Efficient cooling system for lithium-ion battery pack by using non-Newtonian nano-fluid in cooling channel under laminar flow: A numerical analysis

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Abstract

To enhance the efficiency and prolong the lifespan of the power battery module in electric vehicles, we propose a Battery Thermal Management System (BTMS) that incorporates liquid cooling. This study focuses on a numerical investigation aimed at assessing the effectiveness of a cooling channel in reducing thermal non-uniformity in the performance of lithium-ion battery packs. A specially designed wrapped cooling channel is employed to augment the heat transfer area, and its cooling performance under liquid cooling is examined.To enhance the efficiency and prolong the lifespan of the power battery module in electric vehicles, we propose a BTMS that incorporates liquid cooling. This study focuses on a numerical investigation aimed at assessing the effectiveness of a cooling channel in reducing thermal non-uniformity in the performance of lithium-ion battery packs. A specially designed wrapped cooling channel is employed to augment the heat transfer area, and its cooling performance under liquid cooling is examined.The chosen liquid coolant is a nano-fluid consisting of multi-wall carbon nanotubes (MWCNT) as nanoparticles, mixed with a base fluid of distilled water and ethylene glycol. The analysis considers various parameters, including mass flow rate, discharge rate, and configuration, to evaluate cooling performance. The numerical solution employs the laminar flow regime and the SIMPLE method. The results indicate superior cooling performance achieved by the proposed wrapped cooling channel. This approach demonstrates promising results for mitigating thermal non-uniformities and improving the overall performance of lithium-ion battery packs in electric vehicles.

Introduction

Climate change urgency driven by rising CO2 levels from industrial and transport emissions prompts a shift to electric vehicles (EVs), which emit minimal CO2. EVs rely on high-density Lithium-ion battery packs whose performance and safety hinge on maintaining temperatures between 20°C to 40°C. Battery Thermal Management Systems (BTMS) are crucial for regulating these temperatures during charging and discharging, ensuring optimal battery performance and longevity.

In this research, a liquid cooling channel is developed to enhance the thermal uniformity performance of a lithium battery pack. The design of this channel is based on the fundamental Newton law of cooling, which states that heat dissipation increases with the heat transfer area (surface contact) Therefore, the channel is designed to maximize the surface contact area with the battery cell. For comparison purposes, three additional BTMS systems is developed. BTMS1 and BTMS2 are the same, with only the configuration being different. Similarly, BTMS3 and BTMS4 are the same, with only the configuration being different. BTMS1 and BTMS3 have a longitudinal flow configuration, while BTMS2 and BTMS4 have a transverse flow configuration respect to the battery pack. Enhance the cooling performance, BTMS is investigated under various flow velocities, different nano-fluids, and different discharge rates through numerical analysis using fluent software

Design/Other information

Table 1 Labels used for each nanofluid in the following study

Labels	NF1	NF1	NF1	NF1
MWCNTs Vol.%	0.25	1.5	0.25	1.5
Base fluid	30% EG	30% EG	60% EG	60% EG

Table 2 Thermo physical properties of the materials

Material	$\rho\ (Kg/m^3)$	C (J/KgK)	k W/mK	$\mu\ (Kg/ms)$
Aluminium	2719	871	202.4	-
Water	998.2	4128	0.6	1.003×10^{-3}
Battery	2018	1282	2.7	-

Table 3 Volumetric heat generation values for various discharge rate

Discharge rate	Volumetric heat generation (W/m^3)
2C	19452
3C	42400
4C	74163

- Cooling channel taken of aluminium material
- Battery types is cylindrical 18650 model
- Diameter of cell is 18 mm and height is 65 mm
- The number of cells used to present analysis is 30
- The computational method is validated to Wei Li et al. (2020)

Set up

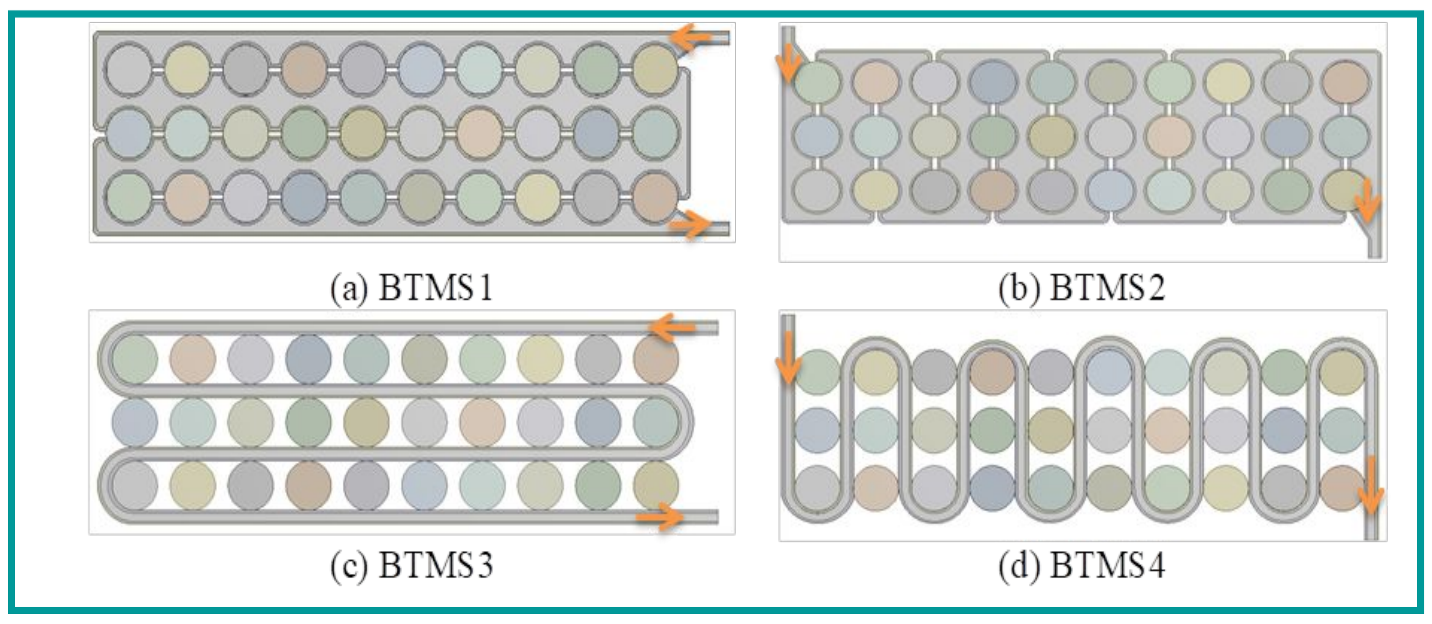
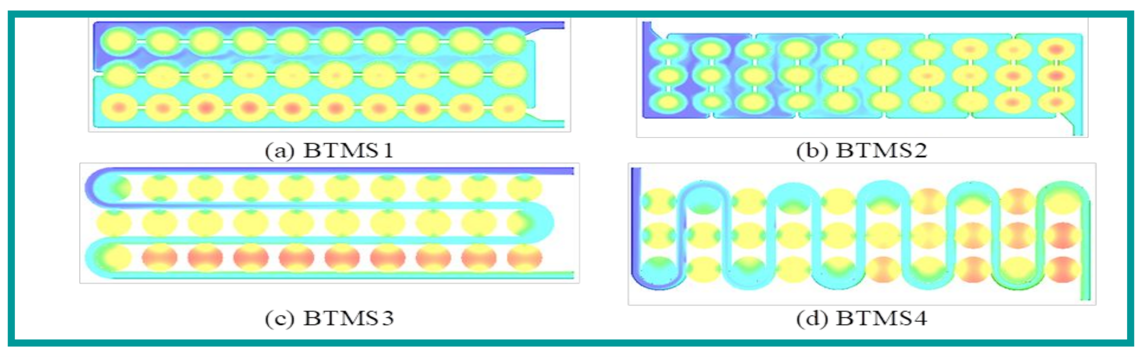
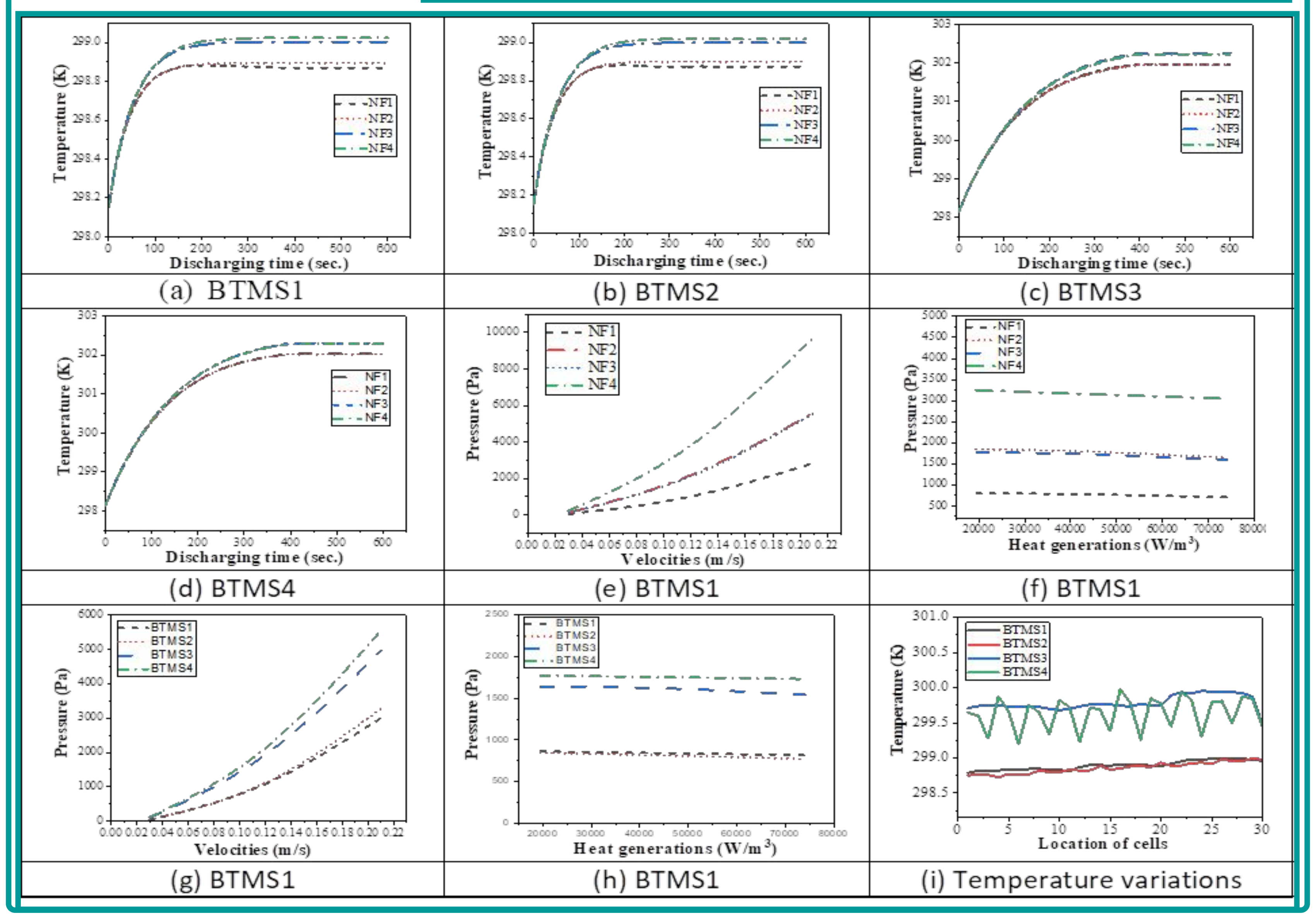


Figure: Wrapped cooling channel (a) BTMS1 and (b) BTMS2, tangent simple cooling channel (C) BTMS3 and (d) BTMS4

Results

Figure: Contours of temperature variation in cooling channels at 3C discharging rate and .12 m/s inlet velocity.





Conclusions

- The minimum average temperature of the battery pack in BTMS1 is 299 K, while the maximum average temperature is in BTMS4 at 302.5 K under a 3C discharge rate.
- The best cooling effect was demonstrated by BTMS1 using nano-fluid NF1, which reduced the temperature of the battery pack from 318 K to 299 K, a difference of almost 19 K, under a 3C discharge rate. It also exhibited better thermal uniformity compared to all other BTMS configurations.
- The pressure drop is contingent on factors such as the flow area, channel length, and fluid properties. BTMS4 experiences the highest pressure due to its restricted flow area and numerous channel bends, while the minimum pressure is observed in BTMS2.

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