Optimization in Cooling of Battery in E.V.

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Abstract— As the power lithium-ion batteries are applied to provide energy for electric vehicles, higher requirements for battery thermal management system (BTMS) have been put forward. The operating temperature, reliability, safety and cycle life of batteries is the key points that people concern. The liquid cooling system is considered as an efficient cooling method, which can control the maximum temperature of the battery and the temperature difference between the batteries in a reasonable range to prolong the cycle life of the battery. Thermal performance of liquid cooling based thermal management system for lithium-ion battery module vary with variable contact surface. This review summarizes the latest research papers of battery liquid cooling system.

Keywords: Battery Thermal Management, Cooling Strategies, Cooling Performance, Power Lithium Ion Battery System

I. INTRODUCTION

Transportation is one of the largest source of green-house gases, Traditional automobiles consume a large amount of oil resources and emit pollutants in everyday use. Electric vehicles are highly recommended to replace the vehicles equipped with combustion engine for reducing the carbon emission and the diminution of petroleum sources. Lithium-ion battery is considered as advanced energy source for electric vehicles. Lithium-ion battery has Advantage of high voltage platform, high specific energy, high power density, low self-discharging rate, long life cycle and suitable operating temperature range.

The electric vehicles development is facing many challenges such as mileage, life cycle, safety, battery price, charging time and reliability. The increase of temperature due to heat generation in lithium-ion battery in the process of charge and discharge directly influences the cycle life, efficiency, reliability and safety of the battery. The temperature either too high or too low affects the performance of battery, even cause safety problems. Therefore, it is important to learn the heat generation process and figure out the heat distribution within the battery when designing a cooling system.

Thermal runaway is one of the major safety issues facing with the battery. When the temperature of the battery rises continuously and the heat cannot be dissipated in time, thermal runaway will occur after the temperature exceeds 80 °C. Thermal runaway is often accompanied by the emission of harmful gases, smokes, fires and even explosions. The low temperature will reduce the discharge capacity of the battery. It has been reported that the operating temperature for lithium-ion battery should range from 20^{0}C to 40^{0}C and the maximum temperature difference should be no more than 5^{0}C in single battery or from module to module. So it is very necessary to design an appropriate battery thermal management system.

Types of Battery Thermal Management System

- Air cooling system,
- PCM (Phase change material) and
- Liquid cooling system.

A. *Air Cooling System*

Air cooling system is one of the widely used cooling system in electric vehicles due to its simple structure, low cost and easy maintenance. Air cooling system was employed in the Toyota Prius and Honda Insight, Nissan and GM also used forced air cooling system to cool batteries. The maximum temperature was effectively reduced and temperature distribution was uniform. However, the temperature gradients along the air flow direction were unavoidable. Air cooling system cannot meet the requirements under severe operation conditions such as fast charge or discharge.

B. *Phase Change Material*

PCM based cooling system is a new type of battery thermal management. PCMs could bring more uniform temperature distribution and keep battery in safe temperature range. Higher thermal conductivity and lower melting point of PCM was very beneficial to decrease the battery temperature. However, they still cannot be widely used limited by their very lower thermal conductivity.

C. *Liquid Cooling System*

Liquid cooling system is considered better BTMS because as compared with air, liquid has higher thermal conductivity which leads to higher cooling performance and is more suitable for cooling large-scale battery pack. Due to its best advantage-super thermal conductivity, it is very popular in thermal management. Compared with the PCM based system, this system presented more effective thermal performance and the maximum temperature could be reduced to 14.8^{0}C.

The design of battery arrangement has an important influence on the overall structure and the cooling performance of the battery pack. The layout of batteries can be divided into series, parallel and series-parallel configuration. For large battery pack, the configurations of series-parallel are more compact, which is beneficial to the layout and the cooling performance of cooling system.

The thermo-physical parameters of the cold-plate, glycol, water and battery				
Material	ρ(kg m^{-3})	C_p(J kg^{-1} k^{-1})	λ (W m^{-1} k^{-1})	λ (Pa s)
Aluminum	2179	871	202.4	-
Glycol	1097	2460	0.258	1.61×10^{-2}
Water	998.2	4128	0.6	1.003×10^{-3}
Battery	2500	1000	3	-

Table 1:

II. RESEARCH METHODOLOGY

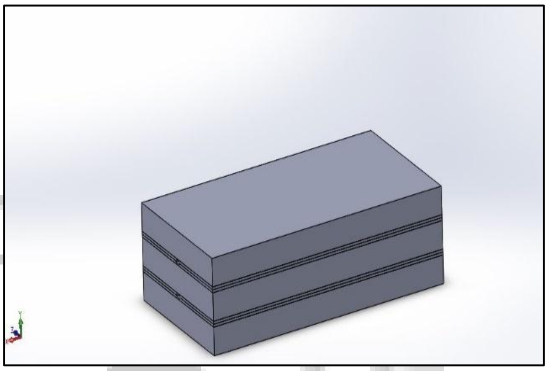
The Software used in this project are solid edge, solid works, Ansys 16.2, micro soft excel.

A. Geometry Modelling:

Solid Edge ST10 was used for modelling. Using sketcher option in software, the active volume of the cell, positive and negative electrode is generated and extruded. The cold plate of the model was also designed in the sketcher option of the software and was also extruded completing the cold plate model. Channels for the cold plate were generated in 3D Sketcher option as volume was generated for the cold plate. The positive and negative electrode, the active volume of the cell and the cold plate was assembled in the assembly option in the used modelling software.

A single battery was sandwiched between two cold plate making one single cooling part assembly. Further to this, 4 batteries and two cold plate were added to the assembly making one module of battery pack. This one module consists of 5 batteries and 4 cold plate. Since the geometry is symmetrical the whole battery pack was cut into half to computational load.

1) Model 1:

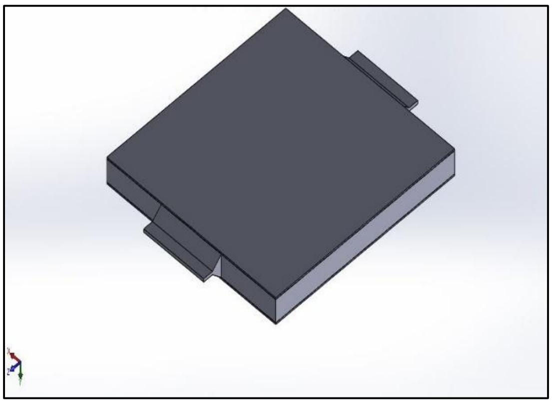


In practical applications, batteries are usually used in the form of pack. The schematic of the cooling system is illustration where in each cold plate is sandwiched by two battery cells. The battery is rectangular in shape. The transfer of heat generated in the cell takes place into the cold plate through the contact surface, and then into the cooling liquid which flows through the mini channel. Each battery pack consists of 5 cells. Since the application of symmetry boundary condition is considered, only half of the pack is taken to reduce the computational load. The battery cells are named as cell1, cell2, cell3 in turn. The battery and mini channel cold plate structure are described in their respective figures. Coolant distribution in the cold plate is considered as non-uniform. Both the side of cold plate have been provided with the inlet and outlet. When the cooling liquid flows into the cold plate, it gets divided into several branches, due to which there is a difference of mass flow rate of the coolant liquid in each branch. Since it is considered that the higher temperature is the near electrode area, the inlet main stream is therefore placed near the electrodes of the batteries. The gap d1 between each channel is the same and d1 is equal to d2. The width of the channel along the direction d3 and the width of inlet and outlet d4 are 3mm. Also, the width of channel long direction is 3mm.

The cold plate is made of aluminum and mixture of glycol and water in ratio 90:10 is employed as cooling medium. Cold plate, glycol, water and battery which are used in this paper have been summarized with their thermal properties in the table.

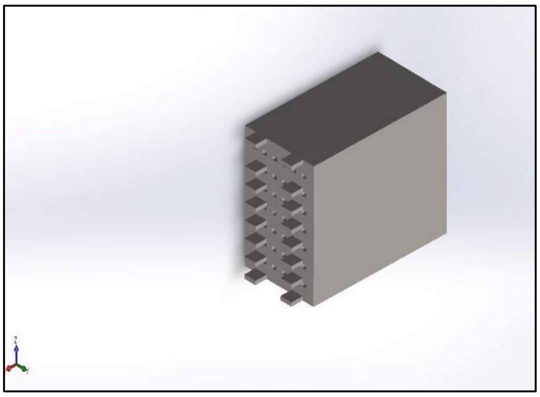
The model was meshed in ICEM CFD and the numerical calculation was conducted in fluent 16.0. Maximum Reynolds number was less than 2300 in this study, so laminar model was employed to the model analysis. Mass flow inlet and outlet were chosen as the inlet and outlet boundary conditions, respectively. The boundary condition of the side surface of the whole pack was defined as free convection with the heat transfer coefficient of 5 W/mk. The inlet fluid temperature was equal to the ambient temperature which was set as 25◦c. The discharge rate of the battery is 5C and discharge time lasts 720 seconds.

2) Model 2:



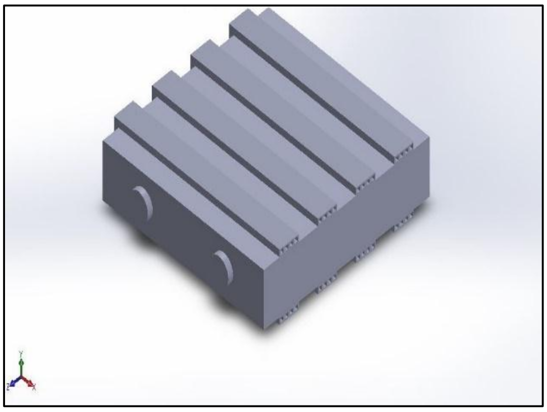
A 35 Ampere-hour prismatic pouch Li-ion cell with dimensions of 169 mm width, 179 mm long and 14 mm thick is modeled for the simulation method. In the above figure, the selected battery model for analysis is shown in the picture. The cell is designed for an EDV battery pack with 1285 Wh/kg energy density. Combustion of NMC and MnO is used for cathode material and graphite is used for anode material. A three- dimensional model is built in Ansys/Fluent. Four parts comprise the model the active volume, positive current tabs, negative current tabs, and skin. The active volume represents the stacked structure, including positive and negative active material, separator layers, and aluminum and copper foils. To collect the current flow through the cell positive tab and negative tab are used. To contain internal component heat conduction through the skin surfaces in the model, a thin skin wrapping the part of the tabs and the active volume is built to represent the pouch. The number of elements of mesh are 66040 and number of nodes are 87787.

3) Model 3:



A schematic figure of the Li-ion battery pack is shown in above figure. Each single battery in the middle of the battery pack is sandwiched by two cold plates. The single battery investigated in the paper is rectangular in shape and has a capacity of 7000 mAh. The number of cooling channels considered is 5. The Li-ion battery and cold plate are assumed to be homogeneous and isotropic for numerical simplicity. Aluminum was used for the cold plate. Considered thermal conductivity and viscosity, mixture of glycol and water in ratio 90:10 was employed as cooling medium.

4) Model 4:



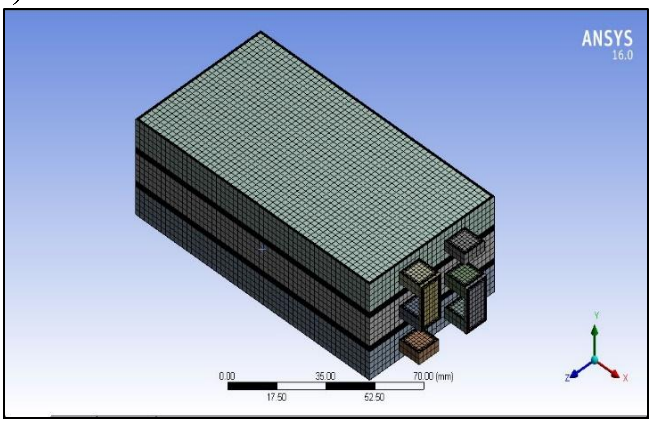
The model used for computational purpose consists of a prismatic geometry as the representative of one single battery cell, the mini-channel cooling system, and the fluid. The dimensions for the cell are 173mm (z height) by 168mm (x width) by 39mm (y depth) and the capacity is 55Ampers-hours.the thermal conductivity is anisotropic and the heat generation inside battery is assumed to be uniform. The aluminum minichannel tubes wrap around there sides of the battery as shown in figure. Different discharge rates will be studied with temperature distribution across. The battery with this minichannel cooling system.

B. *Meshing:*

Meshing is an integral part of the computer-aided engineering simulation process. The mesh influences the accuracy, convergence and speed of the solution. Furthermore, the time it takes to create and mesh a model is often a significant portion of the time it takes to get results from a CAE solution. Therefore, the better and more automated the meshing tools, the better the solution.

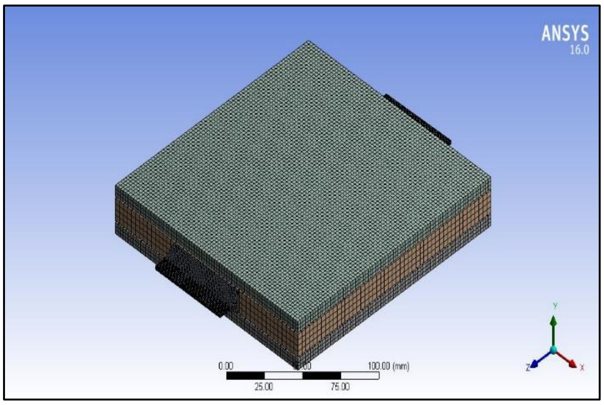
After preparation of geometric model in solid edge ST10 meshing was done. Firstly, two models were auto mesh due to the simplicity of model and the remaining one model was manually mesh using ICEM CFD due to the complexity of the remaining model.

1) Model 1:



The above model shown in the picture was manually meshed using ICEM CFD. The mesh metric was set to orthogonal quality. Number of elements of mesh is 10453998 and number of nodes is 2327420.

2) Model 2:



The mesh metric was set to skewness. Number of elements of mesh is 66040 and number of nodes is 87787.

C. *Analysis:*

The ultimate solution of finite element analysis is to recreate mathematically the behavior of an actual engineering system.in other words, the analysis must be an accurate mathematical model of a physical prototype.in the broadcast sense, this model comprises all the nodes, element, material properties, real constants, boundary conditions and other features that are used to represent the physical system.

ANSYS is a general-purpose finite element software that includes preprocessing (to create the geometry and generating mesh), solver, and post-processing modules in a unified graphical user interface (GUI) environment. ANSYS commonly refers to ANSYS Mechanical or ANSYS Multi-physics. In ANSYS, a problem can be solved in either a batch or interactive mode. In batch mode, an input file is to be created and executed from the command line. In interactive mode, GUI is used and the operations to be performed are either chosen from a menu or typed in a graphics window.

Analysis was done in fluent. The inlet was set to mass-flow-inlet and the outlet was set to outflow for this particular design. All other surfaces were set to wall with no slip boundary condition. Proper materials were assigned to each and every wall. Their material properties like density, specific heat and thermal conductivity were obtained from literature survey. Calculations were done in fixed type and were carried out for 720s.

III. RESULTS AND DISCUSSION

In this section we are going to analyze the effect on the battery pack while changing the channel number which was varied from 2 to 7 while keeping the Inlet mass flow rate constant at 0.001kg/s Fig 1(a) shows maximum temperature under the battery pack at discharge rate of 5C under different channel number. From fig 1(a) it is observed that temperature increases in first part until 320s then it starts decreasing in the second half till 610s and after that it again increases till 720s. The maximum temperature reached during 2 channels is 44.995℃ or 45℃. The maximum temperature is kept under 42 for 50% of the time.

From Fig (b) and Fig(c) it implies that as the number of channels increases the cooling of the battery pack is more effectively, as with increase in number of channels the even and odd form number maximum temperature of the battery is reduced. The more number of channels, the more effective is the cooling, Temperature of the battery pack was reduced by 2.6℃ when the number of channels was changed from 2 to 7. The cooling is more effective because the rate of heat transfer is increased as the surface area increases.

When the channel number is odd, middle channel is far from electrodes as a result more than half of the water flows along the middle channel. Thus, cooling effect of water is poor near the electrode are where the heat generation is more intense. The maximum temperature undoubtedly occurs near the electrode area.

Thus, it is obvious that increase in number of channels will increase the cost of battery. However, fewer channels will lead to poor cooling. Taking above factors into consideration we have selected 5 channel cold plate as it will be optimum.

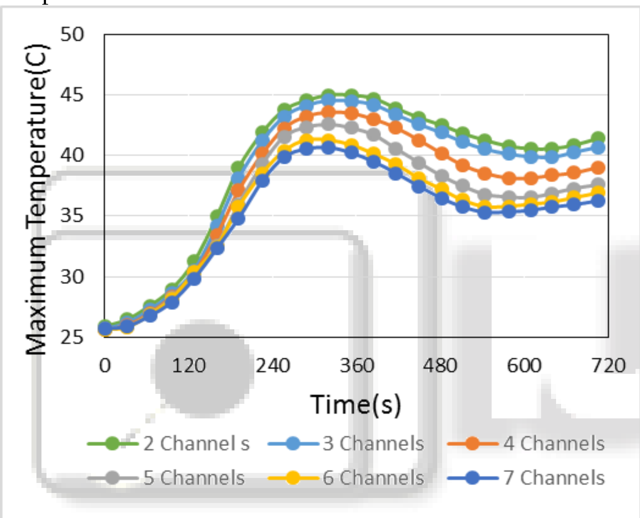


Fig. 1:

The above graph is the result of the analysis carried out on model 1. It shows the different number of channels with maximum temperature versus time. The graph is further divided into two parts to show the effect of odd and even number of channels in the cold plate separately.

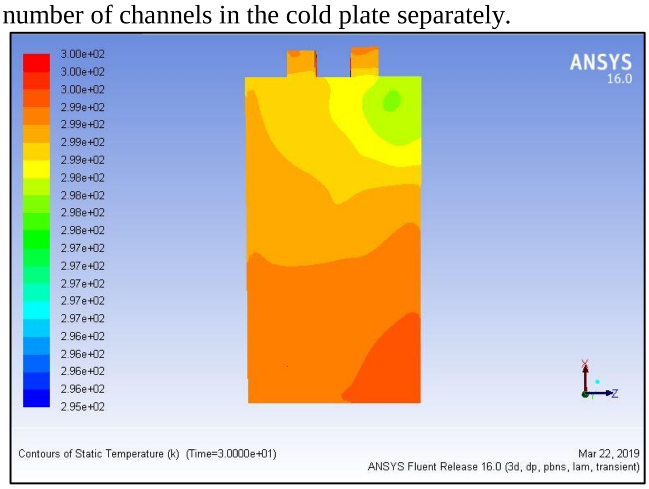


Fig. 2:

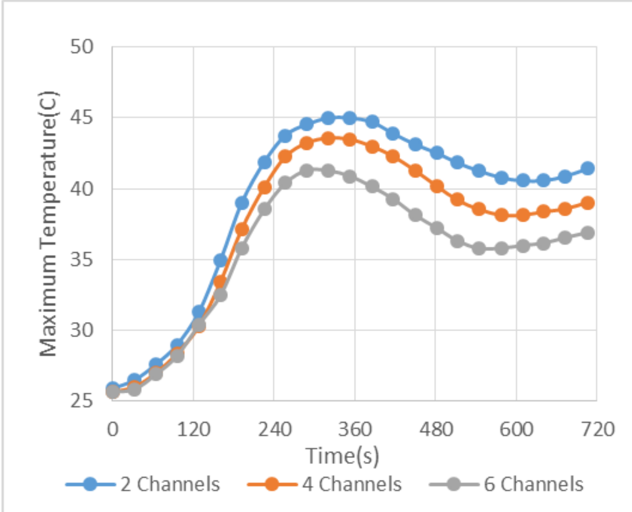


Fig. 3:

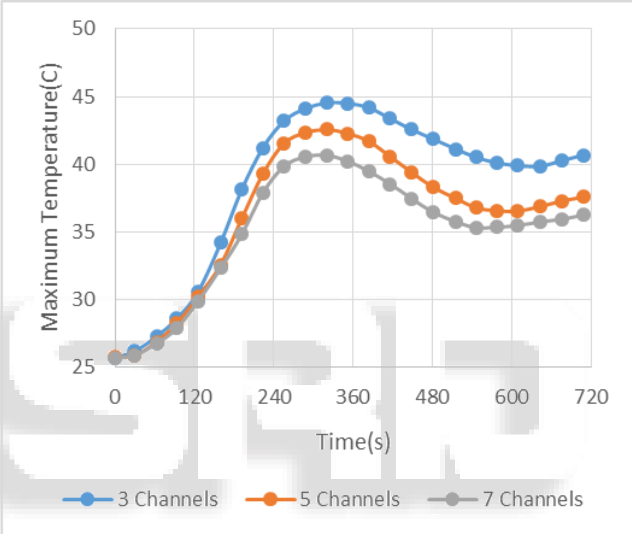


Fig. 4:

IV. Conclusion

After carrying analysis on the battery model 1 with cooling plates and fluid as mixture of glycol and water, the results showed that the cold plate consisting of 5 channels was optimum in maintaining the temperature below 45^{0}C for half of the discharge time. Only a 2 channel cold-plate was able to keep the maximum temperature 45^{0}C.

It was seen that in the cold-plate the more number of number of channels i.e. more than 5 did not have any apparent advantage.

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