Improved Nanofluid Cooling of Cylindrical Lithium Ion Battery Pack in Charge/Discharge Operation Using Wavy/Stair Channels and Copper Sheaths

Ehsan Doakhan[1], Ghanbar Ali Sheikhzadeh[2*]

[1] Faculty of Mechanical Engineering ,University of Kashan, Kashan, Iran
edoakhan@gmail.com
[2] Faculty of Mechanical Engineering ,University of Kashan, Kashan, Iran
sheikhz@kashanu.ac.ir

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Extended Abstract

Introduction: Climate change and its associated implications for human life as well as the depletion of conventional fossil fuel resources have led to intensive research and development in novel energy conversion systems including electrified vehicles (EVs). EVs can help address several environmental concerns that internal combustion engines induce to nature when reaching reasonable mass production. Among the key enablers within the EV field, powering is still an open and challenging issue. As a power source, one of the candidates in the spotlight is lithium-ion batteries (LIBs), which have enormous benefits such as a relatively low cost and self-discharge rate, a long life cycle, and a high power and energy density. However, targeted, comprehensive studies are needed to deal with the problems originating from electrochemical reactions and the corresponding generated heat in a LIB pack. The investigation within the thermal management realm for LIBs thus absorbed an increasingly growing attention to address the requirements for technology commercialization.

Materials and Methods: For the model, a real-scale battery module including 71 18650-format cylindrical batteries was used. The active cooling section included a stair channel embedded above the batteries by using an alumina nanofluid as a coolant and a wavy channel between the batteries that was used to cool the LIB module during discharge/charge processes. Two types of copper structures were added as a conductive substance to the designed system to enhance the functionality of thermal management system further. This was done by inducing a copper mold around the batteries and a copper plate above the batteries. The peak temperature of the battery decreased using this composite cooling method. The influence of the design on the thermal efficiency of the battery was, then, carefully studied by looking at main measures containing the peak temperature experienced by the battery and the temperature uniformity across the battery module.
The proposed method here could help study the thermal performance of the battery module throughout different discharge/charge C-rate conditions, different volume fractions of nanofluid, different fluid flow rates, different initial ambient/fluid inflow temperature, different channels, various interfacing areas between neighboring batteries, and various contact regions between LIBs and the wavy channel.

Results: Simulation results illustrated that the peak temperature and temperature difference for the discharge process decreased 1.2 K and 0.4 K respectively by using 2% volume fraction Alumina nanofluid, in comparison with co DI water. In addition, increasing the coolant inlet velocity led to a decrease in the maximum temperature and in the temperature difference. Different ambient/fluid inflow temperatures of the battery module were evaluated to simulate different weather climates. An innovative design, using the stair channel cooling, was finally developed for the LIB thermal management system. Comparing the two stair and straight channels, it was found out that the temperature non-uniformity for the stair-type channel was almost reduced by 0.19 K and 0.22 K for the discharge and charge processes respectively.

Discussion and Conclusion: In the present study, the enhancement of a thermal model for an 18650-format battery module equipped with a mini-channeled water/nanofluid cooling system-- comprising a 71 18650-format LIBs-- was reported based on a computational fluid dynamics study. Here, a thermal-lumped approach was adopted for treating the single lithium-ion battery based on polling heat, Joule heat, chemical reaction heat, and side reaction heat generation rate during discharge/charge processes. The lumped heat generation rate was, then, carefully characterized during discharge and charge processes. A detailed simulation was also carried out for the conduction of heat between neighboring lithium-ion batteries and multiple heat transfers from LIBs to the channels' shell. Finally, the model was endorsed by comparing the experimental results of one prototypical model with the corresponding numerical results from the present work. The comparison between charge/discharge processes during the 5C rate illustrated that the temperature values were in sensible agreement. Therefore, it was concluded that having the wavy channel cannot guarantee a significantly higher cooling capacity. The improvement suggested in this work is, thus, a confluence of factors, including the addition of stair channel, of a copper sheath, and of nanofluid as a coolant fluid.

The charge/discharge C-rate is believed to influence the battery module's thermal performance considerably. Larger temperature values and reduced thermal efficiency in the battery module are attributable to an increased rate of charge/discharge operations. The generated heat power is almost proportional to the input/output current. It was concluded that adding nanofluid into the stream passing through the channels significantly reduces the peak temperature and the temperature difference in the battery module. Nevertheless, the pressure loss would increase in both channels in this approach.

It was also concluded that an increase in the inlet flow rate could effectively decrease the temperature and improve the temperature equilibrium in the battery module. Nevertheless, the work consumption of the pump increased in this situation. Mimicking warm climates with higher ambient temperatures, the simulation results indicated that during 5C-rate charge/discharge operations, the proposed cooling system reduced the highest difference in the temperature at the end of operations. The effect of stair channel was investigated, and the results indicated a notable improvement in the cooling capacity. An increase in the interface area could improve the thermal efficiency of the battery module to boost the heat conduction between neighboring lithium-ion batteries slightly. Increasing the contact region between the battery and the wavy channel's shell could considerably decrease the highest temperature in the module and simultaneously increase the non-homogeneity of the temperature in the battery module.

The peak temperature and the temperature non-uniformity in the represented lithium-ion battery module could be managed below307 K, and 0.4K, respectively by using the introduced liquid cooling channel system at proper fluid flow situations --for instance, the 2 % volume fraction aluminum oxide nanofluid, the inlet velocity of 0.5 m/s, and the ambient/fluid inlet temperature of 298K and under a high C-rate (5C) discharge/charge processes. ,. This corroborated the performance of the wavy/stair channels with a copper sheath cooling arrangement for thermal management of EVs battery modules. Furthermore, the proposed TMS may have been used to design the stair channel with different stairs and baffles. This may have been completed with a simulation of the various liquid flow directions in the battery module.

Keywords: Battery thermal management systems, lithium-ion battery, liquid cooling, nanofluid, copper sheath.

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