., 2002, Fan et al., 2013, Fathabadi, 2014, Jin et al., 2014), and (b) passive cooling such as phase change materials and heat pipes (Rao et al., 2011, Rao et al., 2013, Goli et al., 2014).

As mentioned above, the performance of the batteries are sensitive to the temperature. Active and passive methods of cooling that mentioned above have this ability to maintain the surface temperature of the battery at an appropriate level, but they are unable to control heat generation and consequently to maintain the temperature inside the battery at a desirable level.

In this study, a special kind of internal cooling (using electrolyte as coolant inside rectangular microchannels in the positive and negative electrodes) was introduced to optimize the thermal management of Li-ion battery pack. Three dimensional transient thermal analysis of an internal cooling of a prismatic Li-ion cell was performed and compared with the results of two dimensional transient thermal analysis of liquid external cooling (Fig. 1).

2. Problem Statement

In this investigation, 5Ah prismatic battery unit was considered to study the thermal management of the Li-ion batteries. For both internal and external cooling methods, only one symmetrical part was considered to simplify the simulations and to focus on the temperature and its deviation inside the battery (Fig. 1).The gap spacing of 3mm was considered for water flow channel height at external cooling.

Battery material and thermo-physical parameters were tabulated in Table 1 (Cheng et al., 2009, Wenige et al.).

Li-ion batteries have no memory effects, and they have low self-discharge rate that prevents them from losing their charge for a long period of time. In addition, these batteries have high voltage and can work on a wide temperature range of operation (Nishi, 2001). While the above features make Li-ion batteries appropriate candidates for energy sources of electric and hybrid electric vehicles, some practical problems such as heat generation and thermal runaway can be encountered during their utilization (Feng and Zhang, 2014a, b).

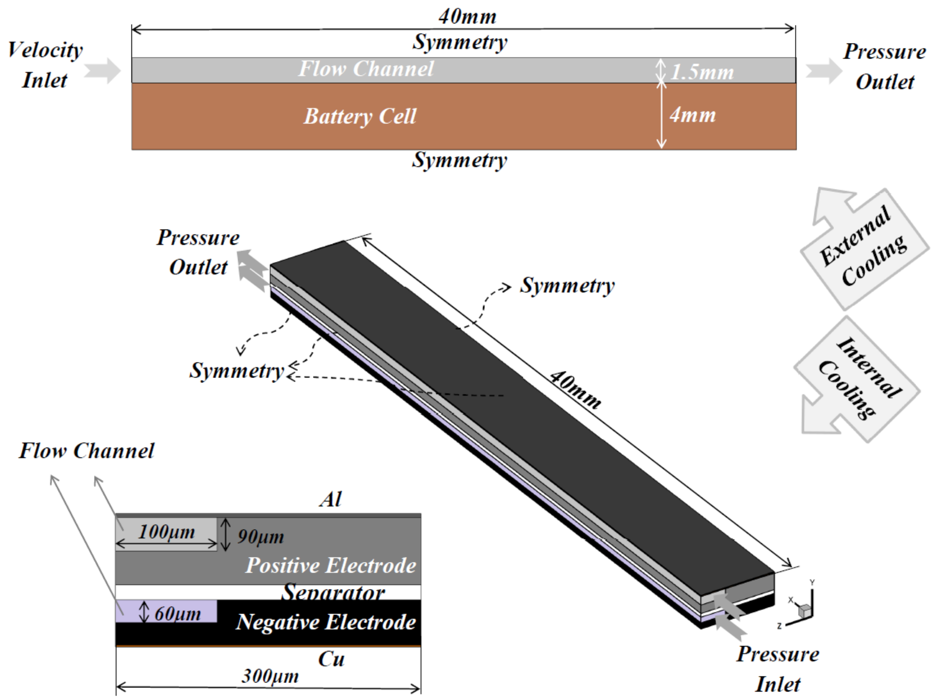

Fig. 1. Schematic, boundary conditions and geometric dimensions of the problem

To calculate the heat generation inside the battery the governing equations similar to (Mohammadian and Zhang, 2015) were utilized. Thermal radiation was assumed to be negligible in this study. It was also assumed that internal cooling microchannels embedded inside the battery cells and fluid flows inside them have no effect on the battery electrochemical performance. Furthermore, it was assumed that the electrodes and separator behave like a solid instead of porous medium.

3. Numerical Solution

A pressure-based, second order transient model in Fluent was utilized to simulate both internal and external cooling methods. The PISO scheme was used for the pressure-velocity coupling that provides faster convergence than the standard SIMPLE approach for transient state. The convergence is checked by monitoring the scaled residuals. The time step for integrating the governing equations was set to be 1s. The convergence criterion was set such that the residuals of the governing equations for flow and thermal energy were below 10^{-6}. The UDF code was written according to above correlations and used to calculate the transient heat generation inside the battery.

For studying the grid sensitivity, 4 different grids have been made for both internal and external cooling modules. The grid independency was conducted under the inlet pressure of 25 kPa and inlet temperature of 27 °C for internal, and inlet velocity of 0.455 m/s and inlet temperature of 27 °C for external cooling methods at the discharge rate of 5C. It has been concluded that the maximum difference between the results for third and fourth grids was less than 0.03%. Thus, the third grids with 1,200,000 and 76,400 cells for internal and external cooling methods has been selected, respectively.

Numerical results estimated by Cheng et al. (2009) are used for validating the numerical solution in this work. Good agreement between the results of this study and Cheng et al. (2009) was achieved. The differences between Cheng et al. (2009) data and the results obtained in this study are less than 2%. So, it can be found that the UDF code and the simulations are reliable.

Table. 1. Battery material and thermo-physical parameters

	Material	Thickness (μm)	Thermal Conductivity ($Wm^{-1}K^{-1}$)	Density (kgm^{-3})	Specific Heat ($Jkg^{-1}K^{-1}$)	Viscosity ($kgm^{-1}s^{-1}$)
Positive electrode collector	*Al*	*20*	*237*	*2710*	*902*	-
Positive electrode	$LiMn_2O_4$	*180*	*1.48*	*2370*	*1321*	-
Separator	*PP/PE/PP*	*40*	*0.35*	*1400*	*1551*	-
Negative electrode	*Graphite*	*120*	*1.04*	*1347*	*1437*	-
Negative electrode collector	*Cu*	*10*	*398*	*8930*	*386*	-
Electrolyte	$LiPF_6$	-	*0.59*	*1223*	*1375*	*0.003*
Prismatic cell (External Cooling)	-	*8000*	*0.81 (Thickness direction) 1.17 (along surfaces)*	*1965.2*	*1166*	-

4. Results and Discussions

The main purpose of a thermal management system is to regulate temperatures evenly inside a battery pack and keep them well within the desired operating range. Another important feature that should be considered to design an appropriate thermal management system is temperature uniformity.

Figure 2 shows (a): the maximum temperature and (b): the standard deviation of the temperature field inside the battery versus the pumping power for different discharge rates and cooling methods at the same state of charge (SOC=0.167). It is clear that increasing the discharge rate leads to increasing the standard deviation of the temperature field inside the battery. Also, this figure shows that the use of internal cooling decreases the standard deviation of the temperature field inside the battery between 3.93-5.33 times for the pumping power of 0.024 W.

Another important issue which is clear in this figure is that with increasing the pumping power, there is no significant decrease in maximum temperature or standard deviation of the temperature field inside the battery at the external cooling. However, increasing pumping power at internal cooling significantly decreases the maximum temperature inside the battery and improves the uniformity of the temperature.

5. Conclusion

Two different ways of thermal management of Lithium Ion (Li-ion) battery pack were considered in this paper. Three dimensional internal cooling and two dimensional external cooling in transient condition for a prismatic Li-ion cell were studied numerically based on a finite volume method. The working fluids utilized for both internal and external cooling were liquid electrolyte and water, respectively. Temperature reduction and uniformity were compared for these two cooling methods at the same pumping power and the significant observations are drawn as follows:

- The advantage of internal cooling, in compare with the external one, is that it not only decreases the bulk temperature inside the battery, but also improves the temperature uniformity.
- Internal cooling decreases the standard deviation of the temperature field inside the battery more than 5 times compare to external cooling at the same pumping power of 0.024 W.

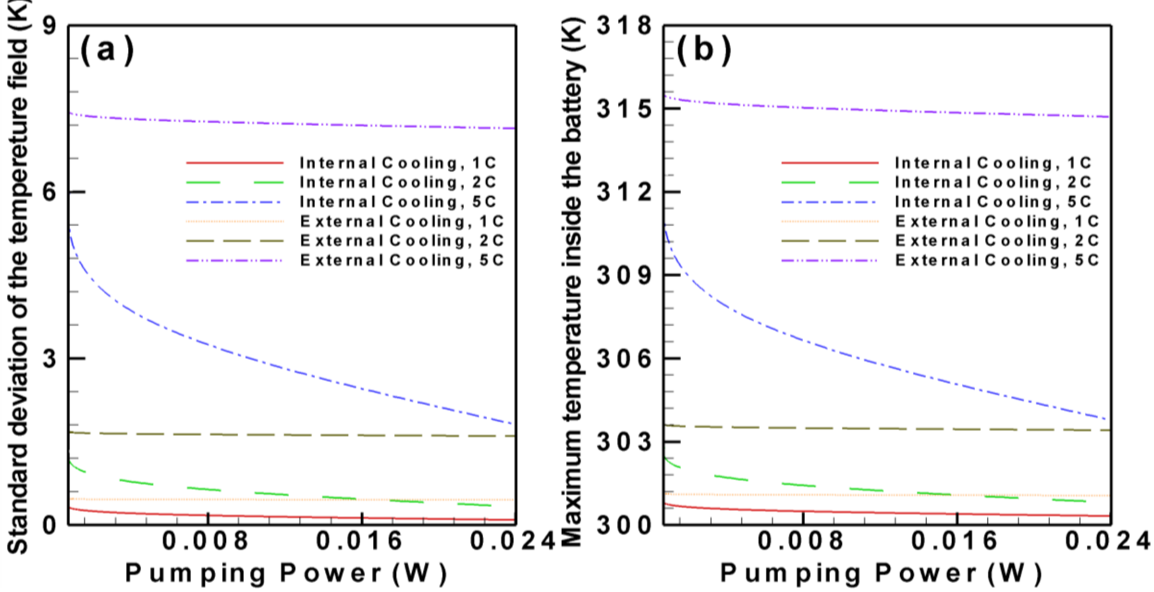

Fig. 2. (a) standard deviation of the temperature field and (b) maximum temperature inside the battery versus pumping power (27C, SOC=0.167)

Acknowledgements

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