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Experimental study of combining air cooling methods and thermoelectric for increasing efficiency and reducing temperature of lithium-ion battery.

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Abstract

Rechargeable batteries have an inseparable role in today's life, maintaining and increasing their lifespan has been one of the challenges. In this article, by combining air cooling and thermoelectric modules, we have tried to transfer battery heat better to reduce its surface temperature. The effect of temperature and different discharge rates is investigated in this article. The battery pack was made of aluminum block with dimensions of 30x10x6 cm. The arrangement of these cells was in the form of 4 rows in 12 columns. Considering the capacity of 2200 mAh and the voltage of 3.7 volts, the maximum power of the set is 390 Wh. By using simultaneously the fan and the thermoelectric, the operating time has increased by 17.1% compared to the mode without the fan and the thermoelectric, and has reached 1900 seconds to 2300 seconds. The surface temperature of the set has decreased by 2 degrees using the fan and the module. The heat transfers by fan cooling system and thermoelectric has improved by 15.2% compared to the case without fan and module. By comparing the results obtained from the tests, the suitability of this cooling method for better heat transfer of the set has been confirmed.

Keywords: Li-ion battery, Forced air flow, Cooling, Thermoelectric generator, Flow of consciousness, Nusselt Number.

1. Introduction

In today's world, batteries play a fundamental and important role in our lives. Lithium-ion batteries are popular in electric vehicles due to their high energy density, long life, and environmental friendliness [1]. However, lithium-ion batteries generate heat during charging and discharging. Li-ion batteries usually work between -20 to 60°C [2]. Until now, various strategies have been implemented for thermal management of battery packs to ensure optimal operational temperature during the set time, such as air cooling, liquid cooling, phase change materials, heat pipes, thermoelectric modules, and a combination of these [3]. The main topic of this article has also been using air and thermoelectric modules. Liquid coolers have a high heat transfer coefficient that efficiently converts it to a compact and efficient cooling medium. However, a conventional liquid cooling system has a large and complex structure that requires high capital investment and electricity consumption [4]. In contrast, air coolers and phase change materials both have lower thermal conductivity and heat transfer efficiency compared to liquid systems, resulting in inefficient heat transfer processes. The main drawback of cooling with a heat pipe is its low thermal resistance, which does not make it suitable for all conditions [5]. On the other hand, air cooling systems are mainly used in light electric vehicles with small battery packs [6]. Due to their simple structure and configuration, low initial cost and maintenance and leak-free operation, they have been more popular compared to other cooling methods [7]. Thermoelectric-based systems, which use the Peltier effect for heat transfer, provide precise temperature control, although often at higher implementation costs [8]. Thermoelectric generators are environmentally friendly as they operate without producing noise pollution. One of the disadvantages of this method is the low energy conversion efficiency of thermoelectric generators, and in addition, modules require a relatively constant heat source [9]. The novelty of this article lies in the combination of two cooling methods with air and thermoelectric modules along with heat sinks, as well as the effect of different ambient temperatures with different discharge rates on the battery performance and surface temperature.

2. Governing equations

To determine the energy balance, the amount of energy stored in the battery pack must first be determined. In Fig 1, the total accumulated energy in the battery pack is shown.

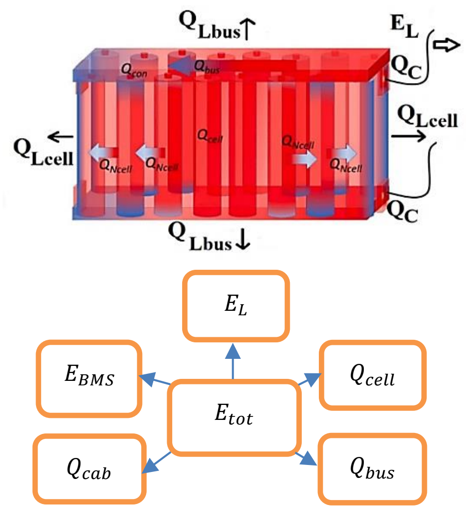

Fig 1. total accumulated energy in the battery pack

The formula of total energy value E_{tot} in a battery pack is:

$$E_{tot} = b \times V_n \times C \tag{1}$$

The following equation related to the heat produced in the cell [10]:

$$\dot{Q}_{cell} = R_{cw} i_{cell}^2 - i_{cell} T \frac{\Delta S}{n_e F} \tag{2}$$

The heat accumulated in the battery pack can be calculated by:

$$\dot{Q} = b\dot{Q}_{cell} + \dot{Q}_{bus} + \dot{Q}_{cab} - (b\dot{Q}_{Lcell} + \dot{Q}_{Lbus}) \tag{3}$$

The heat produced in the battery pack can be expressed by:

$$\dot{Q}_{GEN} = \dot{Q}_{cell} + \dot{Q}_{bus} + \dot{Q}_{cab} \tag{4}$$

The Nusselt number can be calculated by:

$$Nu = \frac{hL}{K} \tag{5}$$

For calculating the uncertainty, Kline and McClintock formula has been used.

$$W_R = \sqrt{\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2} \tag{6}$$

3. Experimental method

To create the battery pack required for this article, an aluminum block with dimensions of 30×10×6 cm has been used, which has been designed and manufactured in this way for the first time. 48 battery cell slots have been embedded on it using CNC machining. The depth of the battery slots is 2.6 centimeters, which has been chosen based on the physical dimensions of the cells.

4. Result and Discussion

Initially, cooling was done without a fan and with a thermoelectric module where cooling was achieved by natural convection. Then, cooling was done with a fan and a thermoelectric module where cooling was achieved by forced convection. Finally, cooling was done with a thermoelectric module and without a fan where cooling was achieved by natural convection.

In Fig 4. Performance duration chart of the set at ambient temperatures of 20 and 25 degrees Celsius without cooling method and with a combination of cooling method with fan and thermoelectric module was shown.

In Fig 7, the voltage drop rate as a function of system load at 35 degrees and a discharge rate of 15 amps is shown. As it is evident, figure has a decreasing trend and rate of this voltage drop is higher at higher discharge rates.

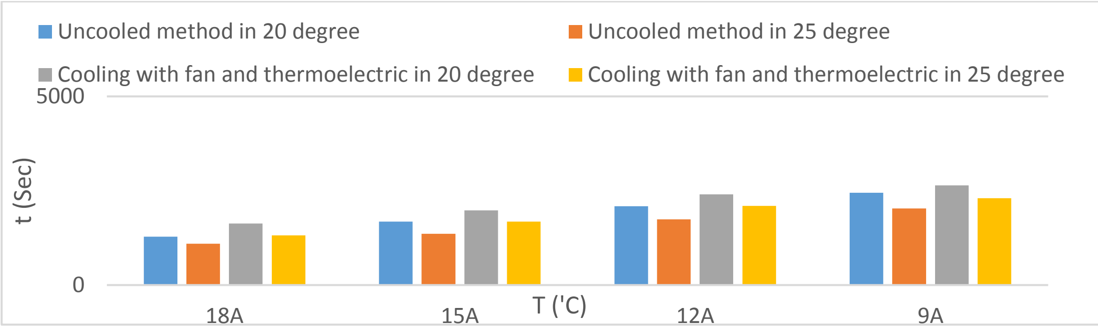

Figure 4. Performance time at 20 and 25 degrees with uncooling method and with fan and thermoelectric module

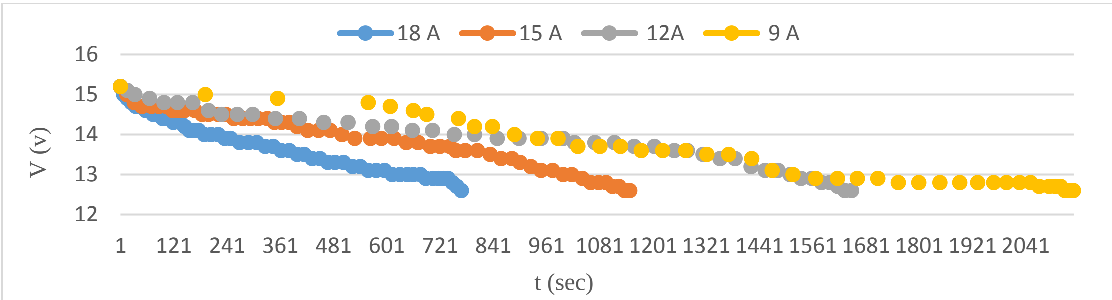

Figure 5. Voltage drop in 35 Celsius degrees at a discharge rate of 15 amperes

Fig 8, shows rate of current drop at 35 degrees and a discharge rate of 15 amps, with fan and thermoelectric module. Over time and operation of the system, the battery has experienced a drop in current.

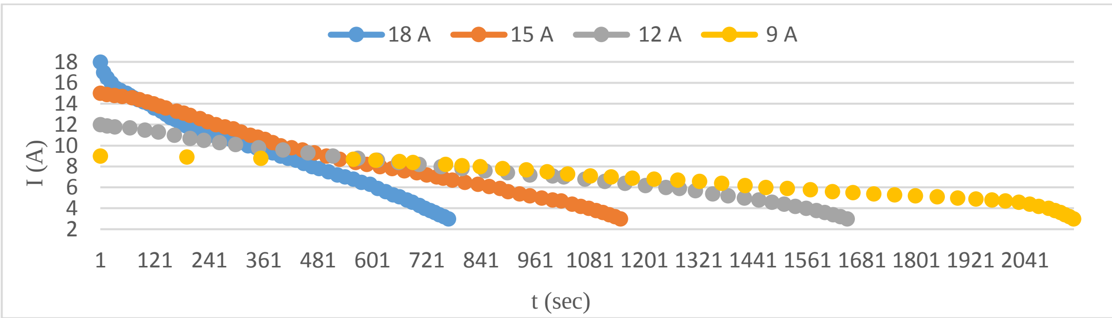

Figure 6. Ampere drop in 35 Celsius degrees at a discharge rate of 15 amperes

5. Conclusions

The main threat for batteries are their operating temperature so it is necessary to use a thermal management system for batteries. the conclusions of this thesis can be summarized in a few paragraphs, which are discussed below:

- The cooling method with the thermoelectric module is the reason for the low efficiency of this method, especially in higher discharge rates such as 12, 15 and 18.
- By creating disorder in the air around the system, causes the cool air to hit the surface of the hot pack at a higher speed and causes the surface temperature to decrease.
- Changing the ambient temperature of the battery pack from 20 to 25°C has increased the average temperature of the battery surface by 17% and the maximum temperature of the battery pack has increased by 19%.

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