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BATTERY COOLING SYSTEM INCORPORATING PCM & NANOFLUID

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ABSTRACT

The automobile industry has been compelled to transition to environmentally friendly vehicles like fuel cell vehicles (FCVs), plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), and electric vehicles (EVs) to address these environmental challenges. The increasing use of lithium-ion batteries in electric vehicles has made it imperative to create more effective and enhanced battery cooling systems. Using n-eicosane (PCM) and mini-channel cold plates (MCPs), a battery thermal management system (BTMS) can be built to cool a battery pack for numerical examination. Under constant heat generation and various intake coolant velocities, several battery configurations using Mini Channel Cold Plates (MCP) and Mini Channel Cold Plates combined with PCM have been compared for prismatic cells. Here we find a configuration with a maximum cooling effect. After a better cooling configuration, the water is replaced with 0.5% Al2O3 in water(nanofluid) and thermal analysis is conducted.

Keywords: Prismatic Battery, MCP, PCM, EV, Nanofluid.

I. INTRODUCTION

Electrification is a viable option for establishing clean and energy-efficient transportation. The environmental impact of conventional vehicles is regarded as a severe issue. EVs reduce greenhouse gas emissions and fossil fuel reliance, despite technical constraints. Battery cooling systems in EVs help maintain optimal temperature range for battery performance, lifespan, and safety by preventing overheating and ensuring efficient operation.

PCM-based cooling systems utilize high latent heat-capacity materials like paraffin wax or salt hydrates to absorb and release thermal energy during phase transitions, offering passive cooling and effective temperature regulation.

The study aims to analyze the cooling of prismatic batteries using different configurations of mini-channel cold plates and to compare their performance using CFD-ANSYS Fluent software. Additionally, the research seeks to evaluate the effectiveness of Phase Change Material and hybrid mini-channel cold plates compared to normal mini-channel cold plate cooling. Furthermore, the investigation aims to understand the improvement in cooling performance achieved by using hybrid mini-channel Cold Plate with Nanofluid over hybrid mini-channel cold plate with water cooling in prismatic batteries through simulation using CFD - ANSYS Fluent software.

The different battery configurations used in the study are cases a, b, and c, as shown in figures 1, 2, and 3, respectively. First, the study was conducted on the three cases; the best one was obtained, and HMCP is incorporated with the best configuration. The effectiveness of HMCP over MCP (the best configuration) is analyzed. Initially, the cooling medium in HMCP was water, and later it was replaced with nanofluid (0.5% of Al_2O_3 in water). The effectiveness of nanofluid over water is analyzed.

II. METHODOLOGY

The study is done to simulate and analyze the thermal improvement obtained by using PCM in battery cooling. This is done using CFD Ansys Fluent. Three different configurations of prismatic battery are used (Case a, Case b and Case c). PCM used is n-eicosane and the coolant fluid used is water and nanofluid.

BATTERY

This study investigates the configuration of battery modules between cold plates, focusing on their orientation and thermal management performance. Three different configurations are studied, varying in size, number of mini-channels, and materials.

Table 1: Properties of prismatic battery

Battery Type	Density ρ(kg/m3)	Specific heat capacity cp (J/(kgK))	Thermal conductivity k (W/(mK))
Prismatic Battery	1700	830	k(in-plane) = 34 k(through-plane) = 3.4

Battery of dimension - 70mm x 100mm (HMCP Case a) Battery of dimension - 180mm x 100mm (HMCP Case b)

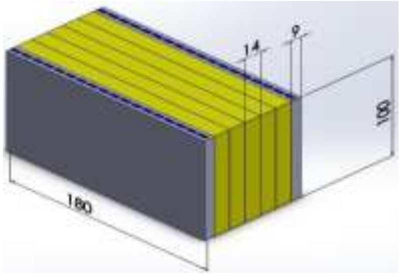


Figure 1: Prismatic Case a Battery Module

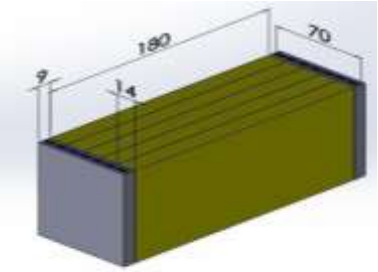


Figure 2: Prismatic Case b Battery Module

Battery of dimension 100mm x 70mm (HMCP Case c)

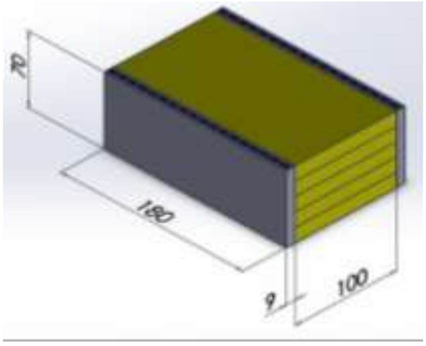


Figure 3: Prismatic Case c Battery Module

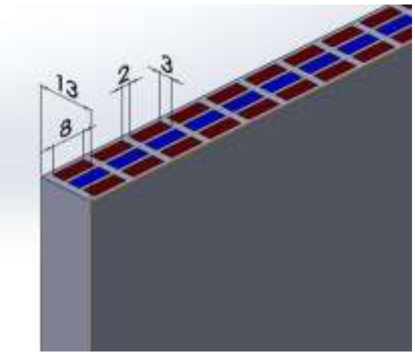


Figure 4: Dimensions of HMCP of prismatic battery

MCP & HMCP

This study investigates the configuration of battery modules between cold plates, focusing on their orientation and thermal management performance. Three different configurations are studied, varying in size, number of mini-channels, and materials.

PHASE CHANGE MATERIAL

Phase Change Material used in this study is n-eicosane ($C_{20}H_{42}$). The dimensions and the method of implementing the PCM are discussed later. N-Eicosane PCM is depicted in brown color in the above figures. The dimensions of PCM implemented are small in both the prismatic and cylindrical cases. This is done to avoid any contact with the environment, to avoid PCM from just flowing away in the liquid phase, and as defined surface for heat exchange.

Table 2: Thermo-physical properties of n-eicosane

	Solid PCM (at 298.15 K)	Liquid PCM (at 323.15 K)
Density, ρ(kg/m3)	910	769
Latent heat of fusion, hsl (kJ /kg)	248	-
Melting point, Tmelt (K)	309.55	-
Specific heat capacity, cp (J/(kg.K))	1926	2400

Thermal conductivity, k (W/ (m.K))	0.423	0.146
Thermal expansion coefficient, β (1/K)	-	8.161×10^{-4}

Dynamic Viscosity (μ) of the PCM is given by: $\mu = (9 \times 10- 4T2 - 0.6529T + 119.94) \times 10^{-3}$

COOLANT-WATER & NANOFLUID

Coolant, also known as antifreeze, is a substance used to regulate and control the temperature of a system by transferring heat away from the source. the coolant used in battery systems carry the heat in the cells to surroundings and re-enter to the cooling channel after cooling. Compared with the air-cooling design, the liquid cooling could eliminate more temperature and produce more cooling effects. Some advantages of using water as a coolant are:

- Cost-effectiveness
- Environmental friendliness
- High specific heat capacity
- Simplicity and ease of maintenance
- Compatibility with existing infrastructure

Table 3: Thermo-physical Properties of Water

Density, ρ(kg/m3)	998.2
Specific heat capacity, cp (J/(kg.K))	4182
Thermal conductivity, k (W/ m.K)	0.6

Table 4: Thermo-physical Properties of Nanofluid.

Density, ρ(kg/m3)	1011.209
Viscosity, μ(kg/ms)	0.001032
Specific heat capacity, Cp (J/kgK)	4121.17
Thermal conductivity, k (W/m.K)	0.6223

III. MODELING AND ANALYSIS

Mesh size chosen for this study is 0.0005m. Details of the mesh for the prismatic and cylindrical battery are provided below

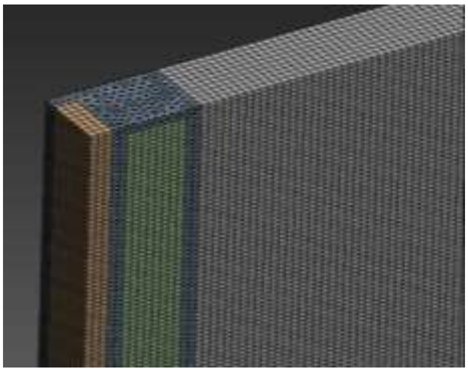


Figure 5: Generated Mesh-Prismatic.

BOUNDARY CONDITIONS

Since the sizes of cold plates and the number of channels is different in each case, the total water mass flow rate is assumed similar for all cases. As a result, the water velocities for cases a and c are 0.01 m/s, case b is 0.0257 m/s and cylindrical cell is 0.001m/s. Initial thermal conditions of the coolant is at 298K.

Table 5: Inlet Velocities of coolant

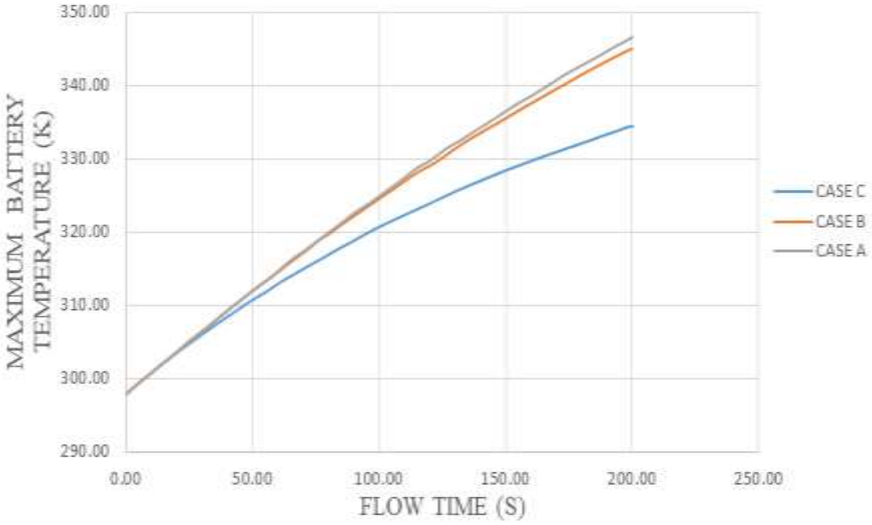
Configuration	Case a	Case b	Case c
Inlet Velocity(m/s)	0.01	0.0257	0.01

- Pressure outlet is at gauge pressure 0 Pa.
- Initial Thermal Condition is set at 298K.
- Calculation is done at 0.5s time step size and max iterations/time step is set at 20.

IV. RESULTS AND DISCUSSION

COMPARISON OF THREE MCP CONFIGURATIONS

Flow time (s) and Maximum Battery Temperature (K) are depicted along X axis and Y axis respectively in figure 6. Case a (70mm x 100mm), Case b (180mm x 100mm), Case c (100mm x 70mm) are the three configurations of the prismatic battery that are compared below.

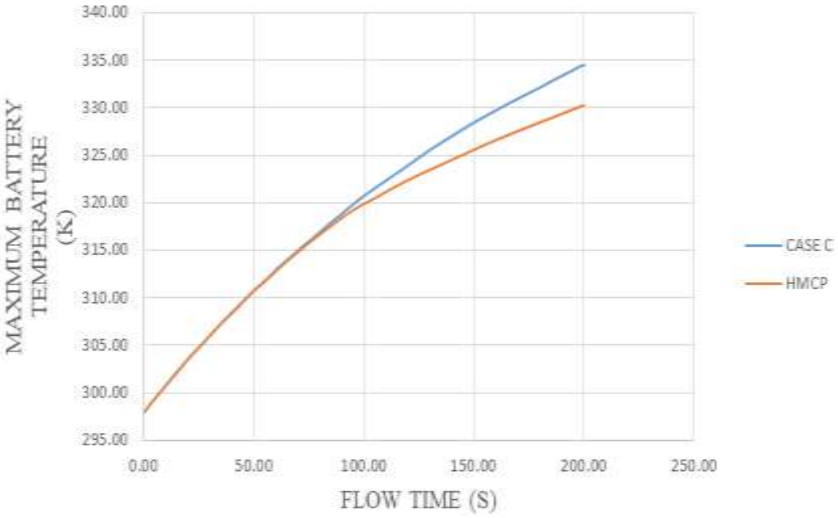


Variation of maximum battery temperature (K) with flow time for all prismatic

Configuration cases

From the graph above, it can be analyzed that the maximum battery temperature of the case c configuration of the prismatic battery has much better thermal performance than cases a and b. It can also be observed that at t = 200s, the maximum temperature of the battery in case c (334.47 K) is 12.2 K lower than case a (346.67 K).

COMPARISON OF HMCP & CASE C

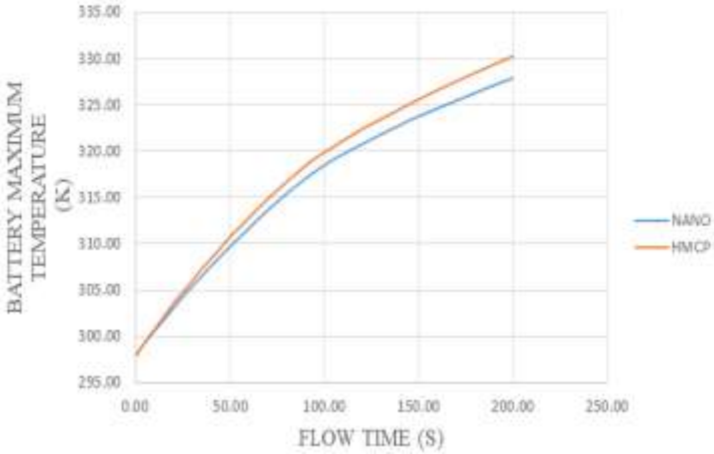


Variation in maximum battery temperature (K) with flowtime for

HMCP (water) and Case C- Prismatic Cell

It is observed that the HMCP and MCP both are performing similarly at the initial part of the flow time. The improvement starts only when the PCM starts melting which is at t = 65s. The difference between the maximum battery temperatures is maximum at t = 200s, the maximum temperature of the battery in HMCP (WATER) (330.26 K) is 4.2 K lower than case c (334.47 K).

COMPARISON OF WATER & NANO FLUID IN HMCP

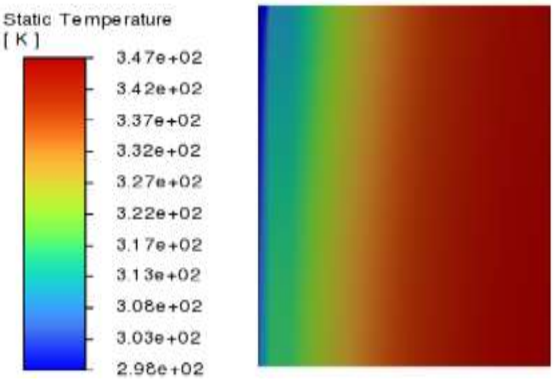


Variation in maximum battery temperature (K) with flowtime for

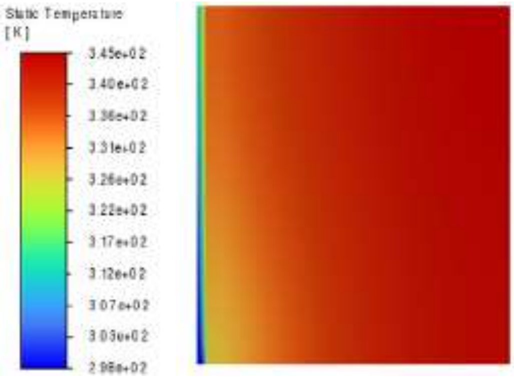
HMCP (water) and HMCP (nanofluid)

From the graph above, it can be analyzed that the maximum battery temperature of the HMCP (nanofluid) configuration of the prismatic battery has much better thermal performance than HMCP (water). It can also be observed that at t = 200s, the maximum temperature of the battery in HMCP (nanofluid) (327.88 K) is 2.4 K lower than HMCP (water) (330.26 K).

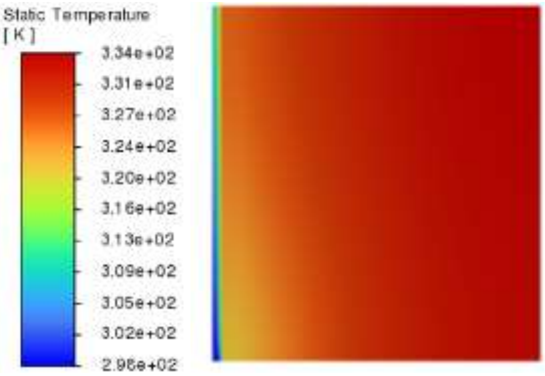
Temperature Contour



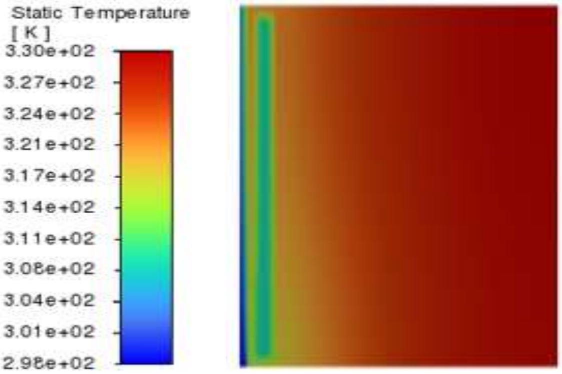
Case (a)



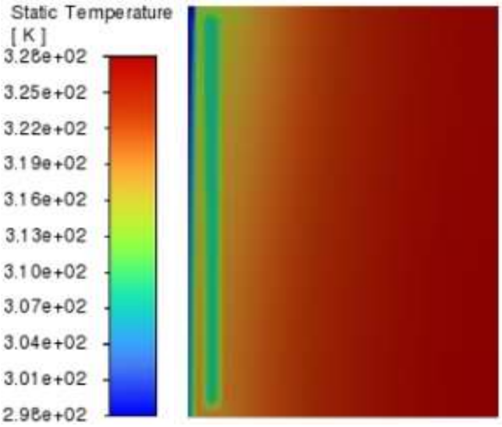
Case (b)



Case (c)



HMCP (WATER)



HMCP (nanofluid)

Figure 6: Temperature Contour

From the graph and the contours above, it is observed that the implementation of HMCP (nanofluid) is beneficial for the thermal performance of the battery since it provides a uniform temperature distribution compared to the others.

LIMITATIONS

In actual situations, the heat generation rate is not constant and varies due to factors like ambient temperature, cell chemistry, etc., which cause thermal fluctuations. The flowrate and velocity of the coolant through the mini-channels greatly influence the melting of the PCM.

Different EV manufacturers opt for different battery module structures, cell types, and cooling structures. Implementing PCM in all cases may not produce the same effect.

V. CONCLUSION

As a part of the study, the thermal performance of different battery structures with and without PCM and nanofluid was studied. The objective was to study the cooling performance improvement that is achieved by the implementation of PCM and nanofluid. The two main types of battery cells that are used in EVs right now are prismatic cells and cylindrical cells. While both have their own advantages and disadvantages based on various factors like cost, availability, charge and discharge rates, energy density, etc., a comparison between the two types of cells based on their thermal performance would turn out to be of no use. Hence, PCM was implemented to improve the cooling of the battery. The heat generation rates of the battery cells in all the studies were set at 400 kW/m3, and the initial conditions of the components and the inlet coolant temperature were set at 298K.

The initial part focused on understanding the different configurations of prismatic batteries and how each configuration was affected by temperature. Out of the three different configurations of the prismatic battery, it was found that case c (100mm x 70mm) had the best thermal performance compared to the other two. The maximum temperature attained in case c is much lower compared to the least efficient case a (70 mm x 100 mm). Temperature uniformity is poor in case a, and hence the edge of the battery in case a has a significantly higher temperature than the edge close to the cold plate. These variations in thermal performance between the configurations are caused by a few major reasons:

- The thermal conductivity of the battery in the through-plane configuration (case a) is significantly lower than that of the in-plane configuration (cases b and c).
- The coolant flow rate in cases a and c is 0.01 m/s, and in case b (180 mm x 100 mm), it is 0.0257 m/s.
- The number of cooling channels is higher in case c compared to case b.

The second part of the study was conducted to determine the cooling improvement of the HMCP structure over the MCP structure in the case of the prismatic battery. Case c configuration of the battery was used in this part as it provided the best thermal performance of all the three configurations, as concluded from the first part. The maximum temperature of the battery is lower in the HMCP (water) implemented battery. This performance improvement of HMCP (water) over MCP is visible only after the PCM starts melting. However, this performance improvement does not last the whole flow time. This is because once the PCM is completely melted, no more heat transfer is present in HMCP than in MCP. Hence, better cooling can be provided if the complete meltdown of the PCM can be prevented.

The third part of the study was conducted to determine the cooling improvement of the HMCP (nanofluid) over the HMCP (water) in the case of the prismatic battery. Case c configuration of the battery was used in this part as it provided the best thermal performance of all the three configurations, as concluded from the first part. The maximum temperature of the battery is lower in the HMCP (nanofluid) implemented battery. Hence, better cooling can be provided if the water is replaced with nanofluid.

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