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Comparison of Thermal Battery Management of a Formula Electric Car Using Passive Cooling with and without a Phase Change Material

Rafat Safayet,Md. Kawser Ahmmed, A.T.M Naser Nahedi Ador, Iftekhar Anam*
Department of Mechanical Engineering, Rajshahi University of Engineering and Technology, Rajshahi-6204, BANGLADESH

ABSTRACT
As charging and discharging state of a battery pack causes electrochemical reaction which give rise to excessive heat resulting in thermal runaway. The performance of an electric vehicle on a great extends depends on the temperature of the battery pack and a nominal temperature reduces the chance of accident and increases the efficiency of the car. In this paper a modelling and simulation of a cylindrical Lithium-ion battery pack, PCM, passive cooling is performed. The objective of the study is to control the temperature of the battery pack by forced convection and phase change material, and a comparison study of both methods. The battery pack is simulated using simulation software and the different temperature of the pack while charging and discharging was presented. The method used for the cell model is lumped battery interface and the thermal model used is modeled using electrochemical heating multiphysics coupling mode the software used is Comsol Multiphysics. Computational fluid dynamics analysis was carried out to investigate the performance of passive cooling with and without PCM. The temperature of the battery pack for both case is within the limit. The passive cooling without PCM method is more efficient. On the other hand, the passive cooling is cheap and it also gives a favorable result. The result was computed using numerical computation method but in the real life experiment there might be a slight change in the parameters but the result is satisfactory.

Keywords: Thermal Management, Phase change material, Passive cooling, Battery pack, Simulation

1.Introduction

Formula SAE (Society of Automotive Engineers) is an international competition, which focuses on the design of the formula style cars. Electric car is a part of the competition. The lithium ion cell is allowed to be used for the car [1]. For an electric car to get a good performance and power backup, a perfect energy system is necessary [2-3]. The first general thermal heat model was developed by Barnati et al [4]. In this model the heat was generated due to joule heating, electrochemical reaction, phase change heat and heat of mixing. It was also stated in the paper that temperature of the battery effects the performance, life cycle and safety of the lithium ion battery. To maintain the temperature of the battery suitable thermal management system is necessary [5]. In the table mentioned below shows the capacity fade percentage depends on the temperature.

Table 1 Capacity fade on different temperature [6].

Battery cathode/anode	Temperature (ºC)	Capacity fade (%)
C/LiCoO2C	21	9
O	45	13
C/LiMnO4	21	28

The important feature of a battery thermal management system is to maintain the temperature of the battery pack [7]. There are many ways to cool the battery pack among them air cooling, liquid cooling and PCM cooling [8]. The electric vehicle is designed for the tropical climate condition, so heating is not considered. The Battery thermal management system using air cooling is applied in many EV and HEV, which results in good efficiency along with minimum cost and maintenance [9]. PCM along with forced convection is used a lot nowadays for BTMS of lithium ion battery [10].

In this paper, simulation of a battery pack with forced convection and forced convection with phase change material is presented. The difference of the two method is represented for a formula student electric vehicle.

2. Model for CFD study

The software that is used for the simulation of the battery pack is Comsol Multiphysics 5.3a. The model that is used for the simulations are transient, convection, conduction and laminar flow. For the PCM material the material is selected as paraffin and for the batteries the material is copper.

3. Governing equation

The conduction equation is used for solving the battery model. Eq(1) and Eq(2) represents the conduction equation.

$$\rho\ (u.\nabla)u = \nabla.\ [-pI+K]+F+\rho g \tag{1}$$

$$\nabla.\ (\rho u) = 0 \tag{2}$$

For the heat transfer from the battery to the air the equation that is used is convection. In case of PCM the same Eq (3) (4) is used. Eq (3) and (4) is used to solve the convection heat transfer. It is also known as multiphysics coupling equation.

* Corresponding author. Tel.: +88-01724632832
E-mail addresses: rafat1165052@gmail.com

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u. \nabla T + \nabla. q = Q + Q_{ted} \quad (3)$$

$$q = -k. \nabla T \quad (4)$$

The air flow model was modeled using Eq (5) (4). Eq (5) is used for laminar flow. It is also known as the multiphysics coupling equation, without the temperature change with respect to time and thermoelastic damping.

$$\rho C_p u \,.\,. \nabla T + . \nabla .q = Q \quad (5)$$

Cp and ρ is constant.

$$q = \varepsilon(G - e_b(T)) \quad (6)$$

Eq (6) is the radiation equation used heat transfer from PCM to air. Here emissivity was taken as 0.9. G is irradiation, $e_b(T)$ is the power irradiated across all wavelength.

4.CAD model of the battery pack

The CAD model of the battery pack was done with Solidworks 2020 CAD software. Fig (1) is the model of the battery pack without PCM and Fig (2) is the model of the battery pack with PCM. Table (2) is the dimension of the battery pack which contain and the PCM.

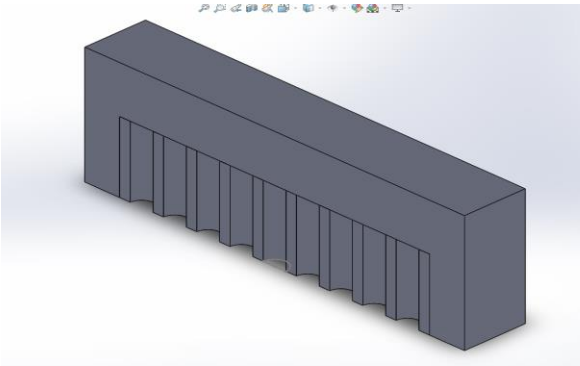


Fig.1 Model of battery pack without PCM.

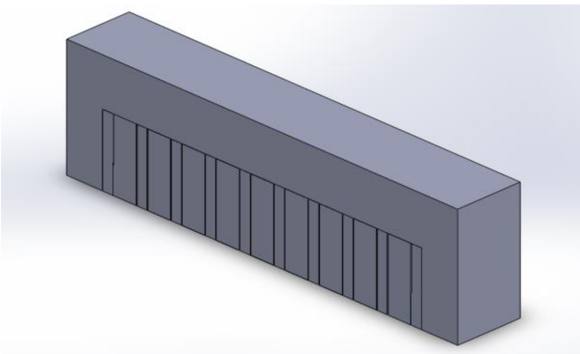


Fig.2 Model of battery pack with PCM.

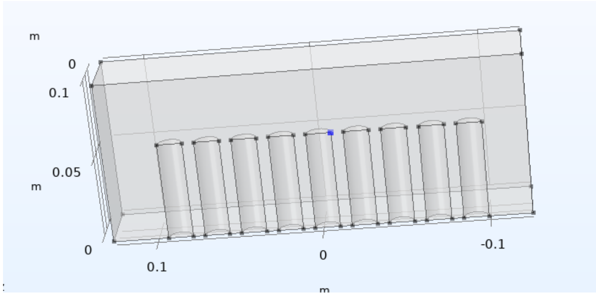


Fig.3 Point selection for boundary

Table 2 Dimension of the CAD model

	Height (mm)	Width (mm)	Length (mm)	Diameter (mm)
Battery	60	-	-	15
Enclosure	100	40	250	-
PCM		12.86	204.02	

The battery CAD model was finalized for simulation.

4.Methodology of CFD study

1. The model was set in Comsol Multiphysics software. Transient, conduction, convection 3d model was selected.
2.The geometry was imported from Solidworks.
3.Mesh was generated. The default mesh option was selected for mesh. Fig (4) shows the mesh of the geometry and Table (3) shows the quality of the mesh of both model.

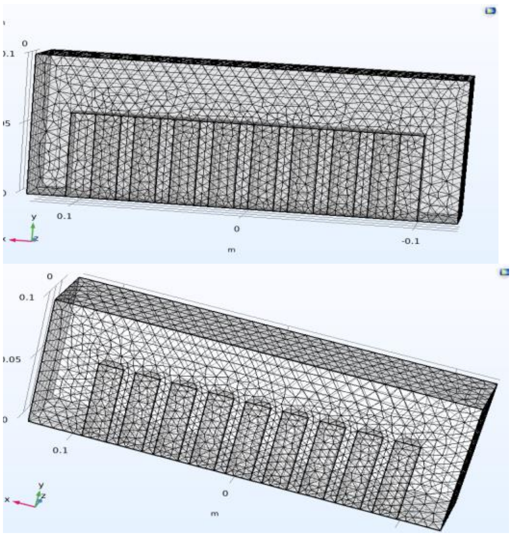


Fig.4 Mesh for Geometries.

Table 3 Mesh quality

Mesh	Number of elements	Average element quality	Mesh Volume (m^3)
Without PCM	33328	.6666	.001
With PCM	32189	.6609	1.574

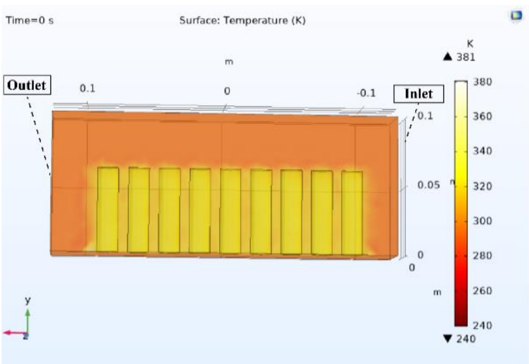
4.The boundary condition was set for the conduction in the battery model. The inlet boundary condition for the forced convection is velocity inlet and the outlet was set to be pressure outlet. Laminar flow was set for the air flow. The convection boundary condition was set between the battery and wall. Fig (3) shows the point selection for the boundaries.

5. For the phase change material, the density of the solid and liquid phase was kept constant, 800 kg/m^3. The phase change temperature from phase 1 to phase 2 was set to be 308K. The transition interval between the phase is set to 1K, latent heat was set to 125000 j/kg. Heat was conducted from the battery to the PCM through conduction Eq (1) (2) was used. For the outside boundary heat was conducted through convection and radiation. Eq (3) (4) and (6) was used for the outside boundary. The surface emissivity (ε) was set to 0.9.

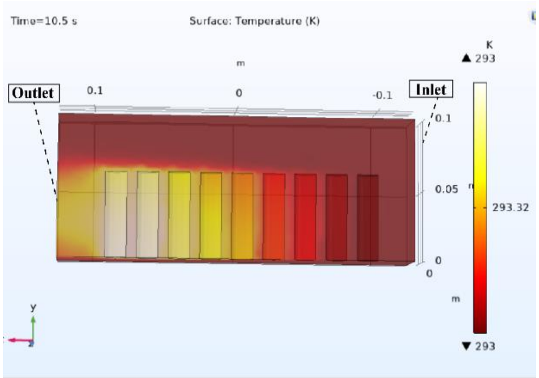
5. The model was initialized using the inlet boundary.

5. Result and Discussion

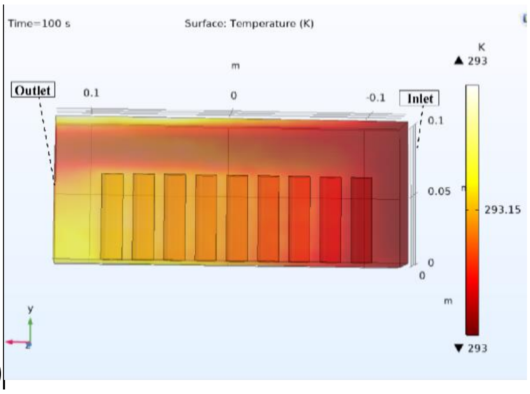
Simulation of both the model showed in Fig (4) and Fig (5) represent the temperature degradation of the models while cooling. In Fig (4) the temperature in the inlet is low rather than the outlet as the air is entering from the inlet. The PCM model along with forced convection shows different simulation.



(a)

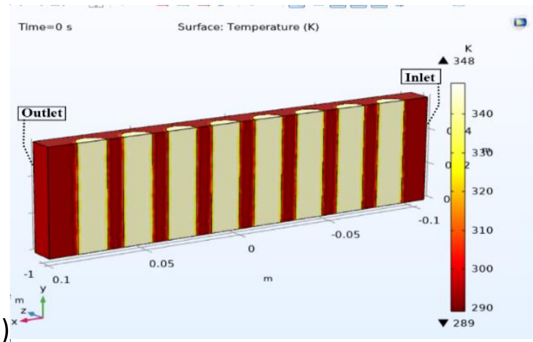


(b)

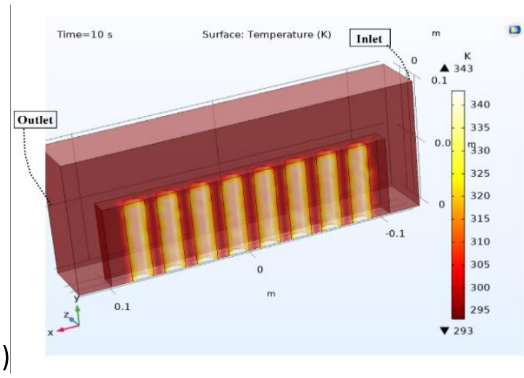


(c)

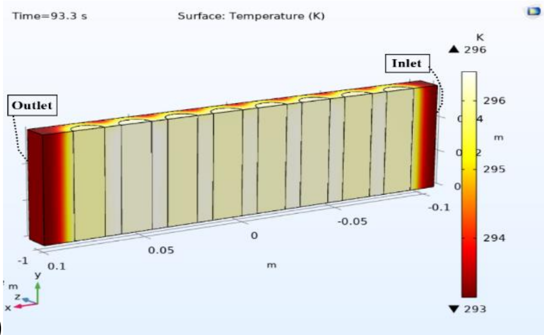
Fig.5 Simulation model without PCM (a) at 0s (b) at 10.5s (c) at 100s



(a)



(b)



(c)

Fig.6 Simulation model with PCM (a) at 0s (b) at 10s (c) at 93.

The two models show two different results on the same material and boundary condition selected for the battery. The simulation model on Fig (5) shows that the highest temperature of the battery was 380 K, for forced convection it came down to 293 K after 100 s. The PCM model in Fig (6), the PCM structure surrounding the model was considered. It is seen that the temperature at the beginning of the simulation was 340 K surrounding the battery, after the forced convection at 93.3 s the temperature cooled down to 296 K.

The velocity magnitude of both the model is presented in Fig (7) the velocity for both the model was same, the velocity was constant at 3.84 m/s.

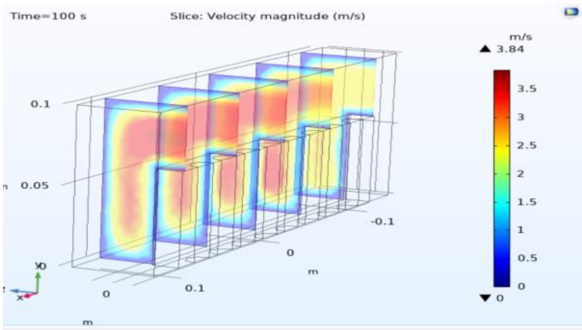


Fig.7 Velocity magnitude of fluid

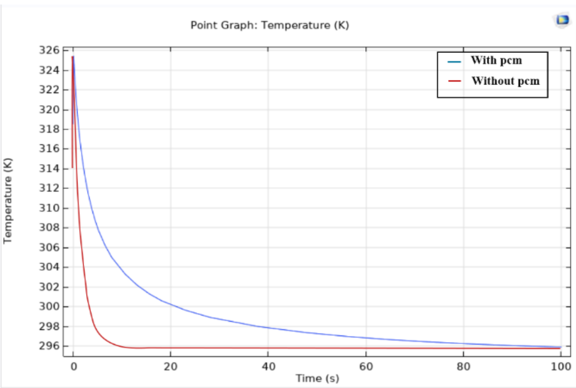


Fig.8 Graph for Forced convection with and without PCM

The two, time vs temperature graph shows different result. The graph in Fig (8) shows that the model, forced convection without PCM shows better result. Temperature comes to steady state after 10 s. for PCM model the temperature comes to steady state after 80 seconds. For battery pack in formula electric vehicle better cooling is necessary. The simulation shows that The two, time vs temperature graph shows different result. The graph in Fig (8) shows that the model, forced convection without PCM shows better result. Temperature comes to steady state after 10 s. for PCM model the temperature comes to steady state after 80 seconds. For battery pack in formula electric vehicle better cooling is necessary. The simulation shows that the model with forced convection without PCM represents good result, then the model with PCM.

Conclusion

Battery pack simulation with forced convection without the PCM shows better result. For electric car cost is a huge factor, forced convection is easy to design with small fan. So, the model without the PCM can be a good choice for a formula electric car. The Phase change materials are expensive and as it doesn't show prominent result it is better not to use the PCM model.

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NOMENCLATURE

C_p : specific heat at constant pressure, $kJ\cdot kg^{-1}\cdot K^{-1}$

F : Force, N

q : Heat flux, kJ

ρ : Density, kg/m^3

p : Pressure, kpa

T : temperature, K

u : velocity, $m.s^{-1}$

g : acceleration due to gravity, $m.s^{-2}$

k : thermal conductivity, $W.m^{-1}.k^{-1}$

Q_{ted} : Thermoelastic damping, W/m^3