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 through out 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 commuting 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.

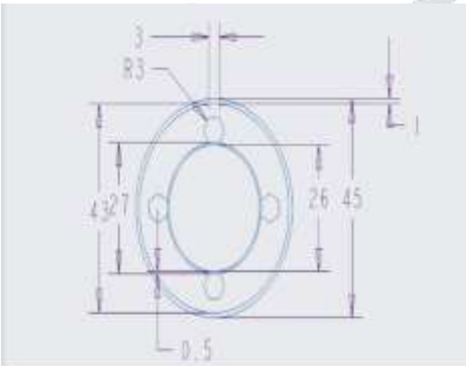
To encounter these types of hazardous and cost surging situations the research works are being carried out for the most suitable PCM's with higher heat absorbing capability materials (Paraffin wax, Methyl-silyl dine, and ethylene glycol) along the side of the shapes of fins like longitudinal rectangular 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 sticked 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 inturn expensive to maintain and afford.So from 2010 research started on PCM to cool the batteries and infact 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 tempertature inside battery modules.This study is based on simulation which is more feasible and affordable.

2.1. SIMULATION SETUP:



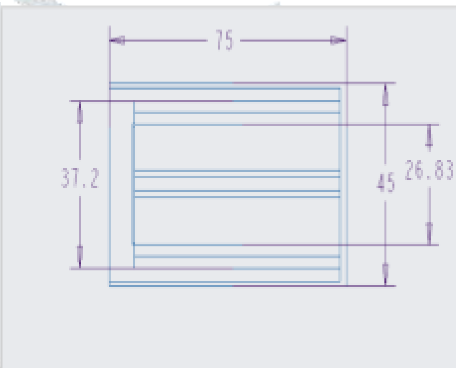


fig1:top view of battery cell with dimensions fig2:side view

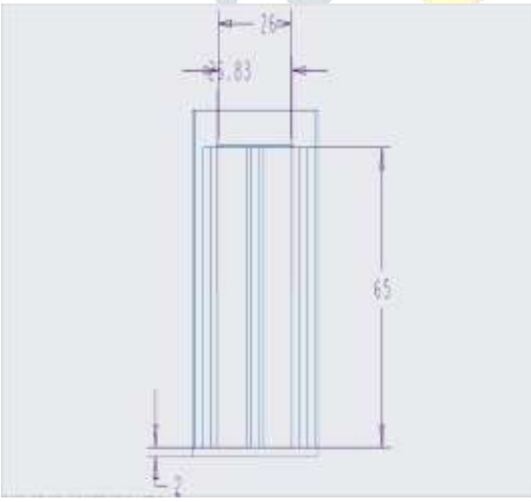


fig3:vertical view

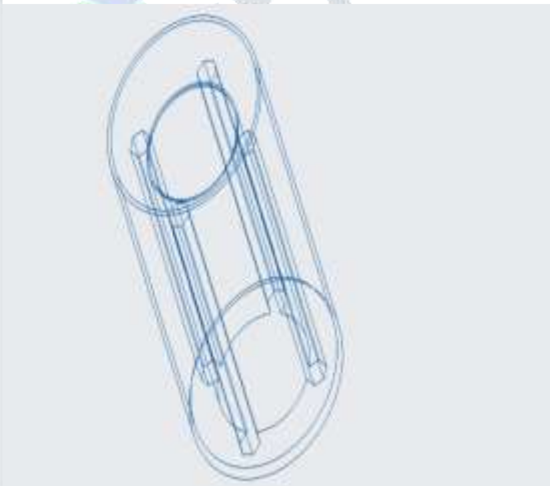


fig4:isometric view

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 1mm 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 10mm. The housing of BTMS is the foremost component for holding Phase Change Material, battery and fins where the geometrical dimensions are taken as 75mm in height and having a diameter of 43 mm and the thickness is considered as 2mm.

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:

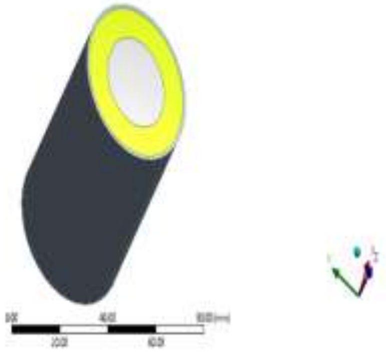


fig 5:BTMS without fins fig 6:BTMS with fins

The geometry of 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:

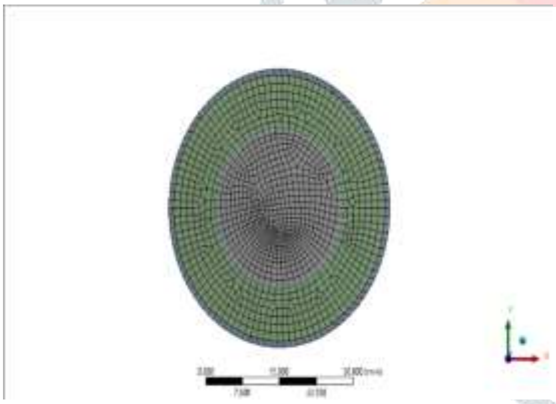


fig 7:Meshing top view without fins

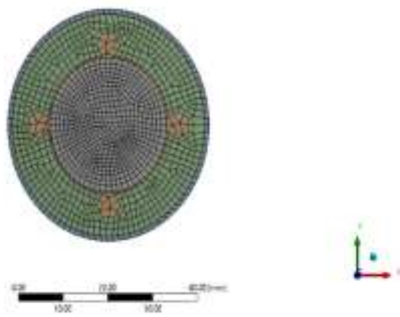


fig 8:Meshing top view with fins

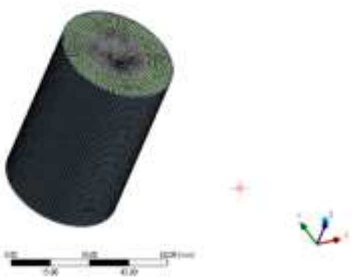


fig 9:Meshing for BTMS with non-accessable fin structure

fig 10:Meshing for BTMS with accessable fin structure

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:

	Without Fin	With Fin
Nodes:	72765	70380
Elements:	68850	66850

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:

Density	8.94 Mg/m^3
Melting point	1355 K
Specific Heat	388 J/Kg-K
Thermal Conductivity:	370 W/m.K

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.

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

Point	Temperature (K)	Value (W/m.k)
1	500	0.486300
2	550	0.496126
3	600	0.505896
4	650	0.515660
5	700	0.525436
6	750	0.535206

Property	Value
Viscosity	0.001372 (Kg/m-s)
Pure solvent melting heat	161000 J/Kg
Solidus Temperature	494 K
Liquidous Temperature	511 K

3. RESULTS & DISCUSSION:

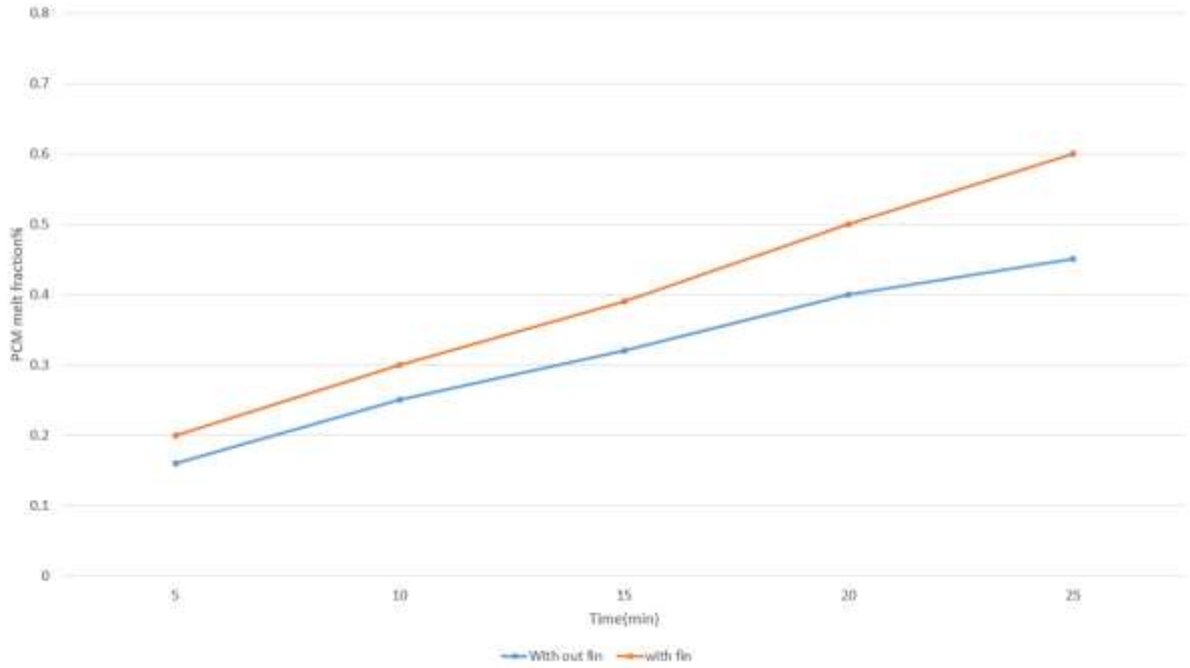


fig 11:Graph for PCM melt fraction with respect to time.

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.fig10shows 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:

1. Wu, Weixiong & Yang, Xiaoqing & Zhang, Guoqing & Ke, Xiufang & Wang, Ziyuan & Situ, Wenfu & Li, Xinxi & Zhang, Jiangyun. (2016). An experimental study of thermal management system using copper mesh-enhanced composite phase change materials for power battery pack. Energy. 113. 909-916. 10.1016/j.energy.2016.07.119.
2. Weng, Jingwen & Yang, Xiaoqing & Zhang, Guoqing & Ouyang, Dongxu & Chen, Mingyi & Wang, Jian. (2019). Optimization of the detailed factors in a phase-change-material module for battery thermal management. International Journal of Heat and Mass Transfer. 138. 126-134. 10.1016/j.ijheatmasstransfer.2019.04.050.
3. Xu, Xiaoming & Tong, Guangyao & Li, Renzheng. (2019). Numerical study and optimizing on cold plate splitter for lithium battery thermal management system. Applied Thermal Engineering. 167. 114787. 10.1016/j.applthermaleng.2019.114787.
4. Weng, Jingwen & Ouyang, Dongxu & Yang, Xiaoqing & Chen, Mingyi & Zhang, Guoqing & Wang, Jian. (2019). Optimization of the internal fin in a phase-change-material module for battery thermal management. Applied Thermal Engineering. 167. 114698. 10.1016/j.applthermaleng.2019.114698.
5. Sun, Zhiqiang & Fan, Ruijin & Yan, Fang & Zhou, Tian & Zheng, Nianben. (2019). Thermal management of the lithium-ion battery by the composite PCM-Fin structures. International Journal of Heat and Mass Transfer. 145. 118739. 10.1016/j.ijheatmasstransfer.2019.118739.
6. Shojaeefard, M. & Molaeimanesh, Gholam Reza & Salami, Yasin. (2019). Improving the performance of a passive battery thermal management system based on PCM using lateral fins. Heat and Mass Transfer. 55. 10.1007/s00231-018-02555-0.
7. Lv, Youfu & Yang, Xiaoqing & Li, Xinxi & Zhang, Guoqing & Wang, Ziyuan & Yang, Chengzhao. (2016). Experimental study on a novel battery thermal management technology based on low density polyethylene-enhanced composite phase change materials coupled with low fins. Applied Energy. 178. 376-382. 10.1016/j.apenergy.2016.06.058.
8. Liu, Wangyu & Jia, Zhikang & Luo, Yuanqiang & Xie, Weigui & Deng, Tao. (2019). Experimental investigation on thermal management of cylindrical Li-ion battery pack based on vapor chamber combined with fin structure. Applied Thermal Engineering. 162. 114272. 10.1016/j.applthermaleng.2019.114272.
9. Li, Xinxi & Zhou, Dequan & Zhang, Guoqing & Wang, Cong & Lin, Ruheng & Zhong, Zhaoda. (2019). Experimental investigation of the thermal performance of silicon cold plate for battery thermal management system. Applied Thermal Engineering. 155. 10.1016/j.applthermaleng.2019.04.007.
10. Liang, Jialin & Gan, Y.H. & Li, Yong. (2018). Investigation on the thermal performance of a battery thermal management system using heat pipe under different ambient temperatures. Energy Conversion and Management. 155. 1-9. 10.1016/j.enconman.2017.10.063.
11. Jin, L. & Lee, Poh Seng & Kong, X. & Fan, Y. & Chou, S.K. . (2014). Ultra-thin minichannel LCP for EV battery thermal management. Applied Energy. 113. 1786-1794. 10.1016/j.apenergy.2013.07.013.
12. Wu, Weixiong & Wang, Shuangfeng & Chen, Kai & Hong, Sihui & Lai, Yongxin. (2019). A critical review of battery thermal performance and liquid based battery thermal management. Energy Conversion and Management. 182. 262-281. 10.1016/j.enconman.2018.12.051.
13. Chung, Yoong & Kim, Min. (2019). Thermal analysis and pack level design of battery thermal management system with liquid cooling for electric vehicles. Energy Conversion and Management. 196. 105-116. 10.1016/j.enconman.2019.05.083.
14. Heyhat, M. & Mousavi, Seyed Sepehr & Siavashi, Majid. (2020). Battery thermal management with thermal energy storage composites of PCM, metal foam, fin and nanoparticle. The Journal of Energy Storage. 28. 10.1016/j.est.2020.101235.
15. Choudhari, V.G. & Dhoble, A. & Panchal, Satyam. (2020). Numerical analysis of different fin structures in phase change material module for battery thermal management system and its optimization. International Journal of Heat and Mass Transfer. 163. 120434. 10.1016/j.ijheatmasstransfer.2020.120434.
16. Zheng, Nianben & Fan, Ruijin & Sun, Zhiqiang & Zhou, Tian. (2020). Thermal management performance of a fin-enhanced phase change material system for the lithium-ion battery. International Journal of Energy Research. 44. 10.1002/er.5494.
17. Safdari, Mojtaba & Sadeghzadeh, S.. (2019). Numerical investigation on PCM encapsulation shape used in the passive-active battery thermal management. Energy. 193. 116840. 10.1016/j.energy.2019.116840.
18. Hémery, Charles-Victor & Pra, Franck & Robin, Jean-François & Marty, Philippe. (2014). Experimental performances of a battery thermal management system using a phase change material. Journal of Power Sources. 270. 349–358. 10.1016/j.jpowsour.2014.07.147.
19. Bhattacharjee, Ankur & Mohanty, Rakesh & Ghosh, Aritra. (2020). Design of an Optimized Thermal Management System for Li-Ion Batteries under Different Discharging Conditions. Energies. 13. 10.3390/en13215695.
20. Verma, Ashima & Shashidhara, Sumanth & Rakshit, Dibakar. (2019). A comparative study on battery thermal management using Phase Change Material (PCM). Thermal Science and Engineering Progress. 11. 10.1016/j.tsep.2019.03.003.
21. Weng, Jingwen & He, Yaping & Ouyang, Dongxu & Yang, Xiaoqing & Zhang, Guoqing & Wang, Jian. (2019). Thermal performance of PCM and branch-structured fins for cylindrical power battery in a high-temperature environment. Energy Conversion and Management. 200. 112106. 10.1016/j.enconman.2019.112106.

22. Zhang, Hy. (2017). Experimental investigation on the thermal behaviour of cylindrical battery with composite paraffin and fin structure. International Journal of Heat and Mass Transfer. 109. 958-970. 10.1016/j.ijheatmasstransfer.2017.02.057.
23. Ouyang, Dongxu & Weng, Jingwen & Hu, Jianyao & Liu, Jiahao & Chen, Mingyi & Huang, Que & Wang, Jian. (2019). Effect of High Temperature Circumstance on Lithium-Ion Battery and the Application of Phase Change Material. Journal of The Electrochemical Society. 166. A559-A567. 10.1149/2.0441904jes.
24. Yazıcı, M. Yusuf & AVCI, Mete & Aydin, Orhan. (2019). Combined effects of inclination angle and fin number on thermal performance of a PCM-based heat sink. Applied Thermal Engineering. 159. 113956. 10.1016/j.applthermaleng.2019.113956.
25. Alipanah Rostami, Morteza & Li, Xianglin. (2016). Numerical studies of lithium-ion battery thermal management systems using phase change materials and metal foams. International Journal of Heat and Mass Transfer. 102. 1159-1168. 10.1016/j.ijheatmasstransfer.2016.07.010.
26. Atkin, Peter & Farid, Mohammed. (2015). Improving the efficiency of photovoltaic cells using PCM infused graphite and aluminium fins. Solar Energy. 114. 10.1016/j.solener.2015.01.037.
27. Abdulmunem, Abdulmunem & Jalil, Jalal. (2018). Indoor investigation and numerical analysis of PV cells temperature regulation using coupled PCM/Fins. International Journal of Heat and Technology. 36. 1212-1222. 10.18280/ijht.360408.
28. Rangappa, Ravichandra. (2014). NUMERICAL ANALYSIS OF PCM BASED THERMAL MANAGEMENT SYSTEM FOR LI-ION BATTERY USED IN HYBRID AND ELECTRICAL VEHICLES.
29. Parsons, Kevin. (2012). Design and Simulation of Passive Thermal Management System for Lithium-Ion Battery Packs on an Unmanned Ground Vehicle. Journal of Thermal Science and Engineering Applications. 9. 10.1115/1.4034904.
30. Wei, Tang & Xiaoming, Xu & Hua, Ding & Yaohua, Guo & Jicheng, Liu & Hongchao, Wang. (2020). Sensitivity Analysis of the Battery Thermal Management System with a Reciprocating Cooling Strategy Combined with a Flat Heat Pipe. ACS Omega. XXXX. 10.1021/acsomega.0c00552.
31. Wang, Ziyuan & Li, Xinxi & Zhang, Guoqing & Lv, Youfu & He, Jieshan & Luo, Jinghai & Yang, Chengzhao & Yang, Chuxiong. (2017). Experimental study of a passive thermal management system for three types of battery using copper foam saturated with phase change materials. RSC Adv.. 7. 27441-27448. 10.1039/C7RA03963H.
32. Amin, Muhammad & Ariantara, Bambang & Putra, Nandy & Sandi, Adjie & Abdullah, Nasruddin. (2018). Thermal Management of Electric Vehicle Batteries Using Heat Pipe and Phase Change Materials. E3S Web of Conferences. 67. 03034. 10.1051/e3sconf/20186703034.
33. Changcheng & Xu, Dengji & Weng, Jingwen & Zhou, Shujia & Li, Wenjuan & Wan, Yongqing & Jiang, Shuaijun & Zhou, Dechuang & Wang, Jian & Huang, Que. (2020). Phase Change Materials Application in Battery Thermal Management System: A Review. Materials. 13. 4622. 10.3390/ma13204622.
34. Chen, Mingyi & Zhang, Siyu & Wang, Guoyang & Weng, Jingwen & Ouyang, Dongxu & Wu, Xiangyang & Zhao, Luyao & Wang, Jian. (2020). Experimental Analysis on the Thermal Management of Lithium-Ion Batteries Based on Phase Change Materials. Applied Sciences. 10. 7354. 10.3390/app10207354.
35. YAMADA, Tatsuya & KOSHIYAMA, Takafumi & YOSHIKAWA, Manabu & Yamada, Takashi & Ono, Naoki. (2017). Analysis of a lithium-ion battery cooling system for electric vehicles using a phase-change material and heat pipes. Journal of Thermal Science and Technology. 12. JTST0011-JTST0011. 10.1299/jtst.2017jtst0011.
36. Katoch, Sourav & Eswaramoorthy, M. (2020). A Detailed Review on Electric Vehicles Battery Thermal Management System. IOP Conference Series: Materials Science and Engineering. 912. 042005. 10.1088/1757-899X/912/4/042005.
37. Ping, Ping & Peng, Rongqi & Kong, Depeng & Chen, Guoming & Wen, Jennifer. (2018). Investigation on thermal management performance of PCM-fin structure for Li-ion battery module in high-temperature environment. Energy Conversion and Management. 176. 131-146. 10.1016/j.enconman.2018.09.025.
38. Stephen & Mahmud, Sahabi. (2019). Electric vehicle battery thermal management system with thermoelectric cooling. Energy Reports. 5. 822-827. 10.1016/j.egyr.2019.06.016.
39. Wang, Xiaoming & Xie, Yongqi & Day, Rodney & Wu, Hongwei & Hu, Zhongliang & Zhu, Jianqin & Wen, Dongsheng. (2018). Performance analysis of a novel thermal management system with composite phase change material for a lithium-ion battery pack. Energy. 156. 10.1016/j.energy.2018.05.104.
40. Zhang, Jiangyun & Li, Xinxi & He, Fengqi & He, Jieshan & Zhong, Zhaoda & Zhang, Guoqing. (2017). Experimental Investigation on Thermal Management of Electric Vehicle Battery Module with Paraffin/Expanded Graphite Composite Phase Change Material. International Journal of Photoenergy. 2017. 1-8. 10.1155/2017/2929473.
41. Ling, Ziye & Jiajie, Chen & Zhang, Zzg & xu, Tao & Gao, Xuenong & Wang, Shuangfeng. (2014). Experimental and numerical investigation of the application of phase change materials in a simulative power batteries thermal management system. Applied Energy. 121. 104–113. 10.1016/j.apenergy.2014.01.075.