BATTERY THERMAL MANAGEMENT USING FINS IN PCM (PHASE CHANGE MATERIAL)

Gajji Naresh, Kakarla Vidya Sagar, Lankala Sethuram Reddy, Eluri Nikhil Reddy, Nalamalapu Subba Reddy, Minesh Vohra
School of Mechanical Engineering
Lovely Professional University, Phagwara, Punjab, India.

ABSTRACT:

In Battery Thermal Management Systems generally the melting of the phase change material became a defiance and leading to a major confrontation for the constant heat dissipation throughout the battery thermal management system due to very low thermal conductivity of the Phase Change Material. Consequently, the hexagonal shaped fins are introduced in this paper and the research work is carried out. The Battery Thermal Management Systems with the hexagonal fin structure plunged into the Phase Change Material is compared with the Battery Thermal Management Systems without any branched or fin structure induced into the Phase Change Material. The results exemplifies that the battery thermal management system where the hexagonal fins immersed into the phase change material exhibits the superior heat transfer and melting rates of the phase change material compared to the convectional Battery Thermal Management Systems which contains the Phase Change Material but with the inaccessibility of the fin structure. In this paper, the Battery Thermal Management System with four hexagonal (honeycomb) structured longitudinal fins are provided at the axis of every 90° around the battery to maximize the surface contact area of the hexagonal fin, improving the exposure of the surface of the fin to the phase change material to generate the instant and maximized heat flow throughout the phase change material compared to the longitudinal rectangular and V-shaped fin structures. The main theme of the hexagonal shaped longitudinal fin is to provide a robust heat dissipation which proportionately inflate and strengthen the battery life, life cycle and superintend the high-density charge output during the battery discharge.

Index-terms: Battery Thermal Management System, Phase Change Material, Fins, Battery Module.

1. INTRODUCTION:

Contemporarily the automobile industry is strenuously commutating its technology from the internal combustion engines to the Battery Electric Vehicle and Hybrid Electric Vehicle Technology. The primary reason is to neutralize the production of green house gases like carbon dioxide, Nitrous oxides and fluorinated gases. On the other hand, the availability of the fossil fuels are drastically decreasing over time. In electric vehicles, lead-acid batteries, nickel-metal hydride batteries and lithium-ion batteries are usually considered to be fitted into their battery packs. But especially the lithium-ion batteries are a standard option for the most modern electric vehicles. Also, many of the giant automotive manufacturers are studious towards the performance and persistence. While in comparison of lithium-ion batteries to all other batteries like lead-acid batteries and nickel-metal hydride batteries, the lithium-based batteries or cells can underpin many advantages. The prerequisite of the lithium-ion battery is its exceptional energy density and specific energy makes the battery much suitable for EV’s. The self-discharge rate of the lithium-ion battery is considered to be 5% in 24 hours, then 1-2% per month, additionally a 3% drain is considered for the safety circuits, which makes it even more accessible for its preference.

However, there are some major setbacks for the electric vehicles too, where the major stumbling blocks are driving range, charging infrastructure and time. Also, there are concerns of lithium-ion battery with reference to overcharging and over heating due to some voltage fluctuations during charging and discharging of the battery and might end up blowing the battery module or leaving the battery dead and uncharged.

To encounter these types of hazardous and cost surging situations the research works are being carried out for the most suitable PCM’s with higher heat absorbing capability materials (Paraffin wax, Methyl-silyl dine, and ethylene glycol) along the side of the shapes of fins like longitudinal rectangular shaped, V-shaped, Y-shaped and X-shaped fins are introduced into the Battery Thermal Management System [1], the composite PCM-fin structure is also reviewed for showing condescending performance compared to the fin less Battery Thermal Management System and pure Phase Change Material systems [2]. Consequently, these developments show the remarkable changes to enhance the heat transfer rates to the Phase Change Material.

There is a notable transpose in this research work by using the hexagonal shaped longitudinal fins throughout the cell instead of the convectional rectangular shaped fins and designed accordingly for pcm and its properties to be assimilated into the Battery Thermal Management System for obtaining the greater heat transfer efficiency and melting rate of PCM under various circumstances. The simulation setup consists of a battery, fins and a container tube which is used to hold battery, PCM and fins inside it, also called as housing. Generally, most experiments and simulations are performed usually at room temperatures but...
based on the battery working conditions, ambient temperature the battery performance could significantly vary, and the boundary conditions are stuck to enhance the optimal battery working area.

2. LITERATURE REVIEW:

During the Past years, there are many experimental and simulation studies are conducted on Battery Thermal Management System (BTMS). Most of the researchers tried to make the battery cooling more efficient with low cost and feasible. Coming to the technical aspect of battery cooling, water cooling is the best way to cool a battery. But it requires a lot of extra energy to run the pump and other peripherals which in turn expensive to maintain and afford. So from 2010 research started on PCM to cool the batteries and in fact it worked. But PCM too has its own limitations that thermal conductivity of PCM is not good. So lot of work has been done on PCM by inserting different fin structures inside them and also some recent research also started using PCM composites like carbon fibre, Metal foam, expanded Graphite, copper Mesh, etc to improve the thermal conductivity of PCM which in turn helps to cool the Batteries. Finally, this study is going to improve the existing design by inserting Hexagonal fins inside the PCM to further increase the cooling rate of batteries and to maintain the uniformity of temperature inside battery modules. This study is based on simulation which is more feasible and affordable.

2.1. SIMULATION SETUP:

![Image 1: Top view of battery cell with dimensions](image1.png)
![Image 2: Side view](image2.png)
![Image 3: Vertical view](image3.png)
![Image 4: Isometric view](image4.png)

**Description of BTMS:**

The simulation setup is comprised with the Battery Thermal Management System and it consists of four major components, they are: Battery, Fins, Housing and Phase Change Material.

The battery is situated at the center of the Battery Thermal Management System considering the height as 65 mm while the diameter is 26 mm and the battery is muffled with the fin structure ring with the thickness of 1 mm and there are four hexagonally shaped longitudinal fins are found around the battery. The side of hexagonal fin is assumed to be having a length of 10 mm. The housing of BTMS is the foremost component for holding Phase Change Material, battery and fins where the geometrical dimensions are taken as 75 mm in height and having a diameter of 43 mm and the thickness is considered as 2 mm.
The Phase Change Material used in the BTMS is methyl-silylidine (SiCH3), the PCM is stipulated especially for this BTMS for various properties by prioritizing the most common properties like melting temperatures and density variations at various temperature zones.

Simulation Process:

The simulation process in the Ansys especially consist of four steps, they are: Geometry, Meshing, Setup and Solution. All of the processes are explained in detail in the following process steps:

Geometry:

The geometry of the Battery thermal management system is primarily designed in Creo parametric 3D modeling software. Then the design geometry is imported to the Ansys for the simulation purpose.

Meshing:

The meshing is the process of disintegrating the geometry into simple elements from a large integrated model to perform the calculations and obtain the results from finite element analysis.
Mesh Statistics:

<table>
<thead>
<tr>
<th></th>
<th>Without Fin</th>
<th>With Fin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes</td>
<td>72765</td>
<td>70380</td>
</tr>
<tr>
<td>Elements</td>
<td>68850</td>
<td>66850</td>
</tr>
</tbody>
</table>

**Setup:** During the setup, the required information for the simulation and analysis is given as input through the interface such as temperatures, specific heat capacities and density, etc.

**Solution:** The solution of the given setup is calculated by the Ansys simulation tool using the Finite Element Analysis (FAE), and the results are taken out.

### 2.2. BOUNDARY CONDITIONS:

Thermo-physical properties of Copper:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>8.94 Mg/m³</td>
</tr>
<tr>
<td>Melting point</td>
<td>1355 K</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>388 J/Kg-K</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>370 W/m.K</td>
</tr>
</tbody>
</table>

Thermo-physical properties of PCM: (Methyl-silylidine)

During the Battery working condition the phase change material behavior constantly changes with respective to the time and temperature. For generating the most effective values the Density, Specific heat and thermal conductivity values are taken as variables to achieve the efficiency of fin used in Battery Thermal Management System.

<table>
<thead>
<tr>
<th>Point</th>
<th>Temperature (K)</th>
<th>Density (Kg/m³)</th>
<th>Specific heat (J/Kg-K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>1945.628</td>
<td>1486.499</td>
</tr>
<tr>
<td>2</td>
<td>550</td>
<td>1913.828</td>
<td>1495.089</td>
</tr>
<tr>
<td>3</td>
<td>600</td>
<td>1882.028</td>
<td>1503.679</td>
</tr>
<tr>
<td>4</td>
<td>650</td>
<td>1850.228</td>
<td>1512.269</td>
</tr>
<tr>
<td>5</td>
<td>700</td>
<td>1818.428</td>
<td>1520.859</td>
</tr>
<tr>
<td>6</td>
<td>750</td>
<td>1786.628</td>
<td>1529.449</td>
</tr>
<tr>
<td>7</td>
<td>800</td>
<td>1754.828</td>
<td>1538.039</td>
</tr>
<tr>
<td>8</td>
<td>850</td>
<td>1723.028</td>
<td>1546.629</td>
</tr>
<tr>
<td>9</td>
<td>900</td>
<td>1691.228</td>
<td>1555.219</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Point</th>
<th>Temperature (K)</th>
<th>Value (W/m.K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>0.486300</td>
</tr>
<tr>
<td>2</td>
<td>550</td>
<td>0.496126</td>
</tr>
<tr>
<td>3</td>
<td>600</td>
<td>0.505896</td>
</tr>
<tr>
<td>4</td>
<td>650</td>
<td>0.515660</td>
</tr>
<tr>
<td>5</td>
<td>700</td>
<td>0.525436</td>
</tr>
<tr>
<td>6</td>
<td>750</td>
<td>0.535206</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>0.001372 (Kg/m-s)</td>
</tr>
<tr>
<td>Pure solvent melting heat</td>
<td>161000 J/Kg</td>
</tr>
<tr>
<td>Solidus Temperature</td>
<td>494 K</td>
</tr>
<tr>
<td>Liquidous Temperature</td>
<td>511 K</td>
</tr>
</tbody>
</table>
3. RESULTS & DISCUSSION:

fig 11: Graph for PCM melt fraction with respect to time.

Battery cell without Hexagonal fins:

Fig 10 shows that the battery cell without fins will not help to maintain the temperature of the battery cell. As discussed earlier, PCM has low thermal conductivity, so it can’t transfer heat to the surroundings when PCM observes heat it changes to liquid phase from solid phase. The most important property from PCM to reduce the temperature of the battery is PCM melt fraction. The PCM melt fraction should be high to keep the battery temperature in check. So battery cell without fins will take longer time to melt the PCM which is not desirable for BTMS. The fig shows melt fraction of 0.45 at 25 mins of time. From this a passive battery cell must requires fins embedded in PCM.

Battery cell with Hexagonal fins:

Fig 10 shows that the battery cell with fins helps to maintain the temperature of the battery in control. Metals are good conductors of heat and electricity. Fins are made from metal. In this case copper fins are used to enhance the heat transfer capability. The heat observed from the PCM will transfer to the fins. This fins transfer heat to the surroundings. Fins also helps to improve the mechanical properties of the battery cell. Strong and sturdy battery is must in mobility in terms of safety and performance. Fig 10 shows the melt fraction of 0.6 at 25 mins of time. This values shows that fins inside battery will further improve the heat transfer capability compared to battery cell without fins. The hexagonal fins used in this study are proven to be show good results in BTMS.

4. CONCLUSION AND FUTURE SCOPE:

In this research work the melting fraction of the Phase Change Material is enhanced through the introduction of the hexagonal shaped fins immersed into the pcm for obtaining the better results. The following conclusions are made in terms for achieving the efficiency of Battery Thermal Management System:

1. The proposed fin structure i.e., hexagonal shaped fins are provided at each 90-degree angle to optimize the heat flow and PCM melting fraction.
2. If the number of fins is increased inside the Battery Thermal Management System, then the effective heat dissipation for the PCM gradually decreases due to the suffocation of Phase Change Material to flow in between fins due to the viscous nature of PCM.
3. The PCM-fin structure used in this research work carried out the results of showing much superior thermal performance compared to the general battery with non-accessible fins or PCM systems only.

Future Design Enhancements:

The research and optimization techniques of the battery could never shorten in the future because of the dependency on thermal management of batteries due to the primary source of plump for the transformation of internal combustion engines to battery electric vehicles. The use of Aluminium Nitride for the solid fins structure could have also serve the same heat transfer rates but manifests many advantages including high thermal conductivity, low electrical conductivity and up to 15 percent of weight saving on the whole battery pack and battery module design. The lower electrical conductivity rate could help the system to terminate the electrical shocks and short circuiting of the battery, which in terms can generate the high electrical impedance.
The usage of hollow hexagonal fin structure with dispensing multi-domain Phase Change Material, one type of PCM inside the hexagonal fins with the higher melting rate and another PCM with different properties could help the BTMS with greater efficiency and sophisticated design and also a cost-cutting factor while choosing the secondary PCM.

REFERENCES:


