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HEAT SPOT REDUCTION IN LITHIUM ION CELL AT HIGH GALVANOSTATIC ISCHARGE USING STAGGERED CELL ARRANGEMENT

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Abstract - *Abstract This research work presents three dimensional transient thermal response, flow field, velocity regimes and temperature regimes of four different Li-ion battery modules operated at constant current (25 A) for 500 seconds. The heat generation in the battery cell during discharge process is calculated to be 43171 W/m³. Different models were developed to generate turbulence which increases the heat dissipation rate. Two partial staggered modules with row displacement and column displacement and one fully staggered module has been analysed and compared with the original inline module. On the basis of heat transfer and reduction in heat spots the best module was found to be the one with row displacement.*

Key Words: *BTMS, Thermal Management, Li-ion cell, Li-battery, EV, HEV*

1. INTRODUCTION

Electric and hybrid electric vehicles in order to be considered as an effective replacement over the traditional internal combustion engines requires a high power and high energy density cell for the battery system, efficient battery thermal management system and the development of charging infrastructure for vehicle use. Extensive work on cell development was carried out, however, due to the high temperature limits of currently available cells, a highly efficient thermal management system is required.

Battery thermal management (including cooling and heating) is essential for electrically powered vehicles to maintain an optimal cell temperature in all weather conditions. The thermal imbalance between the cells has a major impact on the short and long term performance of vehicle battery systems. According to Arrhenius' law of battery electrochemistry, the reaction of batteries increases exponentially with the temperature of the battery cells. As a result, warmer cells break down faster than cooler ones, and these few overheated cells shorten the life of an entire battery. Due to overheating, the capacity of the cell quickly decreases. Manufacturers must ensure that a package can be used for eight to ten years without modification.

Due to its simplification air the preferred choice for cooling. The air-cooled system used forced cooling technology to keep the cell below the desired temperature range. The air system can be classified as an active or passive cooling system. The passive system can use ambient air or air-conditioned cabin air. The active system must be able to heat or cool the system if necessary.

2. LITERATURE REVIEW

Z. Rao et al. [1] Discussed and compared different thermal management techniques applied to different materials such as Phase Change Material (PCM) for battery thermal management system.

Andersen et al. [2] ddescribed that it is possible to reduce greenhouse gas emissions by up to 40% if electric vehicles are loaded with electricity from renewable sources.

S. Panchal et al. [3] Shows the severe effects of temperature on Lithium-ion batteries.

Z. Rao et al. [4] demonstrated the optimal range of temperature for Lithium-ion batteries

Sato et al. [5] confirmed that the incoming and outgoing heat depends on the charge and the discharge. The thermal generation factors are divided into three elements: the reaction calorific value Qr, the polarization calorific value Qp and the Joule calorific value QJ.

Giuliano et al. [6]] concluded in their research that these batteries must be actively cooled during operation to maintain safe operating temperatures.

Zang et al. [7] observed that the lithium-ion battery capacity decreases by up to 95% at low temperature (10° C) compared to 20° C

Jilte et al. [8] conducted three-dimensional transient thermal response, flow field, and thermal regimes analysis that have been developed in the battery module. Different air temperature profiles are confirmed in the direction of flow, as well as across the length and width of the coil. In some areas indicating localized hot spots.

3. GEOMETRIC MOELLING

The battery module contains nine cylindrical lithium-ion cells, which are arranged in various configurations in the direction of the airflow (Figure 3.2). The distance between cells is characterized by the transverse distance (S_T) and the longitudinal distance (S_L). Module dimensions can be represented as the radius of a battery cell (R) to facilitate the addition or removal of cells to vary the capacity of the battery module. Both S_T and S_L are assumed to be 3R. The width and width of the battery module are kept at 10R, while the height of the module is considered L + R. Here L is the length of the battery cell. The space above the cells allows good ventilation and space for circuit connection. A greater distance between the cells ensures sufficient circulation of the cooling air and the elimination of the gases generated by the batteries. Both sides of the battery module are held fully open for the inlet and outlet of the refrigerant. The dimensions of the lithium ion cell and its thermo-physical and chemical properties are given in Table 3.1. The battery material is considered isotropic. The components of the battery cell (cathode, anode, separator, current collecting tabs) can therefore be considered as a homogeneous body with constant values of thermal conductivity and specific heat. This assumption simplifies the numerical model with the lumped system, as explained in the following sections.

Parameters	Details
Battery details	Li-ion battery, cathode: $LiMn_2O_4$, anode: Carbon
Capacity, Ah	3.6
Number of cells	9
Diameter (D), mm	42.4
Length (L), mm	97.7
Mass of cell, kg	0.3
Density (ρ_b), kg/m^3	2007.7
Thermal conductivity (K_b) W/mK	1.0 (radial direction)
Specific heat, ($C_{p,b}$), J/kg K	837.4

Table -1: Thermo-physical properties of Li-ion battery

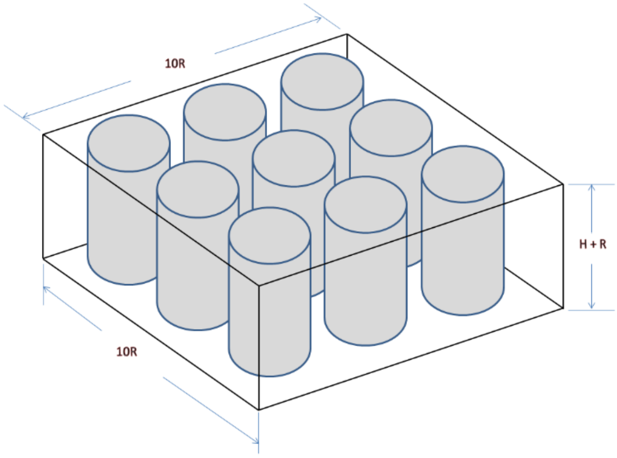
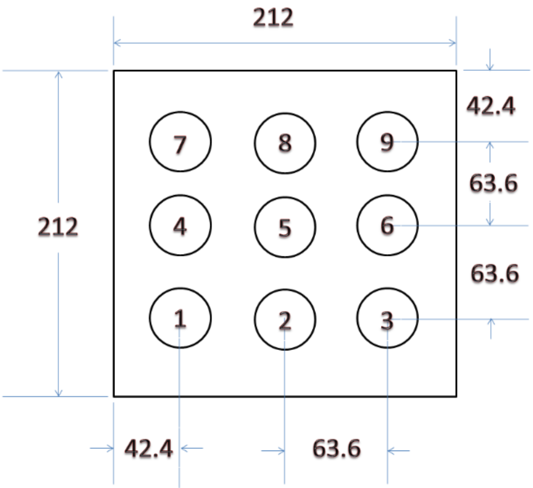
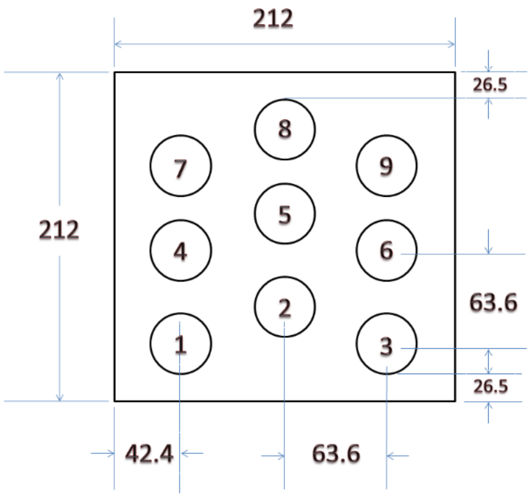


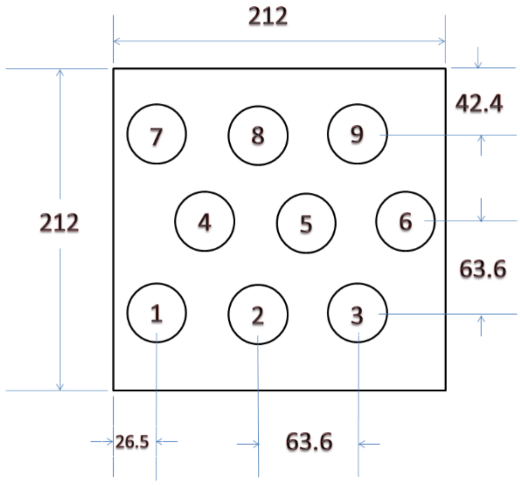
Fig -1: Battery module dimensions



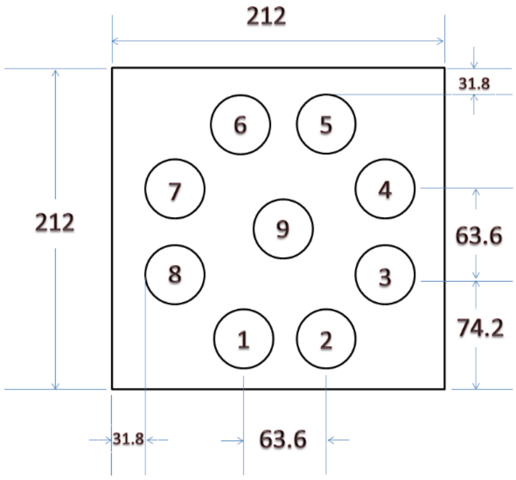
(a)



(b)



(c)



(d)

Fig -2: (a) Module-1: Simple inline arrangement; (b) Module-2: Column staggered arrangement; (c) Module-3: Row staggered arrangement; (d) Module-4: Completely staggered arrangement

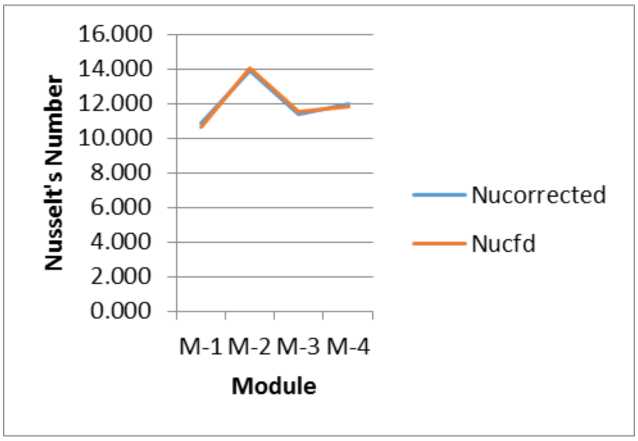


Chart -1: Comparison of empirical and CFD based Nusselt's number

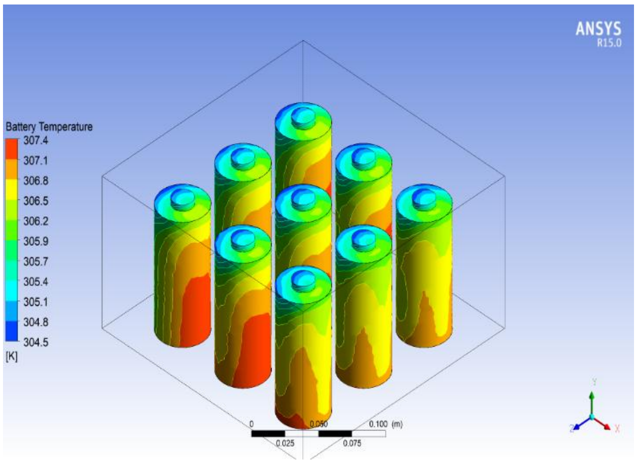


Fig -3: Temperature contour in M-1

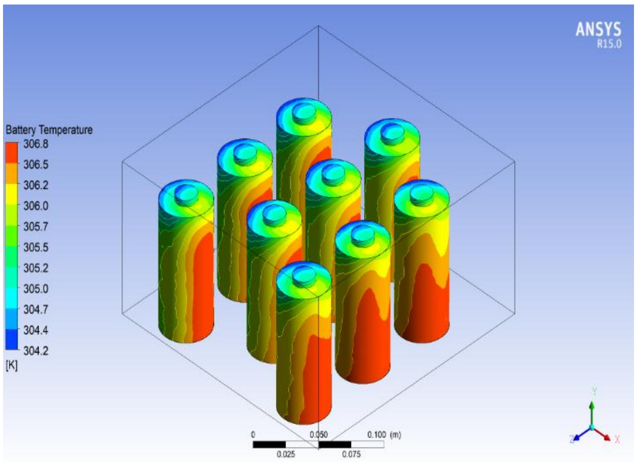


Fig -4: Temperature contour in M-2

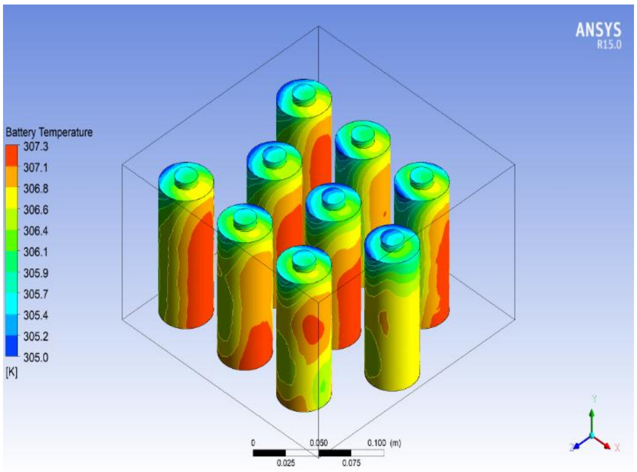


Fig -5: Temperature contour in M-3

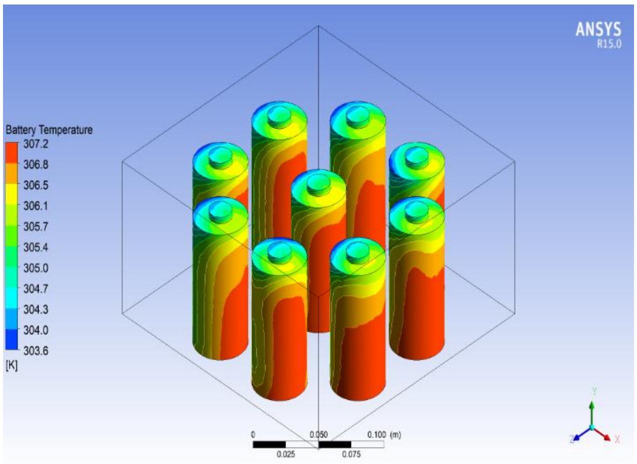


Fig -6: Temperature contour in M-4

4. RESULT

Module	Temperature (K)
1	306.204
2	305.78
3	306.218
4	305.798

Table -2: Area weighted average surface temperature of the battery cells

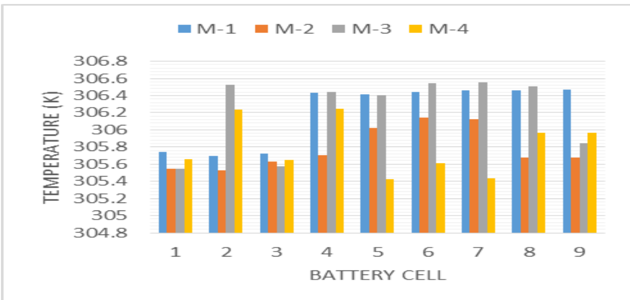


Chart -2: Comparison of area weighted average surface temperature of all battery cells in all modules

Module	Temperature (K)
1	307.832
2	306.872
3	307.292
4	307.014

Table -3: Maximum surface temperature of the battery cells for different modules

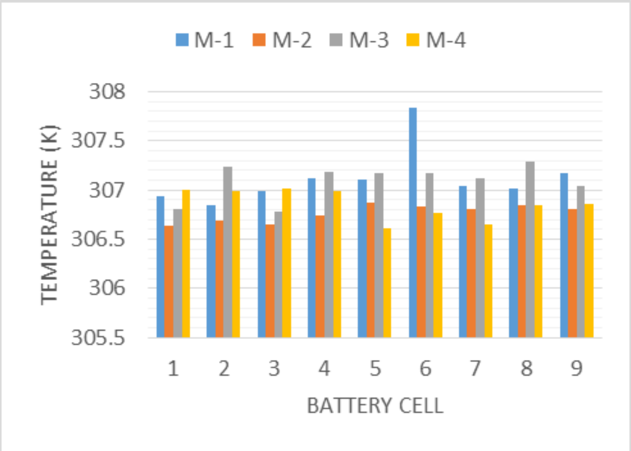


Chart -3: Comparison of maximum surface temperature of battery cells in all modules

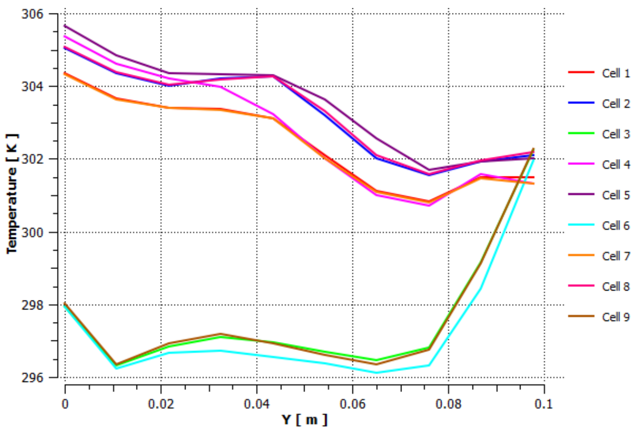


Chart -4: Temperature variation tracing heat spots along cell length for M-1

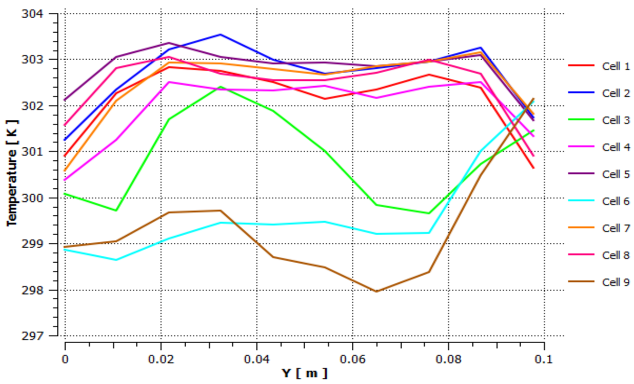


Chart -5: Temperature variation tracing heat spots along cell length for M-2

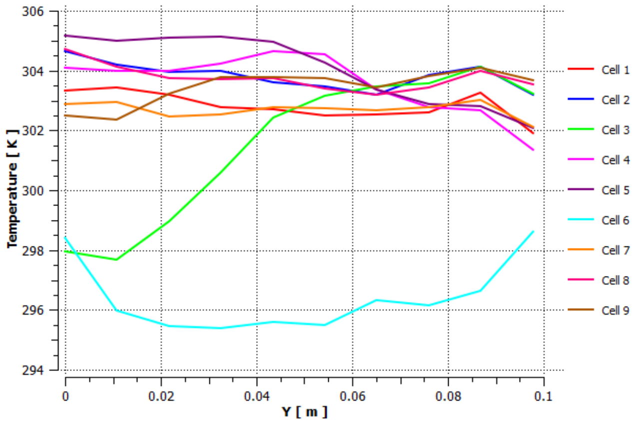


Chart -6: Temperature variation tracing heat spots along cell length for M-3

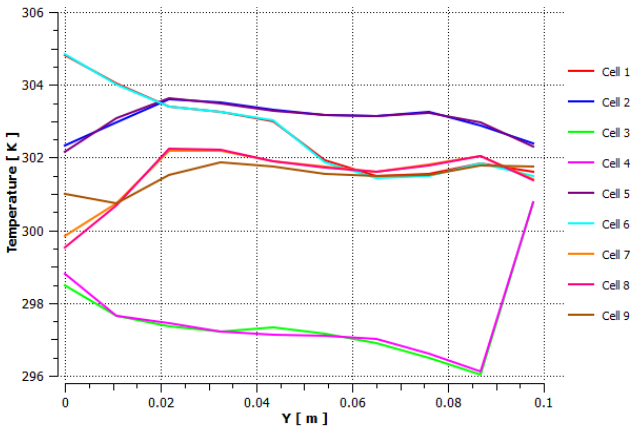


Chart -7: Temperature variation tracing heat spots along cell length for M-4

Module	M1	M2	M3	M4
Skewness	2.34	-0.36	-1.06	-0.61

Table -4: Skewness of temperature distribution in the cells for different modules

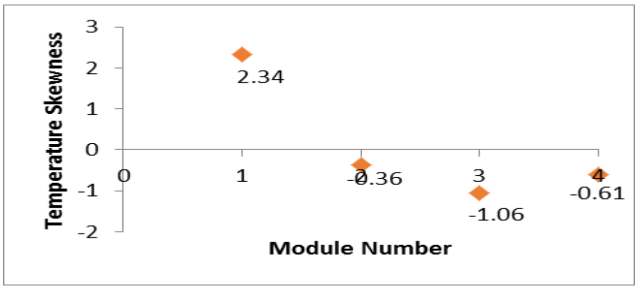


Chart -8: Skewness of temperature distribution in the cells for different modules

5. DISCUSSIONS

For the transient thermal analysis for different modules having different cell arrangements, following points were observed:

1. Module-2 has the least maximum temperature as compared to the other cell modules (shown in the table 4.2 and chart 4.2) which shows its better heat dissipation characteristic.

2. Module-2 has the highest value of Nusselt's number (chart 3.1) which confirms higher value of heat transfer coefficient and thus better heat dissipation.

3. Module-2 has the least skewness among the other cell modules (shown in the table 4.3 and chart 4.7) which shows that Module-2 has a uniformity of maximum temperature among its cells.

4. As compared to the maximum temperature of 307.832 K for the cell arrangement in Module-1, the maximum temperature of the cell arrangement in Module-2 drops to 306.872 K. With the ambient air temperature of 295 K at the inlet we observe a drop of 7.48% in the maximum temperature of the cell.

6. CONCLUSION

In the present work, three-dimensional numerical investigation has been carried out to determine the most efficient battery module out of the four modules with different cell arrangements. This analysis was conducted with a clear set objective to determine the module which reduces the heat spots and provides a better heat dissipation to the battery so that the detrimental effects of temperature on Lithium-ion cell can be minimized. To achieve this four different cell arrangements (Modules) were taken such that intermixing of fluid layers can be increased and flow separation effects can be decreased. To get the transient thermal response of the different cell arrangements transient thermal analysis was conducted using ANSYS-Fluent software. The conclusions drawn can be summarized as follows:

1. In 500s of the transient analysis, temperature of the cell increases from 295 K to a maximum of 307.832 K confirming the local heat spots.

2. Zones with local temperature maxima are observed in the middle of the modules.

3. Heat spots are observed in the regions affected with flow separation.

4. The extent of the flow separation is different across the depth of the cell.

5. The cell temperature differs from each other and is a function of position in the battery module.

6. With the increase in intermixing of layers the heat spots gets reduced.

7. Intermixing of fluid layers decreases the flow separation zones thereby reducing the maximum temperature of cell.

8. Module-2 reduces the maximum temperature developed in the cell of Module-1 by 7.48%. This proves out of the four different modules, cell arrangement in Module-2 has the most efficient heat dissipation characteristic.

9. Nusselt's number value for module-2 is 14.07 which is maximum as compared to the other modules, which shows higher heat dissipation rate.

10. Temperature of cells in Moule-2 has the least skewness which shows its ability to maintain more uniform temperature within its cells.

7. FUTURE SCOPE

1. The mesh generated can be further refined to accurately detect the heat spots generated in the battery cell.

2. Mesh inflation can be easily calculated and applied to capture more accurate boundary layer and flow separation details.

3. A user defined function can be created in ANSYS software to trace the accurate variation of heat generated with the rising temperature in the Lithium ion cell.

4. Pulsating flow can be provided to create turbulence in the cooling fluid medium which can enhance the heat transfer rate.

5. To counter the effect of flow separation completely guides can be provided at some specific positions.

6. By using phase change material the heat capacity of the cooling medium can be increased.

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