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Experimental Investigation on the Performance of Hybrid Thermal Management System Based on Water Cooling and Phase Change Material for a Lithium Battery Module of an Electric Vehicle

S. Hekmat, G.R. Molaeimanesh*

Automotive Engineering School, Iran University of Science and Technology, Tehran, Iran

ABSTRACT: One of the most important affecting factors on the performance of electrical vehicles are their battery systems. Nowadays, lithium batteries are in a promising situation for use in electric vehicles. The performance of these batteries are deeply dependent on the temperature. These batteries have relatively poor performance at low temperature and also suffer thermal runaway at high temperature. Therefore, the use of a thermal management system is necessary for using these types of batteries. The objective of this study is the design and manufacturing of a battery module with hybrid thermal management system, based on water-cooling with phase change material using experimental method. Then the temperature of each cell was measured using active and passive cooling methods and the role of each of the cooling modes was compared with each other. The results of the study presented here indicate that the temperature of the battery without a cooling system in the high discharge rates to be significantly increased and in the next experiment, which was carried out by phase change material, the results showed that these materials absorb heat from the battery and greatly reduce the temperature without any energy consumption.

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1- Introduction

Today, energy supply is one of the great social challenges of the 21th century at global level. In recent years, energy shortages, air pollution dilemma, scarcity of fossil fuels and global warming are among the most critical challenges facing countries [1]. Nowadays, lithium batteries are in a significant position due to the advantages such as particular high energy, high energy density and low self-discharge compared to other batteries, and are a great option to be used in hybrid and Electric Vehicles (EVs) [2]. However, for the commercialization of this type of battery and using it in EVs, some of the performance barriers to these batteries, such as safety, costs, charging time and the ability to recover it, should be resolved. A major limitation in the technology of these types of batteries is their high dependence on the temperature. If the battery temperature goes up or down too much, battery efficiency and battery life will drop sharply [3]. However, effective thermal management of Lithium battery module has always been an essential issue according to the best working temperature range of 25–50 °C and temperature difference below 5 °C in a LIB module [4, 5]. Therefore, the existence of a thermal management system (TMS) to control the temperature of battery cells, especially their cooling at high temperatures, is essential and should be investigated further. In general, the cooling of the batteries is carried out in three main ways. If the cooling of external energy is used to circulate a fluid, then it is called "an active method". In this method, air or water is often used as a cooling fluid, and a pump or fan that consumes energy is usually used to move them. In the second method, there is no need to use energy for cooling, that is, in this state, phase-change materials (PCMs), glycerine oil, Nano-fluid, etc., can be used for cooling. In the third method of cooling, under the various conditions, both mentioned methods are used and is referred to as "the hybrid method" [6].

Corresponding author, E-mail: molaeimanesh@iust.ac.ir

1- 1- Importance of thermal management in lithium batteries and research background

Since a cell of lithium-ion battery alone cannot provide the energy needed to move a hybrid and electric car, a large number of these cells must be put together in series and in parallel. Placing a large number of cells and the high charging and discharge rates in this pack of batteries will increase the temperature caused by electrochemical reactions and the transmission of electrons and will result in a sharp temperature increase in the temperature of the entire battery pack. The absence of control will shorten the battery life, reduce capacity, or even in more severe cases, the battery will be exploded. According to this, the average temperature in the entire battery pack is very important. On the other hand, a collection of battery cells should also work at the almost same temperature with each other, because in case of failure to do so, it will cause non-uniform charge and discharge of cells, resulting in low battery life. As a result, it is very important to use an appropriate thermal management system to neutralize and eliminate these problems in the battery pack, and it is necessary to control both the average temperature and the temperature of each cell within a specific range.

2- Methodology

From the investigation of studies carried out, it can be concluded that an active and inactive combination cooling system is one of the best and the most reliable thermal management methods in lithium batteries of electric vehicle. Therefore, in this regard, we will examine this type of thermal management system empirically. Also, in this study, the effects of each cooling component, including phase-change materials and cooling pipes, are tested to obtain a comprehensive conclusion on the role of the performance of each component in this type of thermal management system. The experimental device is a hybrid cooling device that uses water-cooling pipes placed inside the battery compartment to cool the cells, which require components such as pumps, Arduino controller, thermometer, water flow sensor, radiator and fan to circulate the water and cool it.

2- 1- Types of cases intended for the experiment

Due to the parameters affecting the cooling system, these experiments will be carried out in three different cases. In all of these experiments, the distance between the cells to each other in the battery compartment is 14 mm, the cells will be discharged after that they arranges in series at 0.9 c for 57 minutes; also the initial temperature for all cases is considered to be 28°C and after the experiment, the graphs of temperature- time is obtained for each cell. The cases to be tested are as follows:

First case: Measuring the temperature of the cells in the battery compartment, regardless of the cooling system

Second case: Using phase-change Materials

Third case: Using of phase-change materials and water-cooling pipes

3- Results and Discussion

In this study, three cases were considered for our experiments, and each of the three experiments was tested in the same conditions, including ambient temperature 28°C, constant C-rate discharge of 0.72 C for a period of 57 minutes; each cases examines the changes in temperature in each cell, their average temperature, and the difference in temperature between the cells.

The first case of the experiment, the batteries, without a cooling system, are discharged by natural air circulation for 57 minutes, their temperature increases 58°C, and after discharge in the same state, they start to be spontaneously cooled and after about 98 minutes, the temperature of cells reaches to 30°C and they are cooled. In this case, it is observed that the temperature of the cells is very high and can cause serious damage to the battery in the long run.

The results of the cell temperature when the battery compartment is filled with phase-change materials. In this experiment, only phase-change materials were used to cool the cells. The cell temperature is much lower than the previous one and reaches to a maximum temperature of 32°C, while in the first experiment, without a cooling system, the temperature of the cells increased up to 58°C. Therefore, with the addition of phase-change materials, the temperature of the cells decreased by 26°C. After the discharge stage, the cells are exposed to cooling as a natural air circulation I order to reaches their temperatures to 30°C.

The third case of the experiment, the temperature chart of the cells in the hybrid cooling case of phase-change materials and a water-cooling pipe. In this case, water-cooling pipes are placed within the phase-change materials, and water is flowing at a rate of 133 liters per hour from the beginning of discharging, causing the cooling of the phase-change material simultaneously with warming up of the battery cells. In this case, the temperature of the cells in the discharge mode increased up to 30.5°C, and compared to the previous case of the experiment, which only used cooling fluid, we see that the temperature creases by 1.5°C. This suggests that cool water pipes can have a positive effect on the cooling of phase-change materials. In this experiment, due to the low temperature, it is not necessary to cool the cells after discharge; so, the cooling after discharge has been discarded.

4- Conclusions

From the results it can be concluded that the lithium batteries in high discharge and without any cooling can produce heat from themselves, and this problem can be highly effective on the performance of batteries in the long run and will shorten battery life and other destructive factors in these types of batteries. The results also indicate that the temperature difference between the cells, especially in the first case, regardless to the cooling system, is very high, but this temperature difference has been minimized by adding a cooling system. In another experiment by phase change materials, the results show that the use of these materials without any energy consumption can greatly maintain the heat generated by the batteries, as well as control the difference in temperature of the cells. Also, after complete discharging, the cooling process of phase change materials in the natural air circulation is much lower. Due to the latent heat of phase materials; in this case, an active cooling system can be very important to control the temperature and repulse the heat of the phase change material. In other experiments using a combination of phase-change materials and water-cooling pipes, it can be concluded that the water cooling pipes at least initially cannot have much effect. But in the long run and by increasing the temperature of the phase-change materials, the use of water-cooling pipes can be a good option for heat repulse from these materials.

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