Thermal Analysis of Battery Module

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ABSTRACT

The rate of development of Electric Vehicles has gained momentum in the recent times. The factors like cost, lifetime and safety of the battery are becoming very important. One of the most important components, which are presently in one way deciding the cost and also very important hurdle in the development of the EVM is the battery. Thermal management of vehicle battery plays important part in deciding the battery performance and therefore the proper analysis of the battery thermal management system (BTMS), it is very essential for proper functioning. Analysis of the BTMS can be done in three ways; analytically by solving equations, numerical simulations using ANSYS FLUENT and on MATLAB/Simulink. In this work, simulations are done using ANSYS to understand the amount of heat produced and cooling required for the battery. This work focuses on analysis of lithium-ion battery cell using ANSYS FLUENT in order to study the flow characteristics of air flowing overbattery module. It is observed that such a battery module is prone to overheating and therefore, requires proper cooling arrangement to ensure it efficient operation. Here we mainly focused on finding heat transfer rate and it is observed that optimum air flow rate has to be maintained to ensure maximum cooling and better performance.

Keywords: Electric Vehicle, BTMS Cooling, Heating, ANSYS, Battery Module.

1 Introduction

There are so many blending methods of hybrid EV and 100% EV in vehicle Industry. As per the mixing level, different size and shape, type and numeral of cooling types are fixed in Electric Vehicles. Disparate conventional vehicles, battery cells as source of energy have severe requirement on running environment. They are particularly responsive to temperature. To make sure proper thermal working surroundings, a BTMS will usually be included with battery cells. It mostly consists of following systems: liquid cooling system, air cooling system, phase change material, direct refrigerant cooling system, thermo-electric heating and cooling and last but most simple heat pipe. Therefore, understanding of the suitable working necessities of battery is essential and simulation is done to know how much air and cooling required, and what kind of management systems are capable of meeting these demands in an adequate and efficient manner, as discussed in [1]. The performance and durability of a battery pack in an electric vehicle can be maximized with this cornerstone. Furthermore, due to the battery's limited capacity, the vehicle's electric range is limited. Finding the electric energy usage of BTMS and looking for potential savings is really useful. This discovery will aid battery performance by reducing EV energy usage and electric range.

2 Literature Review

Focus on EVs with other hybrid EVs, semi hybrid EVs and battery EVs have rapidly growth has been found in market, as condition of global warming over world has been 21st century most difficult issue and

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the environmental challenge of greenhouse gas production have been increased. The key challenge for EVs is to discover a reliable and long-lasting energy source, which aids in the development of innovative energy storage systems capable of supporting high mileage, rapid charging, and high-performance driving. Because of higher energy to density ratio, higher specific power to weight ratio, lighter weight, lower time for self-discharge rates, higher recyclability and re - usability, and longer cycle life than other reusable batteries such as lead-acid, nickel–cadmium, and nickel–metal hydride batteries, reusable lithium-ion batteries were previously recorded as the most and common sustainable energy storage tool for EVs. They also have the benefit of having no memory effect. To avoid harmful consequences of lithium-ion batteries, room temperature and maximum temperature differential between cells should be no more than 4–5 °C, as discussed in [2-4]. The energy to density ratio of lithium-ion batteries is better than every last challenging batteries, nonetheless, today's EVs must test at higher energy density batteries than ever before, and more cells in the module must be supported to extend the discharge time. This strategy boosts the batteries' self-heat production and heat accumulation, putting the BTMS at the pinnacle of its utility. The thermal and overall behaviors of the battery were tested at the module level, with total heat generation, heat transfer types, and thermal boundary conditions checked, while various BTMS were investigated at the module level. and tested over fixed period with battery conditions sensors. They examined the capacity of the air-based battery thermal system and the direct liquid-based battery thermal system, respectively, based on cell kinds (serial, parallel, and mixed) and indirect liquid cooling system categories (tube cooling and plate cooling utilizing small channels)., as in [5]. The preceding simulation review studies were mostly concerned with heat transfer methods or materials. In comparison to all other subject study on battery thermal difficulties, there is very little research on the battery thermal management system. As a result, each BTMS has been thoroughly studied in terms of thermal cycle possibilities, and a portion of simulation has been described further in this work. Also, the study has done on battery power capacity calculation so during numerical analysis the capacity has been given and helps solving. All pervious simulation mostly focuses on MATLAB/Simulink based battery simulation but in this we have been tried in ANSYS FLUENT. Density based solver is gives highest most accurate solution and can be compared with analytical solution.

3 Theory and Calculation

Cooling - Battery cells will create electricity and heat due to their inefficiency. When the battery temperature reaches the ideal level, and even before that, this heat must be removed from the battery pack. As a result, thermal control necessitates pack cooling.

Heating - The temperature of the battery pack drops below the lower temperature range in colder climates. As a result, a heating device, such as a PTC heater, is required to get the battery pack to the right temperature in a shorter amount of time.

Insulation – The temperature difference between the inside and outside of the battery pack is significantly greater in cold or hot weather than in normal weather. As a result, the temperature of the battery will rapidly fall or climb outside of the acceptable range. To avoid this, good insulation can reduce the rate at which the battery temperature drops or rises, especially when the car is stopped on the road.

Ventilation - To eliminate the toxic substances from the battery pack, ventilation is essential. This function is integrated with cooling and heating functions in various systems, such as air systems.

Battery capacity Calculations

Charge (C) = Current (A) * Time(s)

and

Charge (C)*Voltage (V) = Energy (J)

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Since Amp hour (Ah) is measure of charge and Joules is measure of energy you can't convert mAh to joule without knowing Voltage at which charge is transferred

So,

mA means 1/1000 of an Amp for an hour and there are 60 * 60 = 3600 sec per hour,

1mAh = 0.001*3600 = 3.6 coulombs of charge.

Choosing 1 volts for voltage can convert mAh to joule

3.6 (C) * 1(V) = 3.6(J)

According to example if we have 2V battery it stores twice energy than 1 V battery

Methods for heating and cooling battery pack, as discussed in [3].

4 Methodology

So, for battery thermal management system simulation we use ANSYS R21 model and the geometry has been drawn in Solid work 2020 version. First for all these simulations we make space for air and 10 cell battery modules. When we combine all battery modules, we get pack so we can install. Analysis of battery pack is difficult so we make model of 10 cell pack and simulate in steady, density based standard k epsilon turbulence model.

To bring model into space claim we have to import it into IGES format. After importing we can close space claim tab and go further. Next is meshing, here we can discretize model into small no of part so whatever equation solver solve with high accuracy. More number of meshing means highest time for mesh and closest to actual value of cell temperature. For next setup we have to give some names like inlet, outlet condition also solid cell, fluid air space and material condition here in meshing. After completion of cell and boundary condition setup we can go for setup of physical conditions. Here we can set steady and density-based solver with five process precision and in this we turned on single energy source. Importing of new plots done, for volume-temperature plot mainly done. Addition of lithium-ion material also done here and after applying pre-processing condition one can close tab move to next for solution and result after calculated up to 500 iterations. In result we analyzed various condition and rendering of planes and volume rendering condition for temperature, mass flux, velocity and cell temperature can be closely monitored for single source of energy. Following are some methods to calculate temperature and cooling rate for battery pack out of which we used ANSYS FLUENT simulation.

1 Analytical Method

2 ANSYS FLUENT

3 MATLAB/Simulink

5 Modelling and Analysis

Following figures 2 & 3 show the lithium-ion battery cells module containing 10 cells is analyzed under steady and viscous and in SST k-omega turbulence model. Total here 141328 meshed cells having air as main fluid having density 1.225 kg/m^3

We know that for thermal analysis we have to draw geometry and below geometry is given. Here are some details about geometry

Cell Diameter = 10 mm

Cell Length = 50 mm

No. of Cells = 10

Module Volume = 25*25*50

Consecutive Distance between Cells = 1 mm.

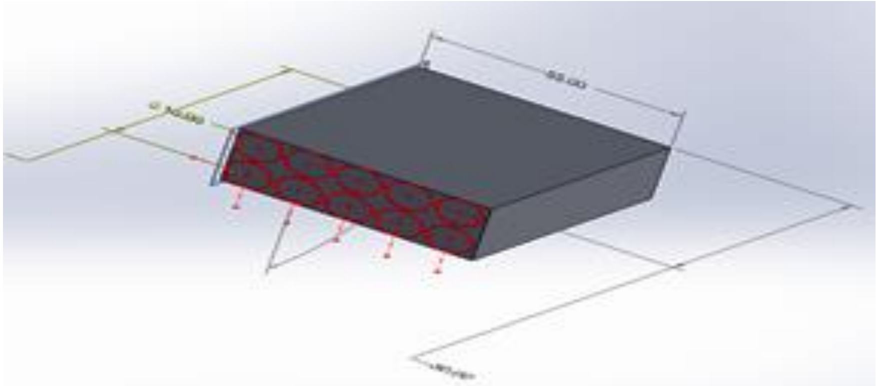
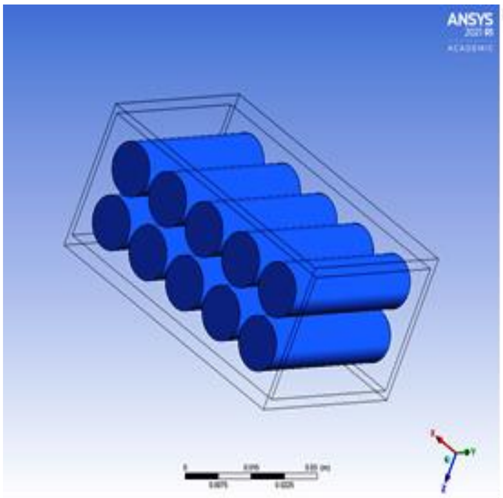


Figure 1: *Geometry*



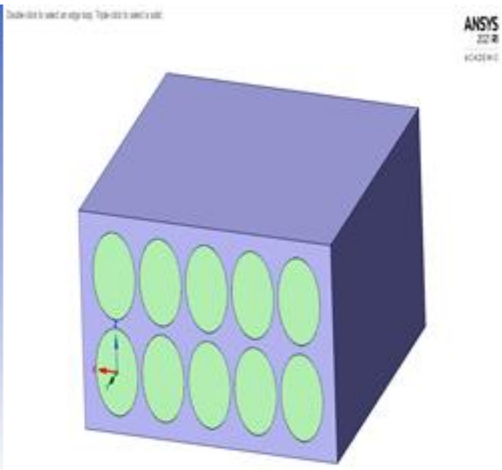


Figure 2: *Cells* **Figure 3:** *Module*

After Meshing of Cell Module, we can make discrete cell so equation is solved with high quality and accuracy. Meshing converts large block area into small number of element and nodes so during simulation time it gives large number and percentage of accuracy. After meshing, we setup physical conditions and further result is analyzed which shows for single energy source temperature plot is being constant or very small changes occurs and after increase of air flow rate the drop can be seen in simulation over period of time. The meshed image of model is below having different mesh for fluid and air part as per design as shown

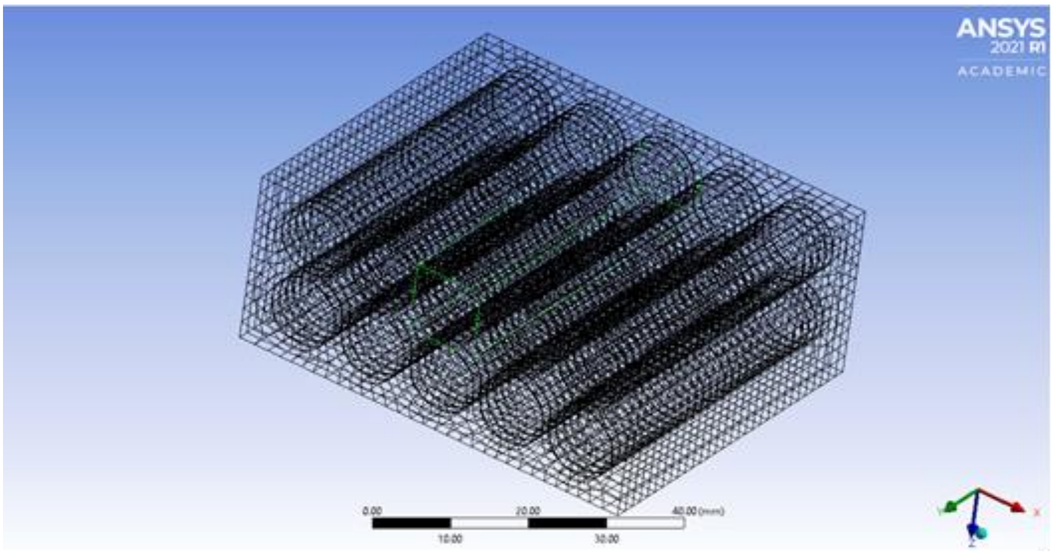


Figure 4: *Meshing*

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So here after meshing we setup above mentioned conditions and part of meshed result is shown below for analyzed and flow of air around cells and heat carried out side of channel first, we had velocity analysis and temperature analysis in volume rendering. Due to Cell the gap between them is not cooled and we can easily find this. We have made conclusion on this is to cool down all cell of modules cross side cooling required cause small change in temperature of cell affect badly to battery pack health condition.

5.1 Case 1

We know that as the mass flow rate and velocity of air rise, the cell temperature decreases. To obtain this we done velocity and temperature analysis and get at 3 m/s air we had 307.4 °k temperature. Here volume rendering shows result. If you once look at both profiles you can find easily that the first cells cool down more cause lower temp of cooling air so henceforth the reddish yellow cells are hot with compare them

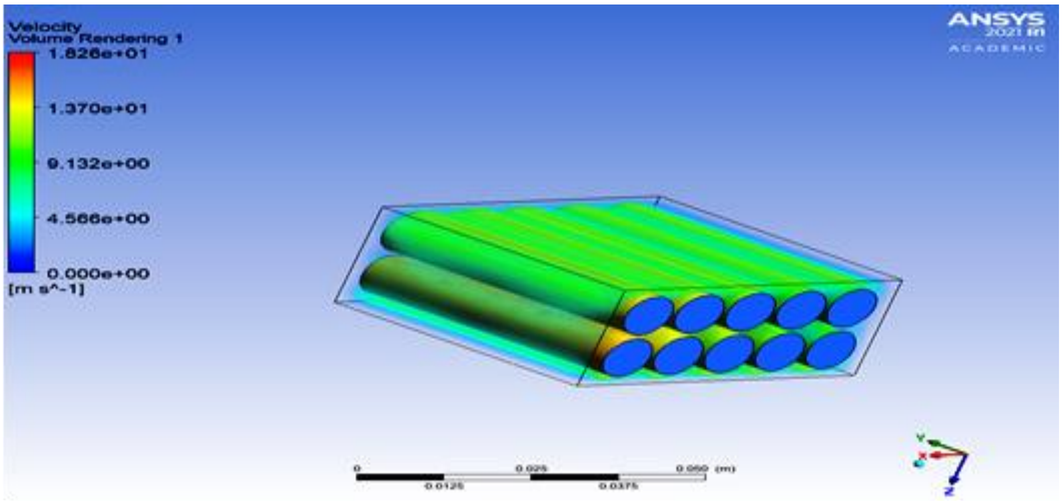

Figure 5: *Velocity Render*

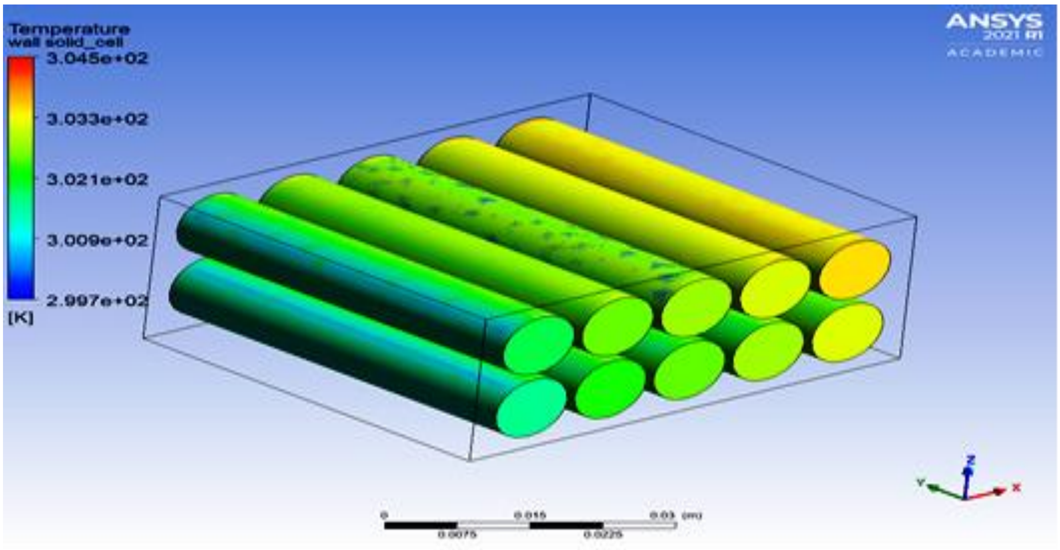

Figure 6: *Temperature Render*

5.2 Case 2

To obtain more cooling we here try with increasing of air flow rate to 9 m/s and we found that the temperature we get in previous analysis is quiet more so here we get 302.5 °k. So, the analysis part is shown below. If you look closely at case 1 and case 2 data the increase in air flow rate had significant effect on temperature of cell. Temperature drop is quickly shown in result. The analysis is same with only inlet parameter change.

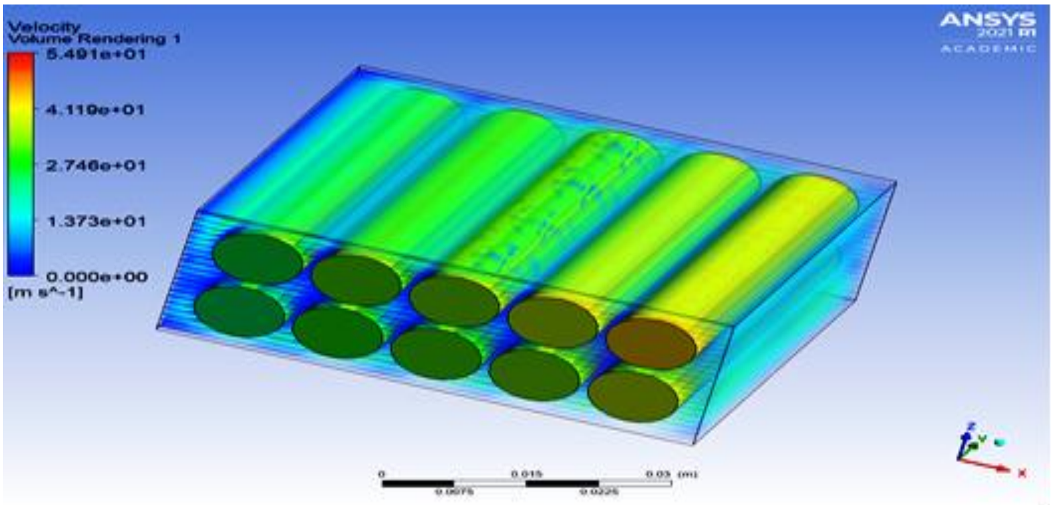

Figure 7: *Velocity Render*

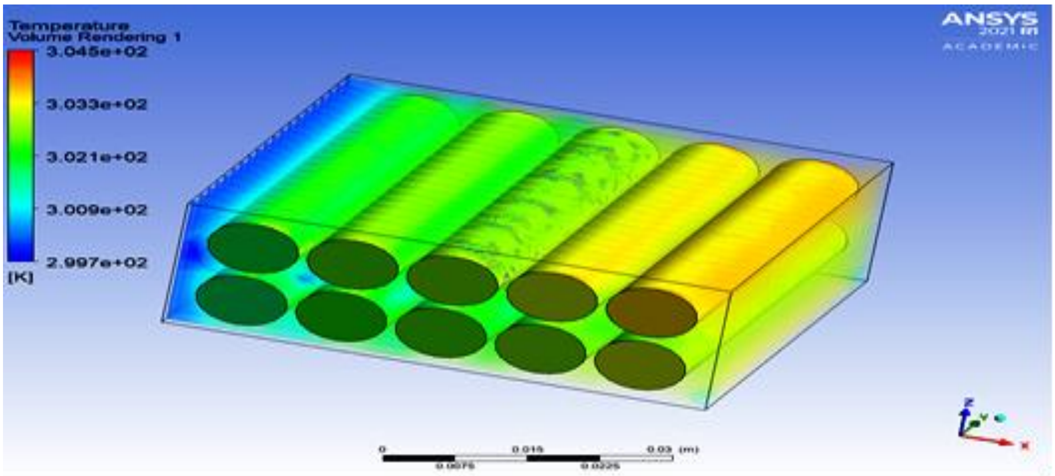

Figure 8: *Temperature Render*

5.3 Case 3

In this last case we add utmost air flow rate 15 m/s and we get temperature very close our inlet air temperature 300.04 °k and our inlet temperature condition is 300 °k. So, if we had air flow rate, we had significant temperature drop in module cell and the purpose of our analysis comes to end as we achieve decrease in temperature of cell. This all things conclude their solution to find battery capacity and depend on battery capacity battery thermal management system control.

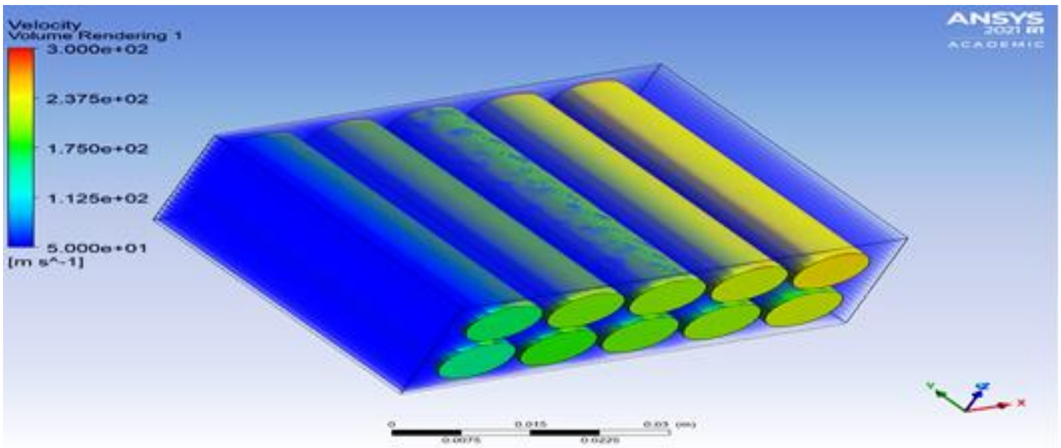

Figure 9: *Velocity Profile*

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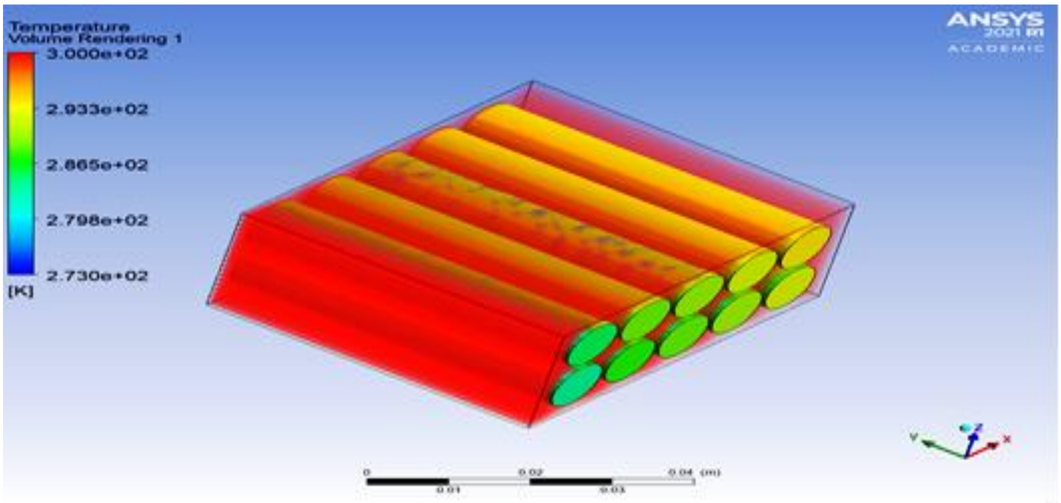

Figure 10: *Temperature Profile*

So, in this case you can easily see due to more air rate the highest heat transfer takes place at module and the cooling of cells are takes place. Due to more heat transfer time required to cool down reduced so much. We did simulation and modelling for almost 7 air flow rates and based on it draw table below comparing velocity and outlet air temperature.

Table 1: *Variation of Outlet Air Temperature with respect to Velocity change*

Sr. No.	Velocity (m/s)	Outlet Air Temperature (°k)
1	3	307.4
2	5	305.25
3	7	304.85
4	9	302.5
5	11	301.75
3	13	301.13
7	15	300.4

5.4 Mathematical Expressions and Symbols

Heat Transfer Rate is calculated by,

$Q = mCp\Delta T$

Q is Heat Transfer Rate [in kW]

m is Mass Transfer Rate [in Kg/s]

Cp is Specific Heat at constant pressure [in joule per kelvin per kilogram]

ΔT is Approximate mean temperature difference [in kelvin]

So, from this we can calculate q and to find q we need to find m

m = ϱ. A. V

Here is example when velocity of air 3 m/s find heat transfer rate

m = 1.225*0.5*.0.25*3 = 0.45 Kg/s

and

Q = 0.45*1*7.4 = 3.33 kW

(Note: Assume at 300 Degree Kelvin, Cp = 1 kJ/kg.k)

Based on this calculation, we had found heat transfer rate with respect to velocity as mentioned in table 2.

Table 2: *Variation of Heat Transfer Rate with respect to Velocity change*

Sr. No.	Velocity (m/s)	Heat Transfer Rate (kW)
1	3	3.33
2	5	4.01
3	7	5.18
4	9	3.47
5	11	2.83
6	13	2.24
7	15	0.91

6 Result and Discussion

After modelling and analysis, we got results through simulation of battery module of thermal management system. We have studied first plot of velocity verses temperature, in which we got result that, as we increase air flow rate the cell temperature goes below. The heat around cells is being carried out to outside the channel and the healthy condition for battery maintain. The air flow rate had significant role in cooing down temperature parameter. Analysis shows that if we had more flow rate the time required for cooling down reduced and hence it benefits battery capacity calculation.

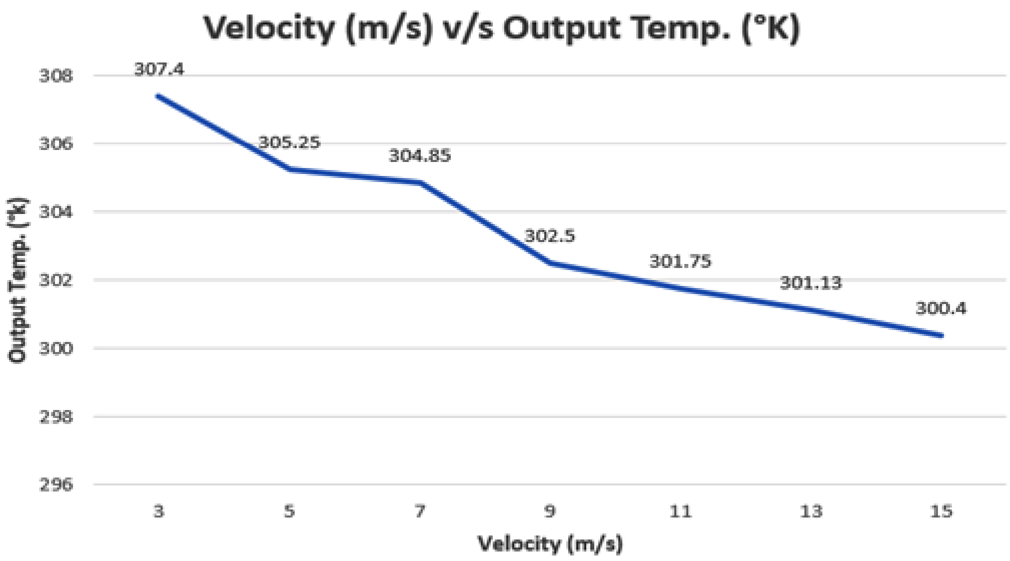

Figure 11: *Graph of* Velocity *Vs Output Temperature*

The second parameter which we have considered is Mass Flow Rate of air and here also we got helpful result. As we increase the flow rate significant drop in cell temperature can be easily shown. The mass flow rate mainly depends upon density of fluid and we had constant density value of air. The graph shows that mass flow rate is also a important parameter to reduce cell temperature and helps in maintain battery thermal management operations.

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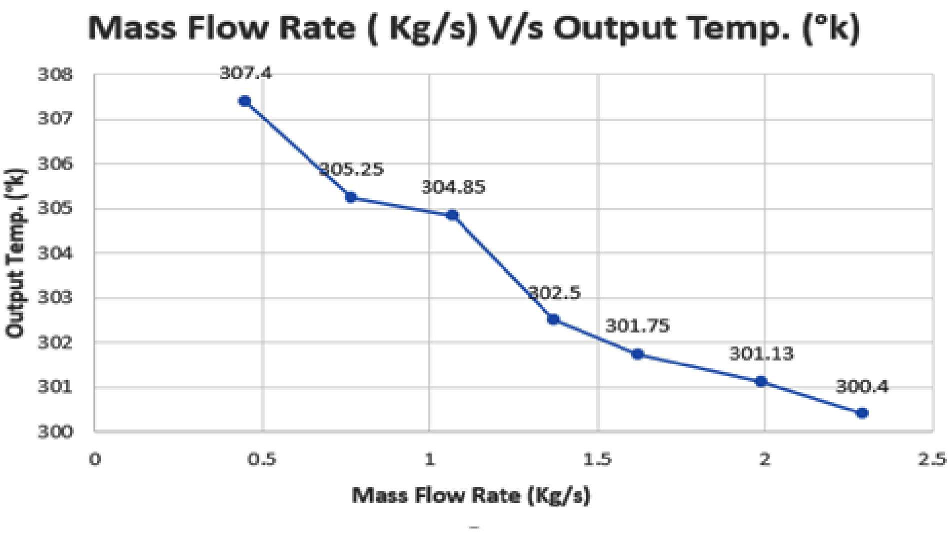

Figure 12: *Graph of Mass Flow Rate Vs Output Temperature*

During battery module design the heat transfer rate takes key role to remove heat from system depend upon fluid used in it. We know that for heat transfer rate first need to calculate heat transfer coefficient and them q can be calculated. We calculated Q and when graph is plotted, we get that after a certain velocity the amount of heat transferred in certain volume reduces as more volume of air is gone through over it. The decrease in fall states that we are successful in our operation to cool down cells and the finally we get small heat cause temperature automatically reduces to certain value near to which we provide intake air. So, we find that heat transfer rate is main key to design battery thermal management operations and analysis gives more correct result.

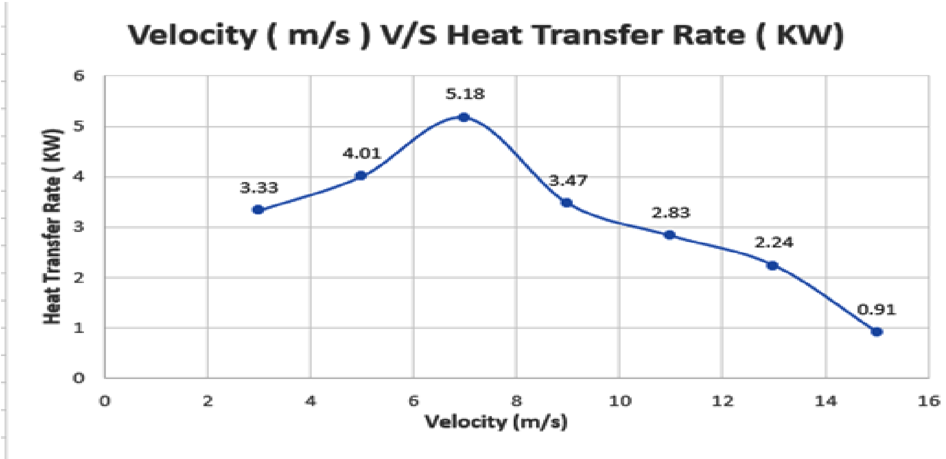

Figure 13: *Graph of Velocity Vs Heat Transfer Rate*

7 Conclusion

Because of high energy density and long cycle life, lithium-ion batteries are commonly utilized in electric vehicles. Temperature has a big impact on the performance and life of lithium-ion batteries, therefore it's crucial to keep them in the right range. Therefore, a numerical study of the heat generation phenomena and important thermal concerns of lithium-ion batteries is carried out. In a battery thermal management system, the velocity of the air and the mass flow rate of the air are two critical characteristics that determine the cooling performance. Furthermore, it has been observed that a 7 m/s air velocity provides the optimum cooling results. In future there is lot of chances to simulate model numerically and calculate proper temperature suitable for battery charging and discharging. The analysis can be also done for complete battery stack used in the electric vehicles.

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