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Research Article

Thermal Reduction in Lithium-ion Power Source Using Multilayer Heat Sink Channels with Different Fluids as Coolant

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Abstract

In this paper, finite element method (FEM) based modelling and simulation of the Lithium Ion Battery (LIB) is carried out with the mechanism of multilayer multichannel heat sink in it. The capability of four different fluid movement and flow pressure were analyzed in the design. Nitrogen, carbon dioxide, hydrogen, and Freon were taken as fluids for simulation. Among these fluids, nitrogen and carbon dioxide showed the highest movement in the channel. Results confirmed them as the better contender for the fluid as heat sink in channel based heat removal from the device.

Keywords: *Lithium ion battery, heat exchanger, heat sink, fluid movement, channels.*

Introduction

Hybrid portable electric systems are becoming a major player in the global market. Lithium-ion batteries (LIB) in small sizes are extensively used to power portable electronic devices because of their high voltage delivering capability greater than 4V and high energy density (*Al Hallaj, S. et al*). These batteries have 4–5 times higher power density than lead-acid batteries, but have thermal stability issue. These batteries are being explored as a potential power source for portable system to provide longer access and lifetime. Designing lithium battery system under excessive and normal operating conditions is a primary challenge due the thermal heat generation. Various chemical and electrochemical reaction as well as transport process takes place during battery charging and discharging. These reactions and processes also continue to operate under open circuit conditions (*Hong, J. S. et al*). Since these reactions are exothermic and if heat transfer from the battery to the surrounding is not sufficient, this may cause heat accumulation inside the battery. If the temperature in the battery rises significantly, it may form hot spots in it. This effect may lead to thermal runaway in the battery.

Efforts are being made to advance the thermal modeling tools for battery cells, to design and operate the battery systems more efficiently (*Mahamud, R. et al*). Thermal modeling is the essential tool for optimizing the design of scaled-up cells and batteries for electrical applications. These types of models are accountable for battery performance and durability. Input properties (such as transport properties, thermodynamic properties and heat effect) and operational parameters are required by these models (*Chen, Y. et al*).

2. Heat Exchangers

Heat removing in heat exchanger is done with the help of fluid. Both liquids and gases are considered as fluids. Heat exchanger performance is characterized by the actual heat transfer rate as a fraction of the maximum heat transfer rate (*McQuiston, F. C. et al*) given by following equation

$$\eta = \frac{q}{q_{\max}}$$

Actual heat transfer rate is given by

$$q = C_h(T_{hi} - T_{ho}) = C_c(T_{co} - T_{ci})$$

where and is the temperature of the hot and cold fluid going into the heat exchanger, and is the temperature of the hot and cold fluid coming out of the heat exchanger (*McQuiston, F. C. et al*). Effectiveness of the heat exchanger wood save large fraction of energy. This can be achieved by using modern technology.

Micro-channel heat exchangers are being developed provide heat removing solutions for compact electronic devices. Improvement in the fields of MEMS, microelectronics, biomedical, aerospace, and fuel processing are pushing the limits to find small device with more thermal control (*Ashman, S. et al*). Flow of fluid in heat exchanger determines its efficiency. High heat transfers rate is achieved with turbulent flow of fluid. At reduced channel hydraulic diameter fluid flow becomes laminar, thus causing reduction in the heat transfer coefficient. Since at small channel diameter, conduction

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distance of heat reduces which compensate for the laminar flow. Also with laminar flow, when velocity of fluid is decreased heat transfer coefficient is maintained. This is due the fact that head loss decreases with lower velocity of fluid. Furthermore, with multiple parallel channels this head loss reduces to great extent *(Zaheed L. et al), (Doty, D. et al), (Denkenbergera, D. C. et al)*.

3. Channel based Heat Sink Modelling

FEM based approach is used to model the multiple parallel channels heat sink in LIB utilizing gases as coolant. Battery model is adapted from COMSOL model library (*www.comsol.co.in*) to simulate the efficiency of multiple parallel channels as heat exchanger with fluid in gaseous form. Structural dimensions of length, width, and thickness are taken for the battery. It consists of three functional blocks: battery section, cooling fins, and channel heat exchanger. The dimensions of the channel in the LIB are of width and thickness. LIB with standard electrolyte and electrodes are used in the simulation. Cooling fins are taken to store the fluid to pump in the channel heat exchanger. Design layout of the structure created in CAD design software shown in Fig. 1.

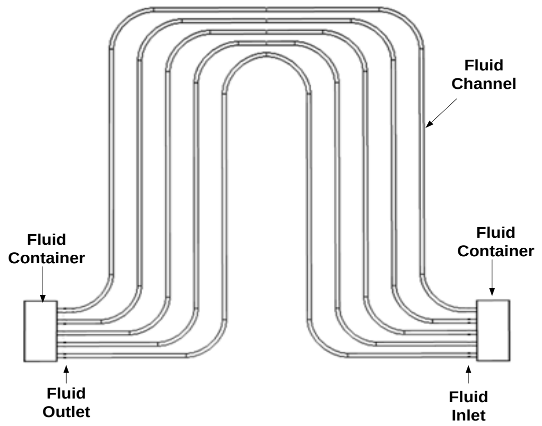

Figure 1 Schematics of fluidic channel layout

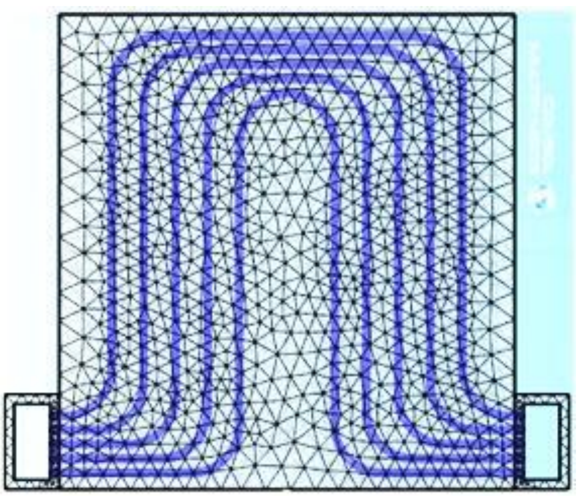

Figure 2 Mesh formation of the model

4. Results and Discussion

Thermal models for batteries simulate temperature profiles inside the battery cell during charge and discharge. Simple one dimensional thermal model of the batteries are available in literature (*Kim, J. et al*), (*Chen, Y. et al*), (*Doyle, M. et al*) (*Fuller, T. F. et al*) (*Nieto, N. et al*) (*Newman, J. et al*) (*Song, L. et al*) (*Pals, C. R. et al*) (*Doyle, M. et al*). The heat generated inside it needed to be removed. So, channel path is designed inside the battery to circulate the gaseous fluid as coolant to remove the generated heat. Various parameters of the fluid inside the channels are computed in the simulation. Fluid movements in the channel for nitrogen, carbon dioxide, hydrogen, and freon and plate channel velocity of the fluids with other fluid properties are given in the Table 1. Carbon dioxide showed the maximum velocity of 0.2620 m/s and also having the maximum plate channel velocity of 0.2790 m/s. Velocity components for hydrogen and nitrogen are comparable, showing the maximum fluid velocity of0.2536 m/s and 0.2595 m/s respectively. The plate channel velocity difference is about 5%.

Fig. 3 shows the graphical representation of the fluid velocity and plate channel velocity of fluid in the modeled battery cell for different fluids. Freon fluid used in the modeling of the heat sink in the LIB battery showed the minimum velocity rate of movement compared to other fluid used in the simulation.

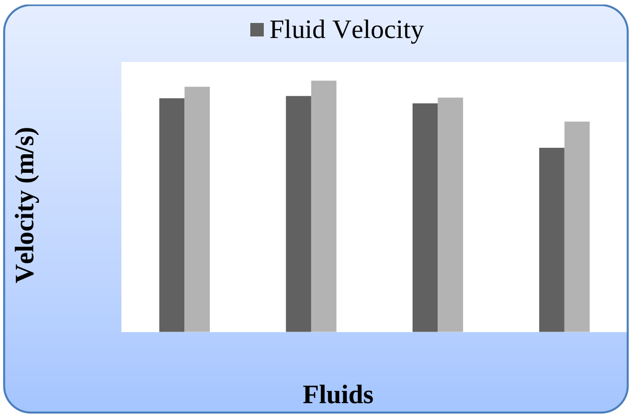

Figure 3 Fluid and plate channel velocity of four different fluids used in the simulation

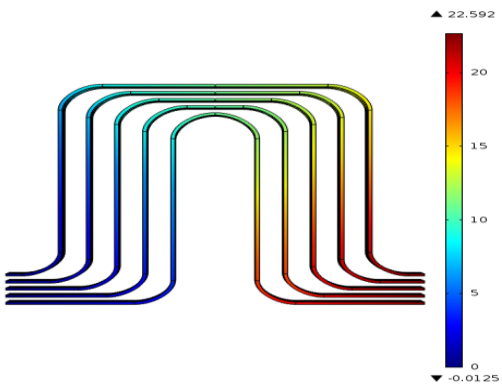

Figure 4 Nitrogen fluid pressures in the channel

Table1 Different fluid property in microchannel

Fluid	Velocity (m/s)	Plate Channel Velocity (m/s)	Dynamic Viscosity (Pa.s)	Density (kg/m^3)	Ratio of specific heat
Nitrogen	0.2595	0.2723	0.018 x 10^{-3}	808.4	1.4
Carbon dioxide	0.262	0.279	0.0156 x 10^{-3}	598	1.3
Hydrogen	0.2536	0.26	0.009 x 10^{-3}	71	1.405
Freon	0.2044	0.2335	0.42 x 10^{-3}	1295	1.15

Pressure of the fluids in the channel during its flow through it is simulated. The pressure variation in different parts of the channels can be distinguished and reveals the fluids shows different behavior in the channel. Figure 4 to 7 shows the pressure flow in the channels for nitrogen, hydrogen, carbon dioxide, and freon.

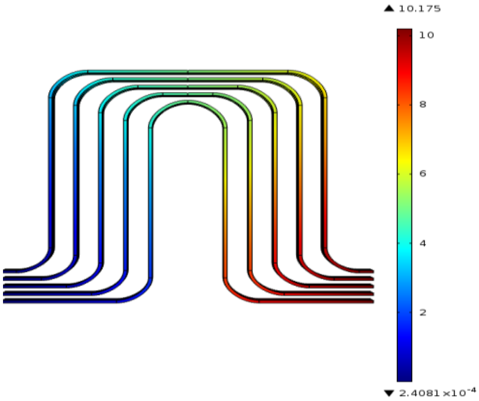

Figure 5 Hydrogen fluid pressures in the channel

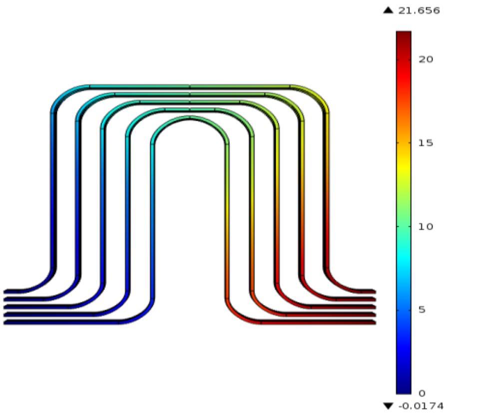

Figure 6 CO_2 fluid pressures in the channel

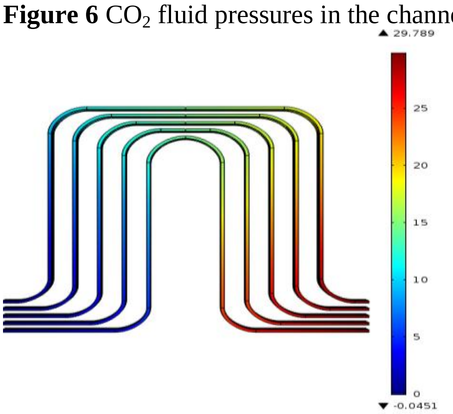

Figure 7 Freon fluid pressures in the channel

The maximum and minimum pressure of fluid in the channels of theses fluids are plotted in Fig. 8 and Fig. 9 respecively. It can be observed from the graph that hydrogen showed the lowest of the maximum pressure range upto of 10.175 Pa among the other fluid taken in the simulation. Maximum pressure is observed for freon i.e. 29.789 Pa. Similarly for nitrogen and carbon dioxide showed the pressure 22.592 Pa and 21.656 Pa respectively.

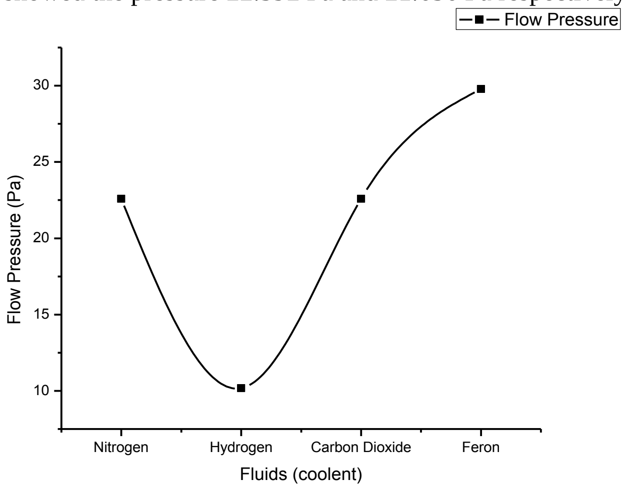

Figure 8 Maximum fluid flow pressures in simulation.

The minimum pressure is obtained for the freon at the outlet of the channels with carbon dioxide, nitrogen, and hydrogen showing higher values respectively.

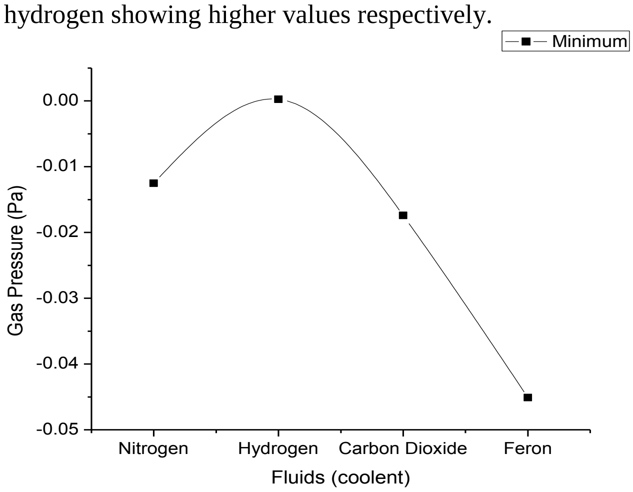

Figure 9 Minimum fluid flow pressures in simulation

Conclusions

The research work is carried out to simulate the effectiveness of the fluid used in the channels modeled in the battery structure to remove the heat from it. Four different gases are considered for the fluid in channels to study their capability of movement so that heat removing process can be done at high rate. Among the fluid taken carbon dioxide and nitrogen showed the relatively comparable velocity of movement in the channel which can be implemented for the fluids in channel for heat removing process. Further work is required to be done on sinking of the heat from the fluid in the channels.

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