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Development of Phase Change Material/ Cooling Plate Coupled Battery Thermal Management System Using CFD

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Abstract - The life of battery can be improved by providing a different cooling technique to remove the heat liberated from the battery. In this investigation, to enhance the performance of the lithium ion battery, the battery modules was designed and numerically analysed based on the conservation of energy and fluid dynamics incorporated with phase change material(PCM) /water cooling plate. The internal heat source of battery is non uniform in nature which is based on 3D-eletro thermal model for LifePo$_4$/c. In this study LlifePo$_4$/c was used as a battery to know the heat generation in simulation. The factors like inlet mass flow rate, phase change material , flow direction , thermal conductivity, water cooling plate were considered to know the impact on the cooling performance of module. To know the effect of phase change material/water cooling plate on preventing the thermal runway, a continuous charge-discharge cycles were used. The results showed that the water cooling plate placed on the surface of phase change material removes the majority of heat generated during discharging and reduces the maximum temperature efficiency of the battery. The uniformity of temperature field can be improved by placing PCM in between the batteries. The results obtained with the combination of PCM/water cooling plate along with battery presents the emergence of thermal runaway and improve the safety of module.

Key words - Phase change material, Water cooling plate, Battery thermal management, Simulation.

I. INTRODUCTION

The development of economy, the greenhouse effect and air pollution have received considerable attention in recent years. To reduce the pollution, some promising solutions to the energy use of electric vehicles (EVs) have been studied. The temperature distribution and uniformity play vital roles in the battery thermal management (BTM) system. The heat generated during rapid charge and discharge cycles will affect the battery lifetime and the thermal performance of electric vehicle. Greco et al. [1]concluded that the lithium ion battery can liberate more heat during continuous charge-discharge. In that time, heat generation cannot be dissipated properly to the atmosphere. Safety and service life greatly affected on lithium ion battery. During this process, lithium ion battery shows the higher amount of heat removal from the battery in cooling system.[2]Nelson et al when compared to other cooling system lithium ion battery performs the best results and also effect manner . during this process lithium ion battery high amount heat removes from the the battery in cooling system Javani et al. [3] investigated the impact of PCM on square lithium ion battery and obtained positive results concluding that uniform temperature distribution can be improved byPCM. The results also includes that usage of PCM can keep battery in safe temperature ranges. Wang et al. [4]observed that more latent heat can be stored by PCM during melting or solidifying process so that BTM system uses PCM in order to give rise to relatively constant temperature in battery system. Panchal et al. [5]employed cooling plate technique with indirect cooling approach for cooling the lithium ion battery at 1C,2C,3C and 4Cdischarge rates. The different inlet mass flow rate can be using the cooling plates and pure PCM consider. The limitation possessed by the use of PCM on BTM system is poor thermal conductivity which can cause thermal gradient of battery pack. Plenty of approaches were proposed for overcoming the limitations such as combining PCM with porous material adding high thermal conductivity substances in paraffin.[6] developing PCM based BTM system with metal finned structure and addition of metal matrix to PCM.A comparative assessment made by Nelson et al. [7]on various cooling systems obtained better results for liquid cooling than other techniques. The higher thermal conductivity of the liquid exhibits higher heat transfer rate thereby improving cooling performance. Kizilel etal.[8] experimented on minute format cells which were surrounded by a wax composite material of expanded graphite and wax and they concluded that failure can be prevented with the help of latent heat of wax.

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II. Model of lithium ion battery module with PCM /water cooling plate

2.1 physical problem

The schematic lithium ion battery module with PCM/water cooling plate is shown in fig below. From the fig water cooling plate is placed in between the batteries in order to better cooling effect. The pure PCM is used in this study generally a pure PCM can storage large amount of heat but release very less amount of heat. Where as a composite PCM can be release large of amount of heat. The only disadvantage of composite PCM is very poor ability to store large amount of heat. In order to overcome this above situations a cooling plate is preferred which is surrounded by pure PCM that is in contact with the battery. The use of change a pure PCM stores large amount of heat and these large amount of heat can be extracted by the cooling water plate inside the cooling plate the materials are used cooling plate is copper due to the advantage of high thermal conductivity.

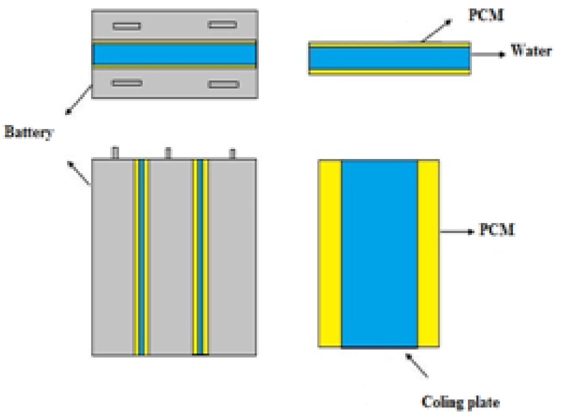

Fig.1.Schematic of lithium ion battery module with PCM /water cooling plate.

Two sets of cooling plate with pcm is placed between the three battery. So that each set of PC/cooling plate will be in between the two battery. The performance of battery can be evaluated at the battery discharge rate at 3c. the heat generation inside the battery is considered as non-uniform and cooling water plate is considered as in compressible. The initial temperature of battery and inlet water temperature of battery and pcm were all set equal that at 300k. The cooling water inside the cooling plate is circulated in 6 different flow directions and different inlet mass flowrate are used. For each flow directions the temperature distribution curves for each mass flowrate , each flow direction were plotted.

The properties of battery ,pcm and cooling plate were listed inTable 1.

Nomenclature	**parameters**	**value**
Sizes of battery	(mm)	100x200 x 11
Capacity of battery	(Ah)	20
Specific heat of the battery	C_b(J kg^{-1} K^{-1})	2138
Density of the battery	ρ_b (kg m^{-3})	1991
Thermal conductivity of battery	(W m^{-1} K^{-1})	0.34
Cathode material of battery	–	$Li_x c_6$
Anode material of battery	–	LiFePO_4
Electrolyte of battery	–	LiPF_6
Specific heat of PCM	c_{pcm} (J kg^{-1} K^{-1})	2000
Latent heat of PCM	l_{pcm}(J kg^{-1})	247,000
Thermal conductivity of PCM	λ_{pcm}(w m^{-1}s^{-1})	0.151
Density of PCM	ρ_{pcm} (kg m^{-3})	778
Viscosity of PCM	υ_{pcm}(kg m^{-1} s^{-1})	0.01
Specific heat of water	c_w(J kg^{-1} K^{-1})	4182
Thermal conductivity of water	k_w(W m^{-1} K^{-1})	0.6
Density of water	ρ_w (kg m^{-3})	998.2
Viscosity of water	ρ_w(kg m^{-1} s-^{1})	0.001003
Thermal conductivity of copper	λ_{A1}(W m^{-1} K^{-1})	202.4
Specific heat of copper	c_{A1}(J kg^{-1} K^{-1})	871
Density of copper	ρ_{A1} kg m^{-3}	300

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III. Results and discussion

In the temperature distribution inside the battery has been simulated by varying mass flow rate of liquid distance between batteries and flow direction of liquid inside the cooling plate. The difference between maximum temperature and initial temperature of battery gives the cooling rate. The influence of PCM/water cooling plate on preventing thermal runaway. were investigated with the use of continuous charge-discharge cycles

3.1 Temperature distribution of a battery:

In this research the lithium ion battery is simulated due to continuous usage of battery the more heat will be generated. In this process input are given 2c discharging the lithium ion battery. The temperature distribution shows fig 2. In this process fluent flow is used in simulate the battery. Considering modelling after that fine meshing, setup and upgrade inputs are given at discharging the 2c shows the results.

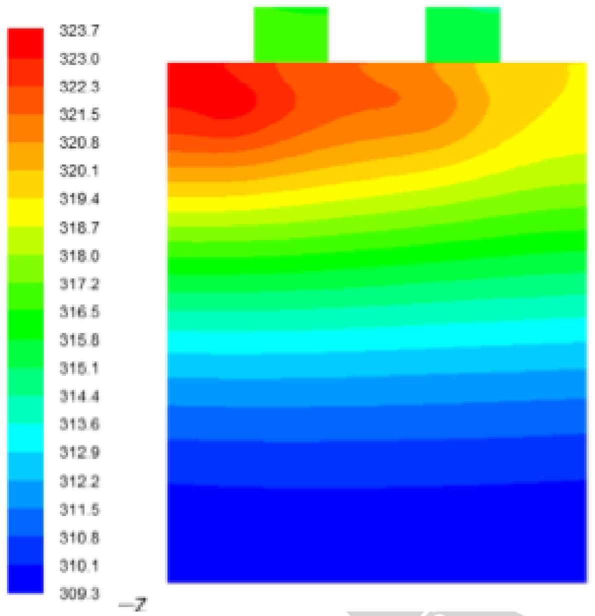

Fig 2.Temperature distribution of lithium ion battery at end of 2c discharging

3.2 Effect of space between adjacent batteries

The PCM and cooling plate was set between adjacent batteries, whose thickness was decided by the space between adjacent batteries. In this section the space between adjacent batteries was changed from 3 mm to 8 mm. The inlet mass flow rate was set as 0.001 kg/s and the height of cooling plate was 5 cm. shows that the maximum temperature decreased and minimum temperature increased as the space between adjacent batteries was changed from 3 mm to 8 mm. In addition, the uniformity of temperature field was improved obviously. When the thickness of the cooling plate increased, the cross-sectional flow area of cooling water was increased and the velocity of inlet cooling water was decreased with the same mass flow rate.

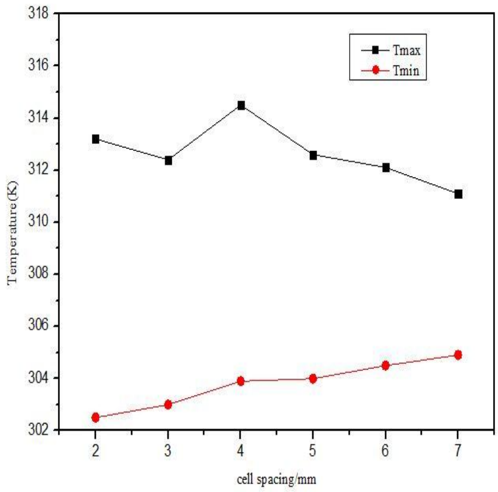

Fig.3(a) Temperature of the module under different space between adjacent batteries

But the uniformity of velocity field was improved, which increased the mean temperature difference between cooling water and battery surface. As a result, both the maximum temperature and maximum temperature difference decreased. Table 3 shows that as the space increased the pressure drop decreased obviously, which led to less energy consumption. When the space was 6mm, And the pressure drop decreased 96% as space between adjacent batteries was changed from 3 mm to 8 mm. Larger space between adjacent batteries could decrease the energy density of pack but lead to lower temperature and pressure drop.Fig.4(b) shows the PCM exceeded melting point closed to the battery with different space between adjacent batteries. It can be seen that the volume fraction of PCM exceeded melting point decreased as the space between adjacent batteries increased as a result of more heat being moved by cooling water.

3.3 Effect of mass flow rate

The variation of temperature distribution in a battery with cooling plate with respect to mass flow rate is depicted in fig 4. Five different mass flow rates of liquid namely 1×10^{-3}kg/s, 2×10^{-2}kg/s, 3×10^{-3}kg/s, 4×10^{-3}kg/s. 5×10^{-3}kg/s were consider in this study. It is observed that maximum temperature inside the battery reduces with the increase in mass flow rate of water. The maximum decrease in temperature is observed for a mass flow rate of 5×10^{-3}kg/s. the primary reason behind that the velocity of cooling water increases which leads to increase in rate of cooling.

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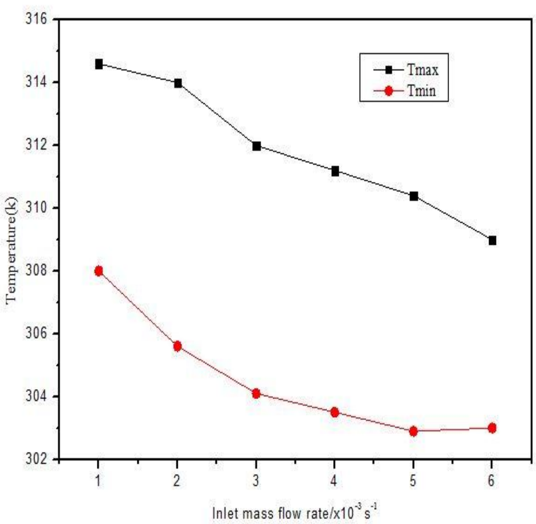


Fig 4. Temperature of the module under different inlet mass flow rates.

Hence it is probed highest mass flow rate contributes to battery cooling rate but at same time pressure drop will be raised because increase I velocity contributes to decrees in pressure. So the resistance will be increased in order to obtain better trade off it is mass flow rate which balance the energy consumption and cooling performance.

3.4Effect of flow direction

The effect of floe direction on temperature distribution or heat transfer rate in a battery. Generally the temperature will be high at a point near the battery electrode. In this study six different types of flow direction were consider with five different mass flow rate for each flow. From case1 and case3 maximum temperature distribution has been showed for case3 due to cooling water inlet on opposite side of cooling plate. The flow direction in case3 acts as a counter flow which will increase heat transfer rate compared to other flows in case3. The velocity of cooling water near to positive phase change material and in other direction the velocity of cooling water near to other phase change material.

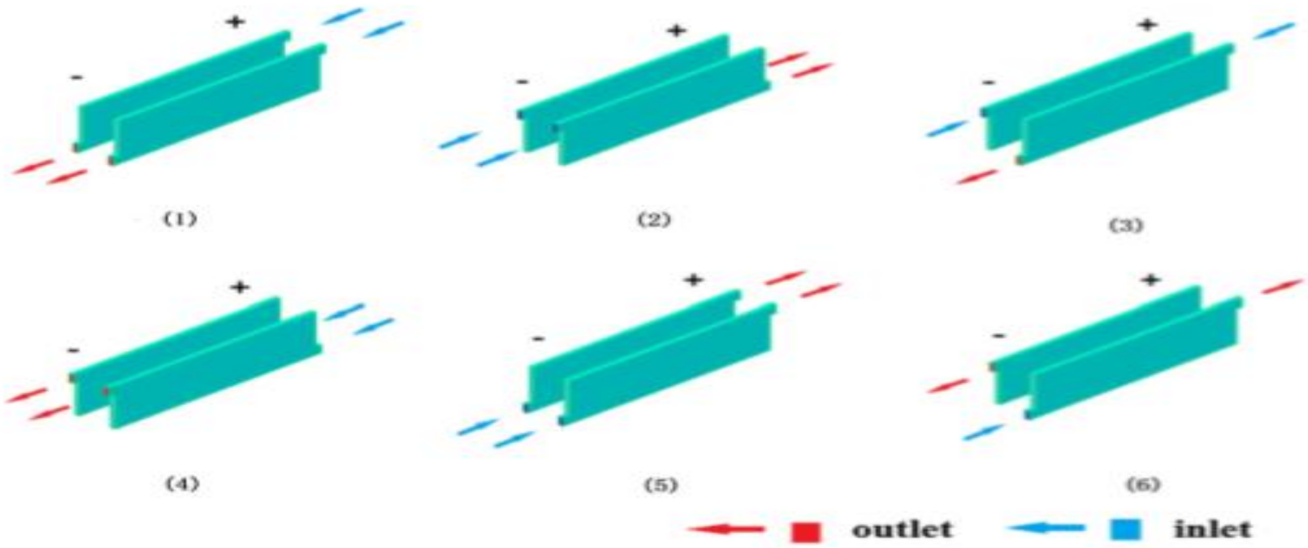
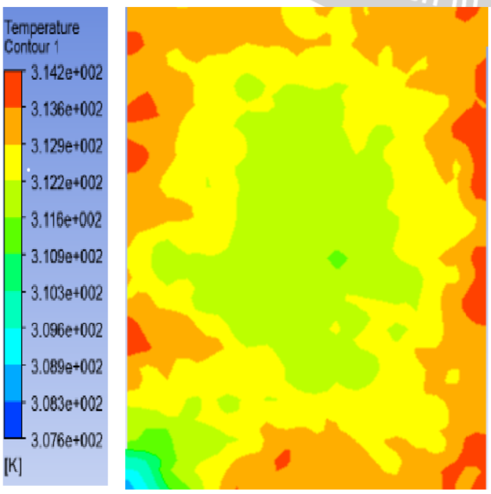


Fig 5.Design of different flow direction.

In this temperature difference in the cooling plate increases the rate cooling there by preventing thermal runway. This from the above direction case3 shoes better cooling rate compared to other flows



Fig(1)Top of cooling plate both inlet bottom of cooling plate

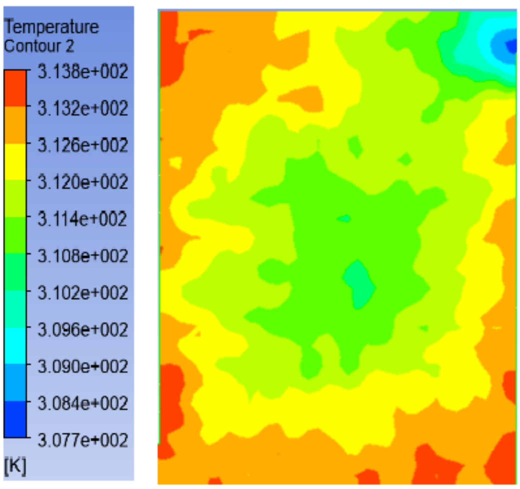


Fig (2)Bottom of cooling plate both inlet outlet top of cooling plate is outlet

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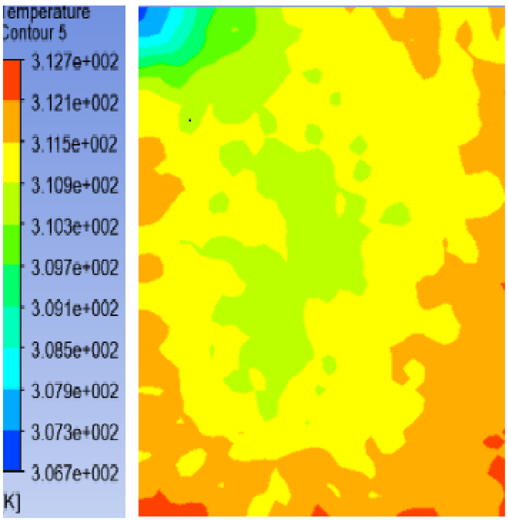
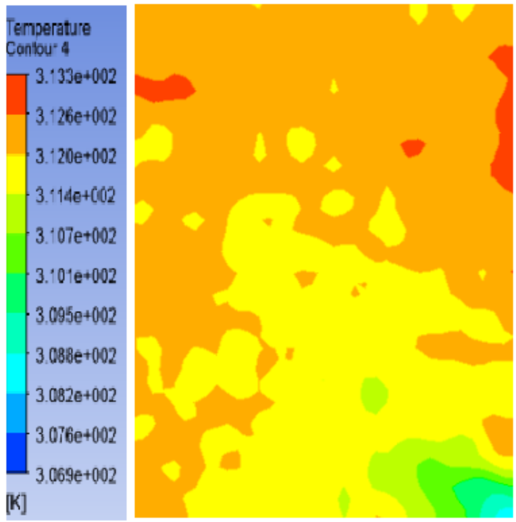
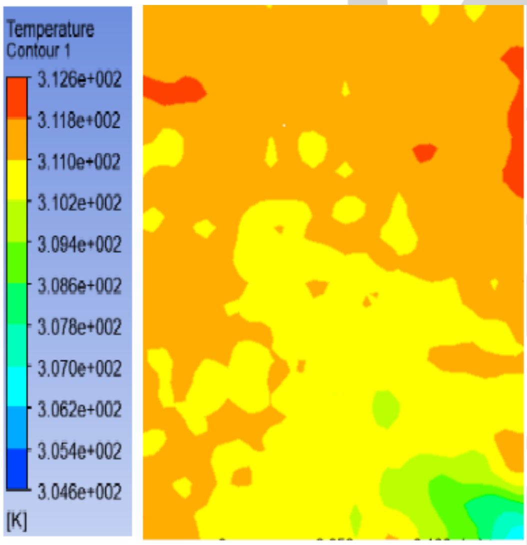


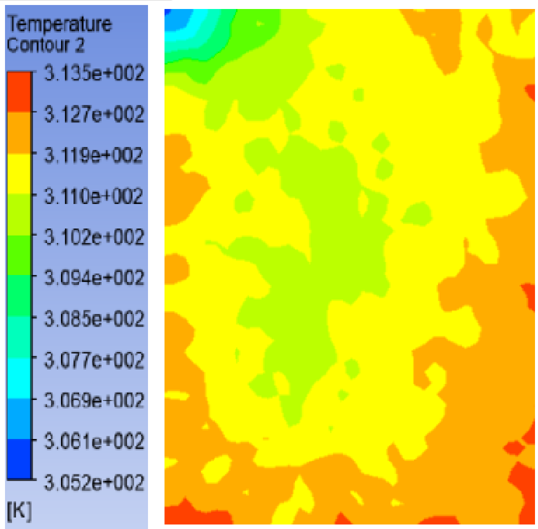
Fig(3) Opp top of cooling plate both inlet cooling plate both outlet



Fig(4) Opp bottom of cooling plate both inletbottom of top of cooling plate both outlet



Fig(5) cooling plate Both inlet and outlet are opposite



Fig(6) bottom of cooling plate both inlet are opposite

3.4 Thermal conductivity of PCM

Displays the maximum temperature, minimum temperature and maximum temperature difference of module with different thermal conductivity of PCM. The increase of the thermal conductivity leads to the slow decrease of the maximum temperature of the battery at the end of the discharging. However, the maximum temperature difference was almost constant, as the region with minimum temperature was close to the water cooling plate. The heat was absorbed as latent heat by the PCM because of large heat storage capacity of PCM.

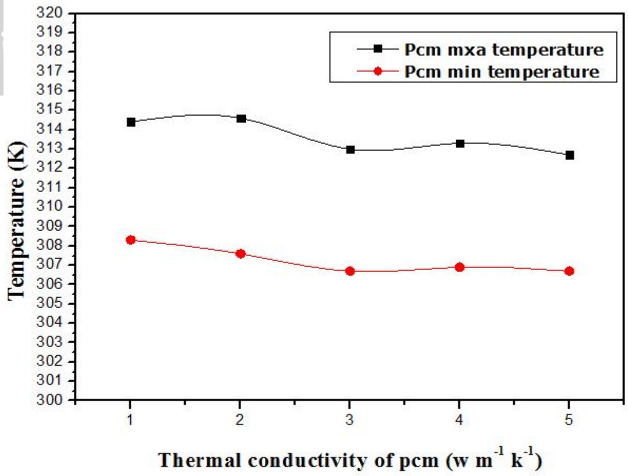


Fig.6 Temperature of the module under different thermal conductivity of PCM.

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As the thermal conductivity has small influence on the cooling performance in this system, there is no need to increase the thermal conductivity of PCM by foam metal or high thermal conductive additive. In order to improve the environmental suitability of module, increasing the melting point of PCM and decreasing the temperature of inlet cooling water properly was necessary

IV. Conclusion

In this investigation, to enhance the performance of the lithium ion battery, the battery modules was designed and numerically analysed based on the conservation of energy and fluid dynamics incorporated with phase change material(PCM) /water cooling plate. The internal heat source of battery is non uniform in nature which is based on 3D-eletro thermal model for lifep0_4/c. In this study lifeP0_4/c was used as a battery to know the heat generation in simulation. The factors like inlet mass flow rate, phase change material , flow direction , thermal conductivity, water cooling plate were considered to know the impact on the cooling performance of module The results obtained with the combination of PCM/water cooling plate along with battery presents the emergence of thermal runaway and improve the safety of module. The numerical results are included

Providing of PCM/water cooling plate best cooling efficiency of the lithium-ion battery controlling the module temperature. And high cooling plate made the best cooling performance. As the space between adjacent batteries increased, the maximum temperature shown little change but the temperature field got more uniform.

Increasing inlet mass flow rate could the maximum temperature and was more efficient than other methods. But the energy consumption was higher as the pressure drop rose quickly. The heat generation of lithium ion battery reduced, by increasing the space between adjacent batteries, inlet of cooling water better cooling performance on high heat generation area of lithium ion battery.

As the thermal conductivity has small influence on the cooling performance in this system, there is no need to increase the thermal conductivity of PCM by form metal or high thermal conductive additive. In order to improve the environmental suitability of module, increasing the melting point of PCM and decreasing the temperature of inlet cooling water properly was necessary

The PCM/water cooling plate could limit the maximum temperature effectively and improve the uniformity of temperature field during the 5 continuous charge-discharge cycles. As a result, it prevented the emergence of thermal runaway and increased the safety of module.

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