Thermal Performance of a Liquid Cooling System for a Li-ion Battery Pack

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Abstract. Battery thermal management has been a very active research field in recent years because of its great essentiality for power battery systems. In order to maintain the maximum temperature and local temperature difference in appropriate range, a newly-designed liquid cooling system for lithium-ion battery pack is proposed in this paper. CFD modeling is employed to investigate the heat transfer performance of the liquid cooling system for the lithium-ion battery pack. It shows that the total temperature rise of the whole battery pack decreases with the temperature of cooling liquid and the maximum temperature can be controlled under 40°C for 192 evenly-distributed prismatic batteries.

Introduction

Some problems, like thermal safety, discharge efficiency reduction and cycle life degeneration of the Li-ion batteries, are seriously restricting their applications in spite of their high efficiency, high capacity, high discharge voltage, low self-discharge rate and harmony to the environment [1]. Maximum temperature and temperature evenness of a battery module/pack are two important factors which affect the performance of the whole battery system. High temperature caused by charge and discharge process will result in temperature exceeding permissible range, decreasing the battery performance, even causing rupture, fire and explosion [2-5]. As well, the temperature distribution within the battery pack will lead to a localized deterioration and mismatches of the state of charge (SOC).

Predecessors around the world have done lots of research in battery thermal management including air cooling, liquid cooling, phase change materials (PCM) cooling and heat pipe cooling [6-8]. However, Different cooling methods have different limitations and merits.

In this paper, a parametric study on the thermal management system of a liquid-cooled battery pack consisting of evenly distributed prismatic lithium-ion cells was performed numerically. The purpose is to reveal the thermal performance of proposed cooling method and develop guideline for system design and parametric research based on numerical model is an effective mean for such purpose.

Cooling System and Numerical Model

The proposed battery pack is geometrically limited in a volume of 576×320×110mm which is designed to contain 192 prismatic lithium-ion cells (50×10×100mm), as is shown in Figure 1. The average heat release per battery cell is 2W. Since lithium-ion cells are arranged in such a compact space, liquid cooling system is conceptually designed to ensure them to work properly under appropriate temperature conditions. The liquid cooling system includes 16 pieces of cold plate made of aluminum alloy; 6 lithium-ion cells are fixed on either big surface of each piece of the cold plate via silica gel with high thermal conductivity (Fig. 1). To eliminate flow rate difference of cooling liquid among the 16 flow channels, a liquid distributor is provided (Fig. 2).
In the present investigation, analysis is focused on a liquid-cooled battery pack containing lithium-ion cells being discharged/charged under an aggressive scaled power profile for a new energy vehicle.

Numerical calculations are conducted to investigate the effect of cooling liquid on the temperature distribution all over the battery cell. The parametric study of the heat transfer performance of the battery pack (computational area including all battery cells, all cold plates and liquid distributor) is based on coupled heat transfer and fluid flow analysis including liquid/solid interaction.

In the numerical analysis, the energy and $k$-$\varepsilon$ turbulent models are employed while buoyancy is neglected. The Reynolds numbers in the flow passages are over 8000. Incompressible air is assumed and all the calculation results are presented at the steady state condition. Polyhedral type with prism layer is used to generate mesh in the computational domain. After testing several grid densities, an appropriate grid system of about 7,000,000 hexahedral cells over the entire computational domain was used. The convergence criterion was set such that the residuals of the governing equations for flow and thermal energy were below $10^{-4}$ and $10^{-6}$, respectively.

**Numerical Results and Discussion**

Fig. 3 depicts the typical temperature distribution of the battery pack employing water under 30°C as the cooling liquid. The flow rate of the cooling water is 2L/min. One can see the temperature distribution all over the battery pack is between 30°C to 35°C. Even if the maximum temperature lies at the middle of the far side opposite to the liquid distributor, the temperature difference within the cell is quite satisfying.
Figure 3. Typical temperature distribution of the battery pack.

(a) temperature distribution of whole battery pack  (b) temperature distribution of liquid distributor

Figure 4. Temperature distribution of the battery pack under different flow rate of cooling water.

(a) 1L/min  (b) 1.5L/min  (c) 2L/min  (d) 2.5L/min

Figure 5. Flow rate of cooling liquid entering different channel of each cold plate after liquid distributor under different total flow rate of cooling liquid.

80
Fig. 4 gives the temperature distribution of the battery pack under different flow rate of the cooling water under a certain inlet temperature of 25 °C. One can see the temperature distributions of the battery pack under different flow rate of the cooling water are quite similar, battery cells at outer sides are cooled better than central ones. The maximum temperature lies at the middle of the far side opposite to the liquid distributor. The temperature level rises with the decrease of the flow rate of the cooling water. The total temperature rises of the battery cells increase with the reduction of flow rate of the cooling water. The total temperature rise of the battery cells under 2.5L/min flow rate is 3.05 °C and the total temperature rise of the battery cells under 1.0L/min flow rate is 5.53 °C. Therefore, under a certain inlet temperature of cooling liquid, the maximum temperature and temperature difference of the Li-ion battery pack can be well regulated by controlling the flow rate of the cooling liquid.

Fig. 5 depicts the flow rate of cooling liquid entering different channel of each cold plate after liquid distributor under different total flow rate of cooling liquid. One can see that the flow rates of the cooling liquid entering outer side cold plates are greater than that of the central one, which is determined by the flow pattern of the cooling liquid within the distributor. With the help of the liquid distributor, the flow rate difference of cooling liquid entering different channel of each cold plate after liquid distributor has only 9% variation. It is the small flow rate differences of the cooling liquid in different cold plates that ensures liquid cooling exploit its high heat flux cooling characteristics and further provide good temperature evenness for the whole battery packs.

Conclusions
In order to maintain the maximum temperature and local temperature difference in an appropriate operation range, a liquid cooling method for a battery pack of 192 prismatic battery cells is proposed in this paper. The cooling performance of the proposed liquid cooling system is very excellent. The maximum temperature of the battery pack lies at the middle of the far side opposite to the liquid distributor. The maximum temperature can be effectively controlled under 40 °C and possess a temperature difference within the whole pack under 5 °C. The liquid distributor is a key part for the provision of nearly-uniform cooling liquid for each cold plate.

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