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Numerical study of thermal cooling for Lithium-ion battery pack using phase change material

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Abstract. The objective of this study is to numerically investigate the battery thermal management of electric vehicles using phase change material. The lithium-ion batteries which are widely used in electric vehicles have an optimal operating temperature range from 25°C to 60°C, above which the battery does not operate effectively. There are various cooling methods such as active cooling method and passive cooling method. The present study is based on passive cooling method where the thermal performance of different phase change materials such as paraffin wax, extended graphene and capric acid are compared for different heat source intensities. The numerical simulation is performed using Ansys Fluent by considering the melting and solidification effects of the phase change materials. The investigation is performed by varying the thermo physical properties of the phase change materials and temperature of the battery packs. The results are analysed by plotting the temperature and velocity contours and the melting and heat transfer rates of different phase change materials are also compared. The results from the present study would be useful in identifying the ideal phase change material with improved thermal performance characteristics.

1. Introduction

There are non-renewable resources like petroleum, which are becoming limited for upcoming generations. So, the automotive industries are focusing on electric vehicles which are being developed using rechargeable batteries. Batteries such as lithium-ion are the most suited for storing energy source with electric vehicles comparing other rechargeable batteries. They are highly efficient in terms of their high-power density, long-self discharge rate, long life span, etc. Although, excess amount of heat when generated will lead to fire and explosion. So, it requires a thermal battery management system that is more effective. Where there are many systems which are being initiated in order to maintain the temperature of the battery.

Implementing phase change material is one of the passive thermal management systems which doesn't require more space, is less expensive and should reduce the heat generated by the battery for optimal performance. Here a device called rectangular that is generally to be known as passive cooling device that works out electronically is implemented mainly for Lithium ion batteries and it is well known that PCM changes from one state to another state at constant temperature during the phase of latent heat [1,2] .The phase change materials (PCM) are used for storing latent heat. It can change its state by absorbing or releasing the energy of latent heat without change in the temperature and a certain phase change, it stores the latent heat. In order to reduce the demand of electricity in building structures, PCM materials can be widely used. It is established that PCM can be emphasized with

many incorporation methods with statistical type of usage that enhance the performance of storage in building application. Here a new based technology is implemented that is hydrated in mainly cooling the lithium ion battery for majorly electric vehicle. The Trimethylolethane hydrate relates mainly with the fraction of mass and thermophysical state of properties [3,4]. There are many types of PCMs like organic and inorganic; Composite PCM's is stored in Phase changing material. Hence the PCM is most widely used in thermal management system with all range of the batteries such as Lithium-ion battery. The main motive of thermal management is to withstand in all range of operating condition suiting up with all environment aspects and the issues regarding the thermal management is also reviewed here such as overcoming over power consumption and mainly deals with maintaining optimum range of temperature with all condition of varying temperature [5].

Without depending on the additional power consumption, the temperature and control performance is based upon its superiority. Here an experiment setup such as heat pipe and a liquid spray is considered to execute the thermal management using materials such as phase change material. This phase change material combines to cool both at high and low temperature that renders to cool and heat the battery at various conditions [6]. Many phase change materials have been analysed using numerical techniques, as they provide accurate solutions to the hard problems. The thermal conductivity is one of the main influences which is responsible for the latent heat storage. There is different thickness of the battery that relates to study the effect of space between the batteries that are adjacent. The major part is the melting point and the thermal conductivity that insist on the cooling performance of PCM. It is to be known that thermal conductivity of phase change material is increased that relates with the result of maximum temperature difference [7]. So, the PCMs with high thermal conductivity are being chosen. In order to increase the thermal conductivity, PCM introduced literally. The composite which is the PCM, has more thermal conductivity which performed better than the other PCMs. In this paper we have chosen paraffin, graphene and a comparative study has been done using Ansys fluent. The optimized back propagation of network shows enhanced performance with the cooling and thermal management ranges in quality of the metamodel [8]. The cooling effectiveness has been enhanced by the current rates of the PCM. It comes to knows that lower melting temperature has better cooling effect compared to high melting point. Overcharging of phase change material with lumped model battery is mainly built here considering the thickness and rate of cooling efficiency that utilizes the PCM for better cooling at low melting temperature. Whereas the density of material relating with the latent heat that tends to be more superior at low temperature compared to high temperature which will result to contribute more understanding with the thermal management of PCM [9]. The hybrid system improves reliability with the PCMs on introducing forced air convention playing a separate role in thermal management. Most of the phase change material causes failure due to more heat accumulation and in order to overcome this condition, the forced air convection can be introduced which will increase the reliability of all range of PCM. It is mainly noted that active cooling plays a wide major role in thermal management of battery that also relates the temperature distribution with the phase change material [10].

2. Methodology
The chosen materials paraffin, graphene and capric acid are studied. The aim of this system is to maintain an optimum temperature through the lifecycle. Over the time and temperature, the rate of electrochemical reaction varies and how the current flows within the device. Nevertheless, they suffer from the effect of Goldilocks when the atmosphere is too hot or cold and they cannot function properly. The thermal runaway is another significant problem. The three materials are simulated under maximum working temperature and results are compared to obtain optimum material for thermal management for Li-ion batteries.

2.1 Governing equations
Heat transfer inside Liquid PCM is taking place by conduction. The Thermal conductivity is in orthotropic direction for the cells. The radiation in the process is neglected.

$$\frac{\partial(\rho H)}{\partial t} + \nabla.(\rho\vec{v}H) = \nabla.(k\nabla T) + S \tag{1}$$

Where, 'H' represents enthalpy, 'ρ' represents density, 'υ' represents velocity of the fluid, 'S' is the source term. The enthalpy is representing as 'H' calculated as the sum of sensible and latent heat.

$$H = h + \Delta H \tag{2}$$

Where 'h' represents sensible enthalpy at a point for a given time, 'ΔH' latent-heat.

$$h = h_{ref} + \int_{T_{ref}}^{T} C_p \, dT \tag{3}$$

where 'href' reference enthalpy, 'Tref' reference temperature & 'Cp' specific heat

$$\Delta H = \beta L \tag{4}$$

Where 'β' represents liquid fraction and 'L' is the latent heat of PCM.

$$\beta = 0 \qquad\qquad if \ T < T_{solidus}$$

$$\beta = 1 \qquad\qquad if \ T > T_{liquidus}$$

$$\beta = \frac{T - T_{solidus}}{T_{liquidus} - T_{solidus}} \qquad\qquad if \ T_{solidus} < T < T_{liquidus} \tag{5}$$

Where, $T_{solidus}$ and $T_{liquidus}$ are the properties of the material.

$$q = \frac{I}{V_b}\left[(E - U + \frac{\partial E}{\partial T}\right] \tag{6}$$

$$q = \frac{I}{V}\left[I^2(R_j + R_p) + IT\,\frac{\partial E}{\partial T}\right] \tag{7}$$

'q' represents heat generation rate / unit volume. R_j and R_p are ohm resistance and polarization resistance respectively.

2.2 Geometry and specifications
The Geometry consists of Battery and PCM block. For this analysis, Li-ion battery at the centre and is surrounded by phase change material. The length 'L' and breath 'B' of the surface is 100mm and battery size 'R' is 26mm. Geometry is shown in figure.1 below
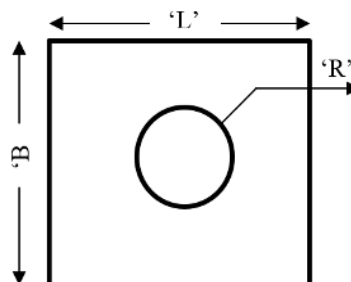
Figure 1. 2D representation of surface model

Interference mesh is given in the contact region which is between phase change material and battery. The quality of the mesh is fine when orthogonal quality and skewness ratio are checked. The phase change will happen when heat is absorbed i.e. from solid to liquid or liquid to solid. Because of its melting and solidifying capacity, they have the advantage of storing and releasing energy. Here capric acid, paraffin and paraffin with extended graphene about 10-25% is used as phase change material. The parameters are used to perform the simulation.

Table 1. Material properties of paraffin, graphene, capric acid.

Materials	Paraffin	Graphene	Capric acid
Density(kg/m3)	780	820	893
Cp (Specific-Heat) (J/kg-k)	2118	2042	2090
Thermal-Conductivity (w/m-k)	0.22	0.3	0.16
Solidus Temperature(k)	319	315	302
Liquid Temperature (k)	328	326	305

3. Results and Discussions

The figure 2 represents the temperature of the protection circuit module having the phase change material as Paraffin. The figure 4 represents the temperature of the protection circuit module having CPCM paraffin with graphene. The figure 6 represents the temperature of the protection circuit module having the phase change material as capric acid. The figure 3 represents the velocity contour of the protection circuit module having the phase change material as Paraffin. The figure 5 represents the velocity of the protection circuit module having CPCM paraffin with graphene. The figure 7 represents the velocity contour of the protection circuit module having the phase change material as capric acid. Graphical representation of temperature and velocity difference of paraffin, graphene, capric acid is shown Figure 8 and Figure 9 respectively. Accordingly, the results are obtained by keeping the x-axis 0.05 and varying y-axis which are shown in Table-2 and Table-3 represents the variation of temperature (K) and velocity (ms-1) of paraffin, graphene, capric acid.
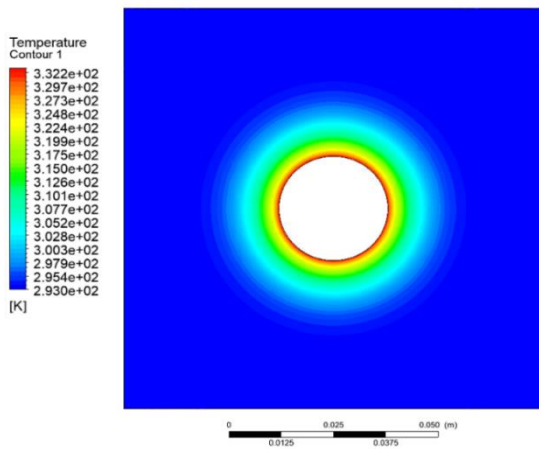
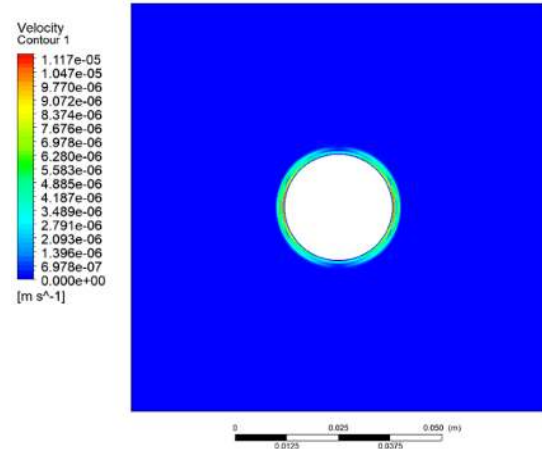**Figure 2.** Temperature contour for paraffin

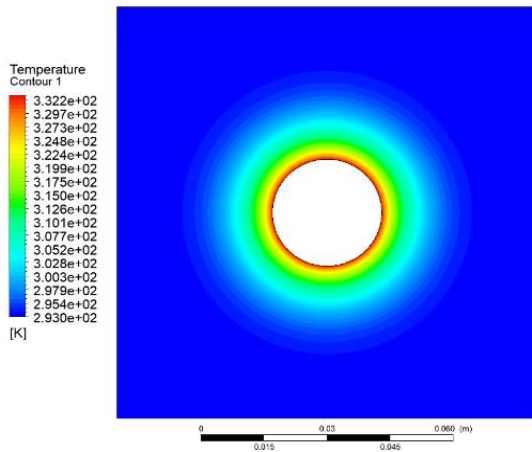**Figure 3.** Velocity contour for paraffin

Figure 4. Temperature contour for graphene
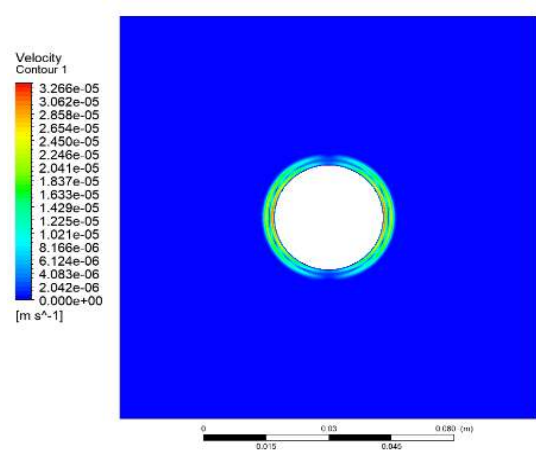

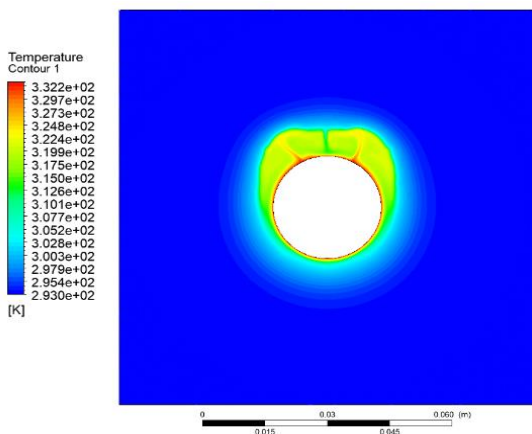**Figure 5.** Velocity contour for graphene

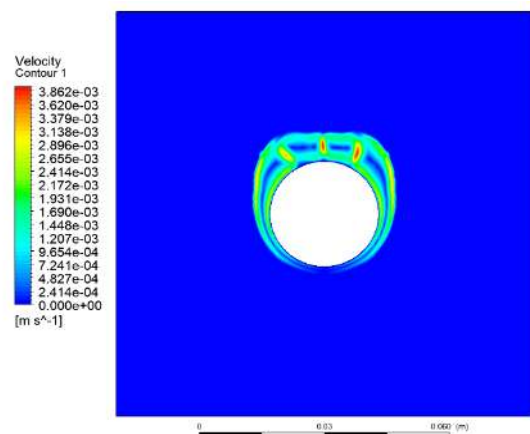**Figure 6.** Temperature contour for capric acid

Figure 7. Velocity contour for capric acid

Table 2. Variation of temperature (K) of paraffin, graphene, capric acid.

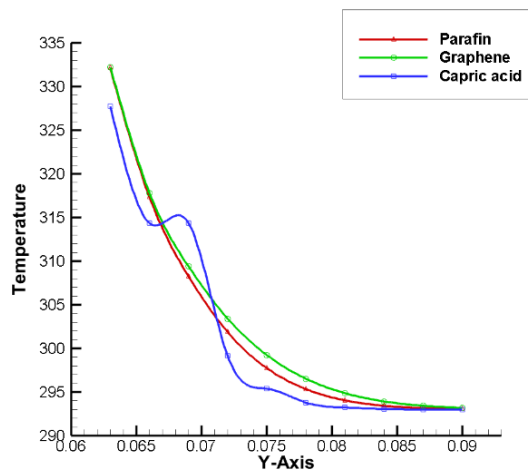| Y-Axis	Paraffin	Graphene	Capric acid
0.063	332.1	332.2	327.7
0.066	317.4	317.8	314.3
0.069	308.2	309.4	314.4
0.072	301.9	303.4	299.1
0.075	297.7	299.2	295.4
0.078	295.3	296.5	293.8
0.081	294.0	294.9	293.2
0.084	293.4	293.9	293.1
0.087	293.2	293.4	293.0
0.09	293.1	293.2	293.0

Figure 8. Graphically representation of temperature (K) difference
of paraffin, graphene, capric acid

Table 3. Variation of velocity (ms-1) of paraffin, graphene, capric acid

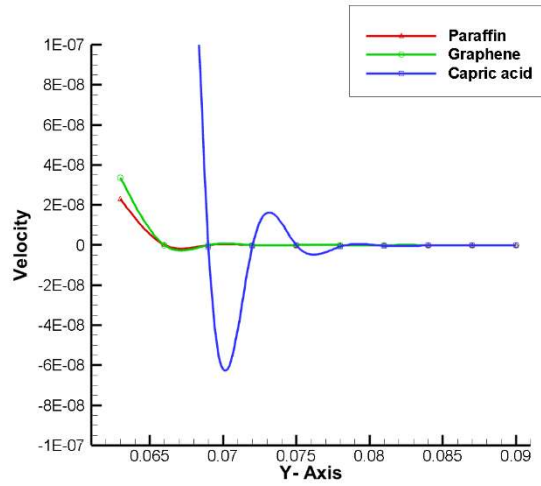| Y-Axis	Paraffin	Graphene	Capric acid
0.063	2.288E-08	3.353E-08	3.175E-07
0.066	2.640E-12	-2.720E-11	5.409E-07
0.069	-8.103E-12	-7.523E-12	-9.476E-10
0.072	-4.684E-12	-4.736E-12	-5.564E-10
0.075	-4.788E-12	-4.809E-12	-1.700E-10
0.078	-2.870E-12	-2.786E-12	-7.679E-10
0.081	-3.945E-12	-4.034E-12	-3.670E-10
0.084	-1.833E-12	-1.718E-12	-1.829E-10
0.087	-3.942E-12	-4.132E-12	-9.649E-11
0.09	-3.880E-12	-4.092E-12	-5.301E-11

Figure 9. Graphically representation of velocity (ms-1) difference of paraffin, graphene, capric acid
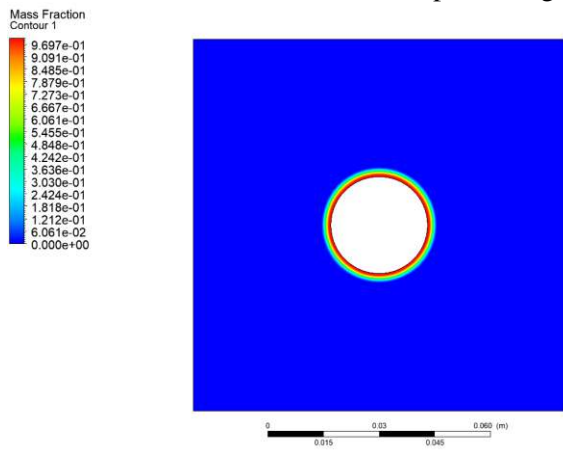

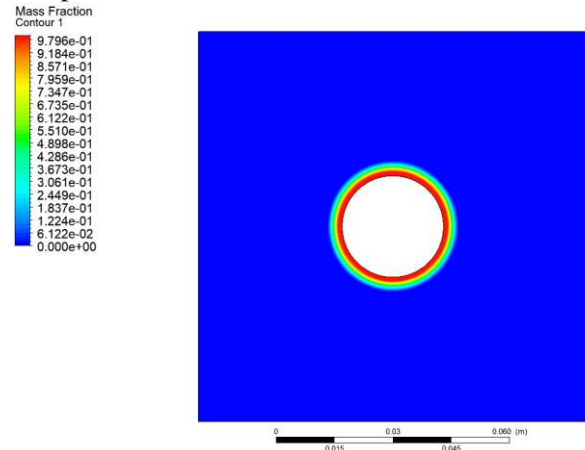**Figure 10** Mass fraction contour for paraffin

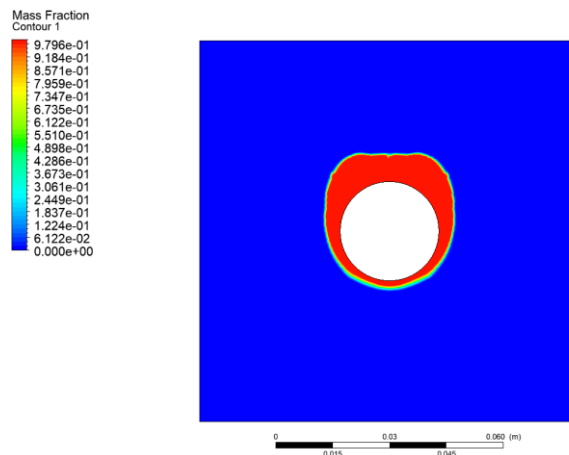**Figure 11.** Mass fraction contour for graphene

Figure 12. Mass fraction contour for capric acid

The figure 10 represents the mass fraction contour for paraffin. The mass fraction contour for graphene is shown in figure 11. The figure 12 shows the mass fraction contour for capric acid. The mass-weighted average liquid fraction for paraffin is 0.01414. The graphene has a mass-weighted average liquid fraction of about 0.02202. The net mass-weighted average liquid fraction for capric acid was around 0.05152.

4. Conclusion

From the above obtained results, we can see that capric acid has low melting and solidification temperatures and has less thermal efficiency compared to paraffin. The change in heat generation depends on both the discharge rate and the ambient condition. The composite phase changing material has performed well in reducing the temperature of the battery when compared the normal paraffin. One of the main reasons, CPCM has more thermal conductivity than paraffin and capric acid. It can also bring more uniformity in temperature reduction than paraffin and capric acid. So, the composite has more hopes for reducing temperature and maintaining uniformity of temperature in future. We can also see that the performance and efficiency of battery are also affected by the atmospheric conditions.

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