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CFD Analysis of Cylindrical Lithium-ion Battery Pack for BTMS

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***Abstract*— As today's trend, the electrical vehicles are coming in market; EV's are capturing the big share in automobile sector. The Battery is power source for electrical vehicle which giving electric power to motor. In electric battery, electric energy is stored in the chemical form. The battery is charged to store energy and discharged to get energy back. While working of electrical vehicle the battery continuously supplies energy to electric motor by doing chemical reaction in it. During charging and discharging, the heat is generated in the battery due to chemical reaction and resistance; it causes heating of the battery cells continuously. But, cooling of heated cells is necessary to maintain it in required temperature limit (15 to 35 degree celsius). Currently, there is a lack of Battery Thermal Management System (BTMS) which has desired effect on battery temperature. Presently, coolant is used for cooling the battery and it gives good results at initial period, but as time passes, the coolant also gets heated. Due to this, coolant is not able to absorb heat from the battery cells further. So, there is need of system which can absorb heat from coolant for efficient working of BTMS. Currently, there are various methods of cooling of battery which include air cooling, liquid cooling, Phase change materials, etc. As per literature review, liquid cooling has high efficiency, so decided to consider liquid cooling method for the further analysis of the proposed work. Analysis of Cylindrical Lithium-ion Battery Pack is carried out to maintain the temperature in required range, prevent battery deterioration by managing heat generated, stabilize the temperature dissipation and prevent the uncontrolled pressure in the cells and battery pack. Using the Star CCM+ software, CFD analysis is performed with a selection of boundary conditions. For the analysis, two different models of similar battery pack are used by varying size of cooling channels. The cooling performance of battery pack is increased in present work study.**

***Keywords*— BTMS; CFD Analysis; Lithium ion; Battery Pack; Liquid Cooling.**

I. INTRODUCTION

The thermal management of battery is very important in electric vehicles as it help to maintain temperature as result in increased the battery life. Also, the battery efficiency is increased and various hazardous situations (like catching fire & explosion of batteries) can be avoided. The rise of renewable power generation in the current energy market has created an immense potential for different forms of energy storage. At the forefront of these storage technologies are the lithium batteries as they are lightweight with high energy density. The characteristics of Lithium batteries have made themattractive both for stationary and automotive applications. Temperature has a large effect on the safety, lifetime and performance of Li-ion batteries. The optimum operating range for these batteries is 20-45ºC, otherwise theperformance and lifespan will be reduced and furthermore hazardous incidents such asthermal runaway might occur.

In addition, temperature difference among cells and modules in a battery pack must be controlled; else it will impact the operation and aging of the battery. Thus, an effective battery thermal management system is necessary to dissipate the heat generated inside the batteries. Moreover, in low-temperature scenarios, heating is required to ensure the best performance. As per literature survey [1-9], liquid cooling has high efficiency, so decided to consider liquid cooling method for the further analysis of the proposed work. This paper aims to analyse and compare the performance of liquid cooling usedfor thermal management of lithium batteryconsisting of 21700 cylindrical cells. Thecomparison is done by simulating the performance of a 96-cell pack using Computational Fluid Dynamic Analysis Software- Star-CCM+. The software replicates the flow distribution and properties of the cells and the media around them.

A. Geometry of Battery pack with cooling system

The present work is carried out on the two models, the first one is having cooling microchannel with equal cross-sectional area and another model is our proposed model having decreasing cross sectional area at start after increasing cross sectional at the end. The geometry contains 96 cells arranged in zig-zag manner to save space. Each cell having 1.5 mm spacing which is minimum spacing determined by minimum possible distance between cells provided by Northvolt. The cooling plate is in maximum contact with each cell with curved shape, to give greater cooling performance.

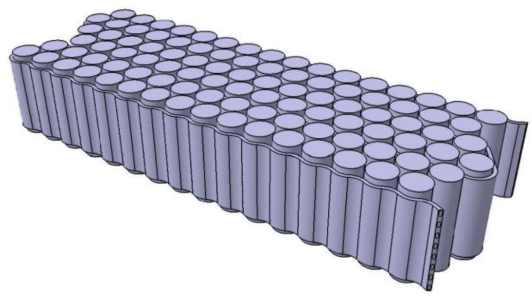

Fig. 1 Geometry of model 1

In this model 1 shown in Fig.1, 8 channels having equal cross section are in cooling plate. The microchannel is elongated holeshape having 2 mm radius and length is 4 mm.

The second model having same dimension of micro channel at starting 50 mm and decreasing up to length 225 mm and having continuous cross section in contact in battery pack and then increasing cross section up to length 225 mm and having equal cross section at last 50 mm length. The fins having 1 mm thickness and 20 mm length are attached at the end of cooling plate so that the heat generated in the fluid can be rejected to the atmospheric air. The model 2 geometry view is shown in Fig.2 below.

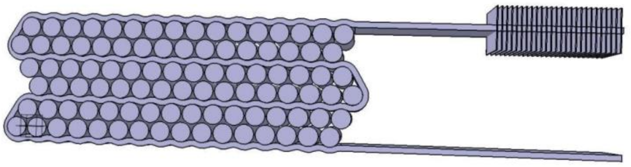

Fig. 2 Geometry of model 2

Due to decreasing cross section of the microchannel the coolant pressure as well as temperature decrease so it can absorb more and more heat, same way as increasing cross section coolant pressure as well as temperature increase as a result it can reject more and more heat to atmosphere. According to Bernoulli's equation, a decrease in temperature can occur due to a change in dimension. Bernoulli's equation describes the relationship between fluid velocity, pressure, and elevation in a flowing system. When fluid flows through a constricted section of a pipe or channel, such as a nozzle, the fluid's velocity increases, and its pressure decreases. This phenomenon, known as the Venturi effect, is based on the conservation of energy principle. As the fluid's velocity increases, its kinetic energy increases at the expense of its potential and internal energies, resulting in a decrease in temperature. Therefore, when there is a change in dimension that causes a flow constriction, such as a narrowing of a pipe or a reduction in cross-sectional area, the fluid experiences an increase in velocity and a corresponding decrease in temperature, as per Bernoulli's equation. Due to the constricted section at inlet the temperature of coolant is decreased around 5 degrees according to the Bernoulli's equation.

Also model 2 is having fins at outlet. When temperature rises above the ambient temperature fins which is exposed to environment air is rejecting heat to atmosphere.

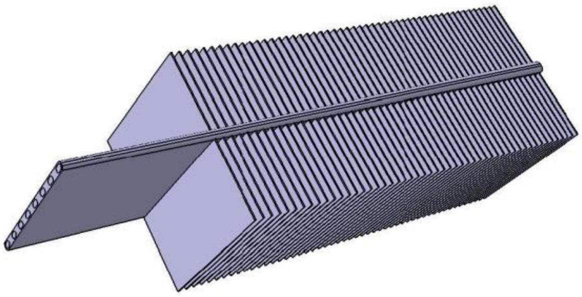

Fig. 3 Geometry of Heat Exchanger

The outlet having 50 fins with 2 mm spacing between them is shown in Fig. 3. These reject heat to atmospheric air to maintain temperature of coolant in optimum range so that it can cool battery cells.

B. *Mesh Generation of Geometry*

Surface Re-mesher, Polyhedral Mesher, Prism Layer Mesher these methods of mesh are used in such a way that a fine mesh region is obtained. Later, names were assigned to the inlet, outlet, Cooling Plate, Battery, etc. The Battery cells along with cooling plate meshing having fluid domain is shown in Fig.4. Mesh for model 2 having same process and mesh generated is also same. Mesh Generation of Heat Exchanger is revealed through Fig.5.

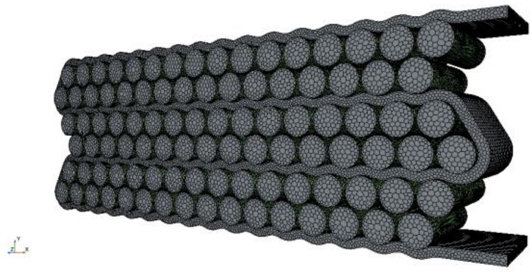

Fig. 4 Mesh Generation of model 1.

Fig. 5 Mesh Generation of Heat Exchanger

II. Process of Analysis of Battery Pack using Star CCM+ Software

A. Boundary Conditions

The analysis in STAR-CCM+ incorporates the application of ethylene glycol as a coolant fluid. Ethylene glycol, a commonly used heat transfer fluid, offers excellent thermal properties and is well-suited for managing temperature regulation in various systems. By applying ethylene glycol as the working fluid, the simulation can accurately capture the heat transfer characteristics and performance of the system under realistic operating conditions. This enables comprehensive analysis and evaluation of thermal management, ensuring efficient cooling and optimal performance of the analyzed system. Appropriate properties of Ethyl glycol coolant are taken for further process.

Li-ion cell properties are taken as mentioned below:
Density = 2871.826 kg/m^3
Sp. Heat = 1200.0 J/kg-K
Thermal Conductivity = 11.55 W/ mK
Heat Source = 2 W
Initial condition = 300 K

B. Process Followed

The CATIA v5 software is used to create 3D model of battery pack. After completing the 3D part, it is imported in Star CCM+ software as a surface mesh. In Star CCM+ software it is first edited in 3D-CAD where operations like imprinting bodies giving inlet and outlet regions are done. After Geometry edit each part from geometry is assigned to a new region. Then new physics continua are created from continua. Model is selected for every physics continuum. Each continuum is edited according to the specification of model which includes material, material properties, etc. According to model continuum is attached to each part.

Automated mesh from Operations is carried out for that Surface Remesher, Polyhedral Mesher, Prism Layer Mesher are used to get fine mesh.

The coolant used is ethylene glycol 50/50 solution having good thermal properties. For Analysis we have taken the 20 degrees as inlet temperature for coolant and each cell generates 2 W heat. Ambient temperature is applied as 30 degrees Celsius.

III. Result and Discussion

The analysis consists of flow of coolant through channel which absorbs continuously generated heat by battery cells. As the fluid passes through channels, it gets warmer from the heat generated by the cells. As a result, the cells close to the inlet are cooler than the ones at the outlet and the hottest cell is located at the end of the cooling channel. The cells that are at the bends of the cooling channel are further cooled due to the higher contact surface with the cooling channel.

A. Models 1 results for 1st iteration

For model 1, the results are calculated at coolant inlet temperature as 300 K, Battery cell generating 2 W heat and ambient temperature is also 300 K. The result for battery cell temperature and coolant temperature is shown as below Fig.6.

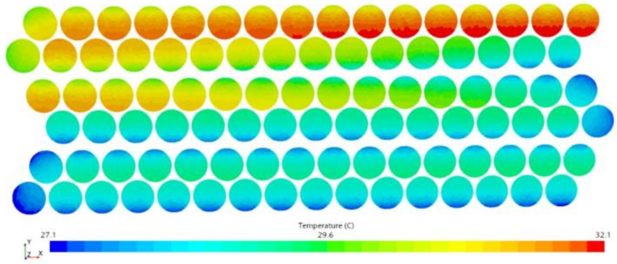

Fig. 6 Temperature distribution of battery cells for 1st Iteration

As shown in Fig.6, temperature of cells is reduced due to low temperature coolant coming from inlet. As coolant flow through channels due to heat absorbed from battery cells, coolant's temperature also continuously increases.

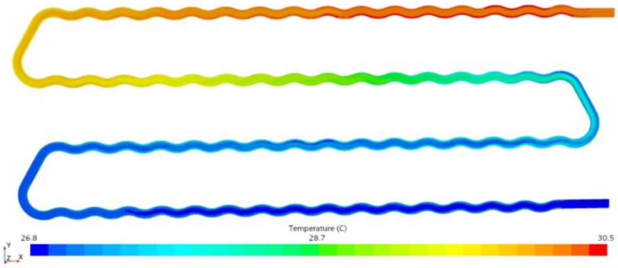

Fig.7 Temperature distribution of flow channel for 1st Iteration

The temperature distribution inside the module (shown in Fig.7) running at 2 W heat generation per cell. As the fluid passes through channels, it gets warmer from the heat generated by the cells. As a result, the cells close to the inlet are cooler than the ones at the outlet and the hottest cell is located at the end of the cooling channel. The cells that are at the bends of the cooling channel are further cooled due to the higher contact surface with the cooling channel.

B. Models 1 results for 2nd iteration

From result i.e. Fig. 8, the outlet temperature is around 32 degrees Celsius; so, after some time the coolant temperature become around 30 to 30 degrees Celsius.

By using this as an inlet temperature the result is again calculated which shown below.

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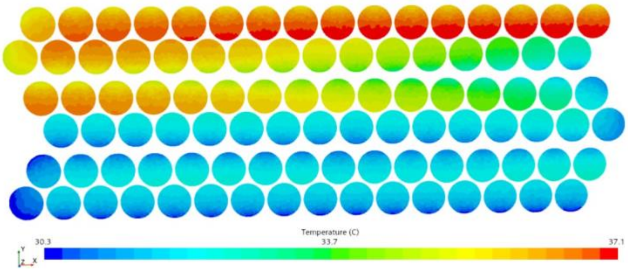

Fig. 8 Temperature distribution of battery cells for 2nd Iteration

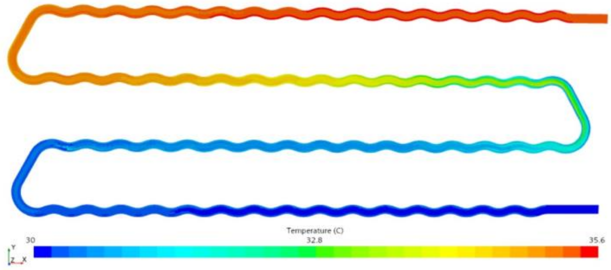

Fig. 9 Temperature distribution of fluid flow for 2nd Iteration

In these above results i.e. Fig.9, clearly seen that, the outlet temperature of coolant will always rise and there is no provision for the dissipation of heat from it.

By recirculating the coolant temperature is always increases and graph for the outlet temperature of coolant is shown below Fig.10.

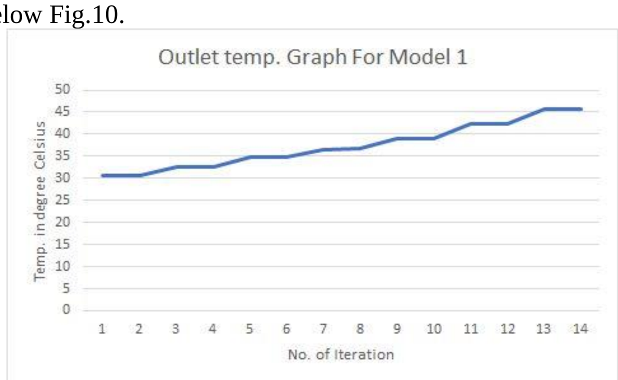

Fig.10 Graph of outlet temperature for model 1

C. Scalar scene for cooling channel

For second model, firstly passed coolant through the cooling channel having large cross section at start and decreasing up to 200 mm length; as a result the coolant pressure is reduced and velocity of coolant is increased. The result for the coolant before inlet as shown below.

Pressure is reduced as coolant flow through the cooling channel due to that coolant can absorb more amount of heat from the battery cells. The negligible change is seen in the temperature from Fig.11 & Fig.12.

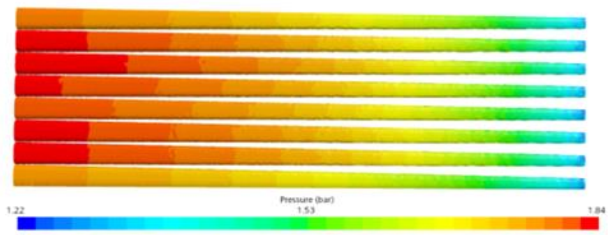

Fig.11 Pressure distribution of coolant before inlet

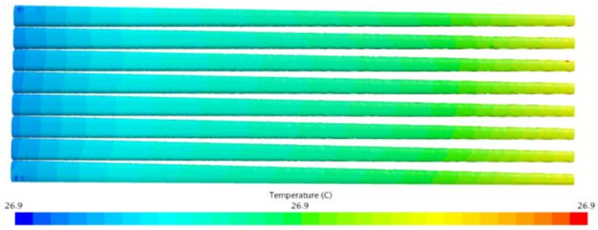

Fig. 12 Temperature distribution of coolant before inlet

D. Models 2 results for 2nd iteration

The all conditions of battery cells and coolant are same as model 1 except pressure and velocity which is changed due to throttling process in decreasing cross section at inlet and result is calculated.

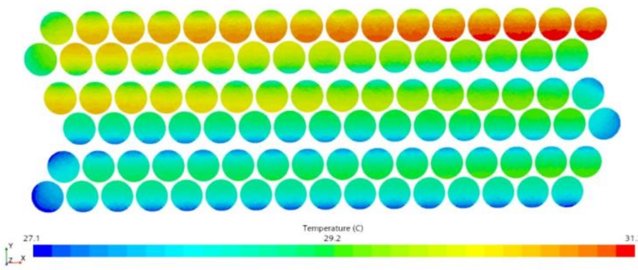

Fig.13 Temperature distribution of battery cells for 1st Iteration

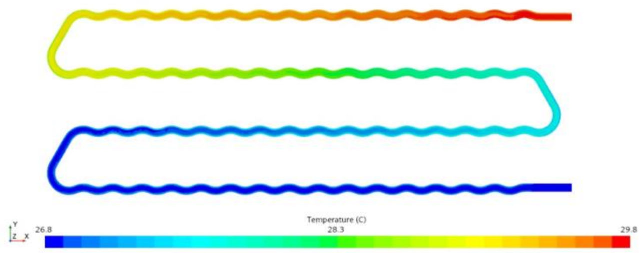

Fig. 14 Temperature distribution of coolant for 1st Iteration

The coolant temperature at outlet of battery pack is around same temperature as for model 2 and it is shown in Fig. 13 & Fig.14. Then coolant is passed through the heat exchanger to reject heat to atmosphere.

E. Heat Exchanger analysis after outlet of coolant

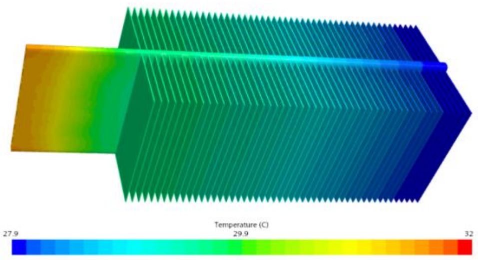

Fig.15 Temperature distribution in Heat Exchanger

Coolant is passed through the heat exchanger as shown in Fig.15; having fins attached to the cooling plate. Due to atmospheric air high temperature coolant is cooled and this coolant can now be used for the next iteration.

F. Heat Exchanger analysis after outlet of coolant

The temperature distribution for 2nd iteration for battery cells and coolant are shown in Fig. 16 and Fig. 17.

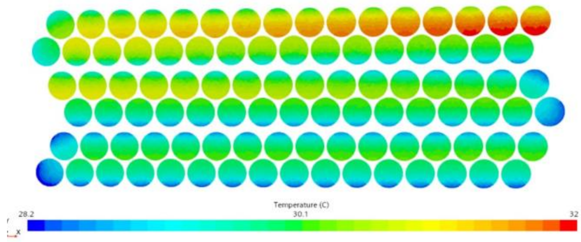

Fig.16 Temperature distribution of model 2 for second iteration

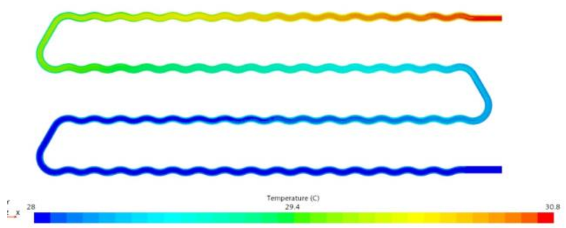

Fig. 17 Temperature distribution of model 2 for second iteration

By using this model, 7 iterations have been calculated using outlet coolant again and graph is plotted as shown in Fig.18.

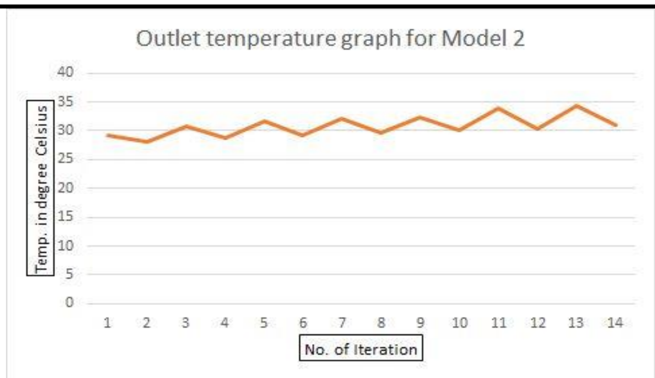

Fig.18 Graph of outlet temperature for model 2

G. Heat Exchanger analysis after outlet of coolant

The graph of model 1 and model 2 is combined and it is shown in Fig. 19 below.

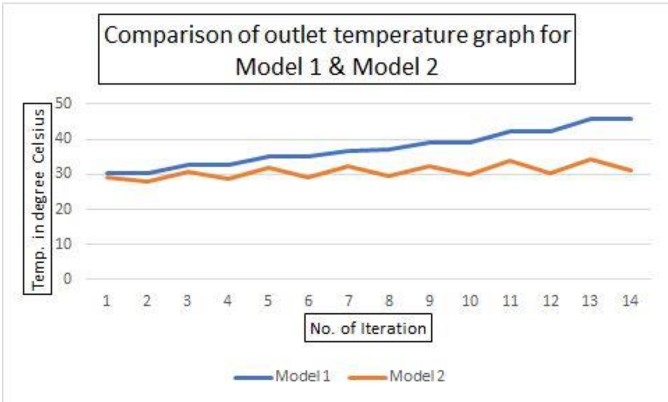

Fig.19 Comparison of outlet temperature graph for Model 1 & Model 2

From above graph, it is clear that, the outlet temperature is continuously and greatly increasing in model 1 while in model 2 it is increasing and then decreasing due to heat exchange.

IV. CONCLUSIONS

Battery Thermal Management System (BTMS) is most important to extend life of battery pack in electric vehicle. Present study represents the CFD analysis of battery pack with and without heat exchanger.

The following key findings from the present study are mentioned as follows:

- From the results, it is seen that, temperature of coolant is greatly increasing in model 1.
- Temperature of coolant in model 2 slowly increasing, due to heat exchanger rejects the heat.
- The cooling performance in model 2 is increased and battery cell temperature is maintained in required

range.

V. Future Scope

- In the present study, results are calculated up to 7 iterations only, more results can be carried out.
- Battery cells is limited in touch with the cooling plate, one can design efficient battery pack model.
- We used Ethyl Glycol 50/50 Solution as a coolant, one can use other.

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