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Lithium-Ion Battery Thermal Management System For Electrical Vehicle Application

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Abstract:

This paper presents lithium-ion battery thermal management is difficult to achieving the better performance and extended life of batteries and state of charge in electrical vehicles. Li-Ion battery is the major source among the Electric Vehicles and Hybrid Electrical Vehicle. To get better the thermal effectiveness and to raise the calendar life of battery, appropriate newly introduced orthosilicate complex Li2MSiO4 is use as a cathode substance to improve the thermal behaviors of batteries. It is the cheap substance with high early allege profile and enhanced ionic conductivity and has better temperature withstand capacity. The Computational fluid flow analysis is done using ANSYS FLUENT v6.3.2.6 software to analysis thermal system of battery and investigates the thermal flow in battery during state of charge and discharge.

Keywords: Lithium Ion battery, State of charge, ANSYS FLUENT, Electric Vehicle, Hybrid Electric Vehicle.

I.INTRODUCTION

The Hybrid Electrical Vehicles (HEV) and Electrical Vehicles (EV) become more popular in recent days due to various factors like greenhouse gases and exhausting fossil fuels. The battery becomes the most important source for Energy Storage System (ESS) in Hybrid Electrical Vehicles (HEV) and Electrical Vehicles (EV). Among the battery Energy storage system lithium based battery have high voltage, good energy density, low self discharge rate of good stability as become the major source for Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV) [1]. In conventionally HEV and EV use Nickel Metal Hydride (N-MH) and Lead acid batteries has storage system which has minimum energy density and reasonable price. However Lithium battery has high calendar life and high energy density is preferred for HEV and EV vehicle which is readily available in the market [2]. Although Lithium Ion battery have very high performance sensitive towards the thermal problem like continuous charging, discharging working under high temperature become the major impact lead to cell degradation affect Lithium battery life and performance of the battery. The battery management system investigates the important parameters like state of charge, state of health of battery. An Effective thermal management system must to maintain in battery pack of HEV and EV system that could maintain the operating temperature in the lithium battery for batter State of charge (SOC) and improved calendar life of Lithium-Ion batteries [3,4]. Various thermal management systems for battery pack are their like air and liquid are used as cooling medium. Finite Element Analysis of Lithium –Ion battery for Electric vehicle application [5] propose a new material for cathode of Lithium–Ion battery a recently introduced Orthosilicate Compound Li2MSiO4 is used as cathode material. It is the cheapest material with high initial charge profile and improved ionic conductivity and has better temperature withstand capacity [6]. The main purpose of the study is carried out the thermal flow analysis to investigate the temperature distribution at the state of charge and discharge condition of the Lithium Ion battery module used for an EV.

II.STRUCTURE OF LITHIUBAM AND OPERATION BATTERY

Structure And Operation

The Lithium Ion battery consists of negative electrode (or anode), positive electrode (or cathode), electrolyte, separator, the negative and positive electrode are separated by the separator, and the electrodes are filled with electrolyte are shown in Fig1. The electrolyte act as good ionic conductor, it acts as a transport medium for lithium ions to travel between two electrodes. The exothermic reaction taken place inside the batteries, the chemical energy is converted into electric energy [7]. It based on the second law of thermodynamics, the energy loss occurs inside the battery because of conversion between two forms of energy.

Selection of Nano Material for Cathode

The choice of advanced material for cathode is preferred to reduce the thermal issue problem in Li battery. The cathode materials are developed with high energy density, safety, durability, less cost, and high calendar life.

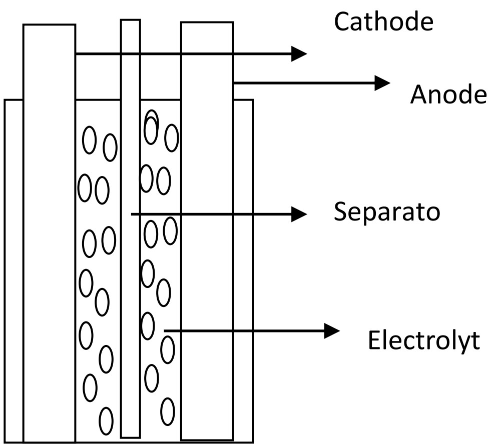

Fig1: Schematic Diagram of Li-Ion Battery

In the study of cathode material in recently developed materials are Olivine structure (LiMPo4) (LiFePo4), Orthosilicate structure (Li2MSiO4) are the advanced developed nano materials [8]. In this analysis Orthosilicate structure (Li2MSiO4) has been used as the cathode material for the optimization of thermal issue problem in Li batteries.

Orthosilicates Li2MSiO4 (M = Fe, Mn, Co) has been selected as the novel Cathode material for Lithium Ion battery. Li2MSiO4 The reversible capacity of Orthosilicate cathode material greatly benefited from the improved conductivity and was able to achieve 150 mAh/g at 25 8C and 200 mAh/g at 55 8C [9,10]. To improve the ionic conduction and chemical performance the carbon coating is done and Li2MSiO4 to 209 mAh/g reversible capacity on the first charge Table1.

Material	Structure	Potential versus Li/Li+, average V	Specific capacity mAh/g
LiCoO2	Layered	3.9	140
LiNi0.8Co0.15Al0.05O2 (NCA)	Layered	3.8	180-200
LiMn2O4 and variants (LMO)	Spinel	4.1	100-120
LiFePO4 (LFP)	Olivine	3.45	150-170
Li2MSiO4	Orthosilicates	4.8	150-200

Table1: Characteristics of Li Ion Cathode material

II.COMPUTATIONAL FLUID DYNAMICS MODEL

A 12v 20ah Lithium battery measuring of 10 mm thickness and 305 mm in height is shown in Fig2, in closed plastic casing with small amount of air gap in the side of casing [15]. Therefore a three-dimensional model has been developed. The dimensions of different domains (Electrodes domain, Separator and Electrolyte) of the battery are described. The each domain is made of different materials. A thermal flow analysis of conduction equation is sufficient to describe the thermal issued in the battery and the convective term inside the battery (electrode-electrolyte) can be neglected [11]. The model of geometry of battery was developed in the AutoCad11 and imported in ANSYS Fluent Fig2.

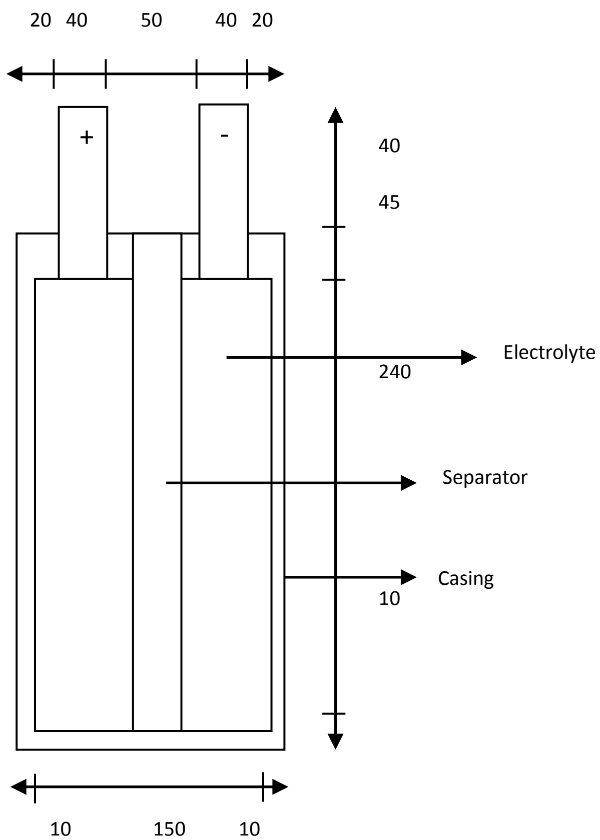

Fig 2: Schematic Model and dimension of Li Ion Battery.

The boundary condition and the energy balance equation of the lithium ion battery model enable to predict the transient response and the temperature distribution for the 3D fluent flow analysis modeling is formulated as [12]:

- In the Positive and Negative Electrodes domain

$$k[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial z^2}]+q_g=\rho.c_\rho\frac{\partial T}{\partial t} \quad (1)$$

$$q_g=\frac{1}{V_{batt}}[RI^2+(T[\frac{dE}{dT}])I] \quad (2)$$

In the terminal domain

$$k[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial z^2}]=\rho.c_\rho\frac{\partial T}{\partial t} \quad (3)$$

Where $\rho(Kgm^{-3}), C_p(J.Kg^{-1}.K^{-1}),$ and $k(W.m^{-1}K^{-1})$ are the average density, the average specific heat and the average thermal conductivity along the x-direction y-direction and z-direction. The density of heat flux from battery surface to the surrounding is given by both the radiation and the convection heat contributions.

$$q_s=h(T-T_a)+\in\sigma(T^4-T_a^4)$$ Where (4)

$h(W.m^{-2}K^{-1})$ is the heat transfer coefficient, ε the

Material	Emissivity
Graphite	0.96
Orthosilicate	0.89
Separator (Polyethylene)	0.81
Fluid (LiPF6)	0.76
Plastic	0.85

emissivity of the battery cell surface, σ the Stefan–

Table 2: Radiation of material PropertiesBoltzmann constant, T the battery surface temperature and Ta is the ambient temperature. The battery is painted black, and then the emissivity is taken equal to 0.95. In this case the battery is cooling by natural convection. In natural convection, the Rayleigh number controls the flow system [13]. The Rayleigh number is defined as:

$$Ra=\frac{g\beta_{air}(T-T_a)^{L^3}}{V^2_{air}} \quad (5)$$

Where: g: The acceleration of gravity (m/s2) L: The length of the battery (m) .The thermal parameters used in this work are listed in Table1

Material	Density (Kg/m3)	Specific heat (J/Kg/K)	Thermal Conductivity (W/mK)	Viscosity
Fluid LiPF6	1050e3	140.8	1.9	0.789
Plastic	1402	1052	0.18	-
Anode (Graphite)	2460	830	1.2	-
Cathode (Li2MSiO4)	2400	712	2.2	-
Separator (Polyethylene)	960	180	0.12	-

Table 1: Thermal Properties of Material model

To know the heat generation value and the temperature distribution the battery pack is stimulated using the ANSYS Fluent Software with the thermal parameters. Table 2 shows the radiation of material properties [14].

III.MATHEMATICAL MODELING

Heat transfer on the solid material in the mode of conduction

$$q=kA\Delta T \quad (6)$$

Unit of heat transfer $w/m^{2\,o}c$ where K is thermal conductivity, A is the area, ΔT is the temperature difference. Heat transfer coefficient $\frac{q}{A}=h\Delta T$

(7) Unit of heat transfer $w/m^{2\,o}c$ where K is thermal conductivity, A is the area, ΔT is the temperature difference. Heat transfer on the fluid is based on convection mode of heat transfer $L=\frac{A}{P}$ Where A is the area, P is the perimeter Rayleigh number

$$R_{aL}=\frac{g\beta L^3(T_s-T_\infty)}{\vartheta\alpha} \quad (7)$$

$R_{aL}<10^9$ Heat Transfer on the vertical plate

Nusslet Number

$$\overline{N_{uL}} = 0.59 R_{aL}^{1/4} \; for 10^4 < R_{aL} < 10^9 \quad (8)$$

$$\overline{ht} = \frac{\overline{N_{uL}} k}{L} \quad (9)$$

Unit of heat transfer $w/m^2 k$, where $\overline{N_{uL}}$ is the Nusslet number, K is the thermal conductivity, and L is the length in the vertical plane.Rate of heat transfer

$$Q = \bar{h} L (T_s - T_\infty) \quad (10)$$

Unit of rate of heat transfer is watts, Q is the rate of heat transfer, $\bar{h}$ is the heat transfer rate, L is the length, T_s is the temperature Overall heat transfer

$$Q = \frac{T_a - T_b}{\frac{1}{A}\left[\frac{1}{h_a} + \frac{1}{h_b} + \sum \frac{L_n}{k_n}\right]} \quad (11)$$

Where h_a the heat is transfer coefficient of solid and h_b is the heat transfer coefficient of the liquid.

IV.ESTIMATING CHARGING AND DISCHARGING CHARACTERISTICS OF BATTERY

The estimation of SOC and DOC in the power battery of electric vehicles is important parameter. The SOC means ratio of reaming power under the rated condition of the capacity. When battery under discharge ratio condition. The mathematical expression of SOC [16].

$$\text{SOC} = \frac{p_a \times t_{res}}{\int_0^{t_0} P(t)dt + p_a \times t_{res}} \quad (12)$$

The state of charge and depth of discharge of battery depends on the internal resistance Ri ohm. The internal resistance of the conventional lithium battery pack is 0.9ohm it leads to slower charging and increases in temperature and affects the calendar life of battery pack. To reduce the internal resistance of the battery and to make the battery quick charging and increasing discharging time. The thermal management is important by using the high thermal resistivity cathode material Li2MSiO4.

$$R_i = \frac{[C_{bat} + C_{cell}] \times [T_2 - T_1]}{\int_{t_1}^{t_2} (I(t))^2 dt} \quad (13)$$

From the equation 13 we can estimate the internal resistance of the battery. Ccell is the cell voltage and T is the temperature of the battery. C_{bat} is the heat capacity from the above equation the internal resistance of the proposed battery is calculated 0.041ohm. With the reduced internal resistance of the battery we can state that battery have maximum conductivity and reduced charging time. SOC is 100% at fully charged condition. The charging current rate 10A C-rated 0.5C. The charging time of battery calculated using the formula. SOC =current capacity/ nominal capacity. The battery charging time can be estimated using the C-rated and charging time of battery. With the minimum C-rated the battery can be charged in 2 hours [17]. The discharge current rate can calculated using the Perukerts law

$$T = H\left(\frac{C}{IH}\right)^k \quad (14)$$

Where H rated discharge, C is the rated capacity, I is the actual discharge current, K is the Perukerts constant. From the above equation discharge amp of battery is 1A and C-rate of discharge is 0.05C the battery discharged in 20hours. The discharge time of battery is increased compared to the conventional battery pack. Fig3 shows the discharge characteristics of conventional LicoO4 battery discharging time 6.66hours.

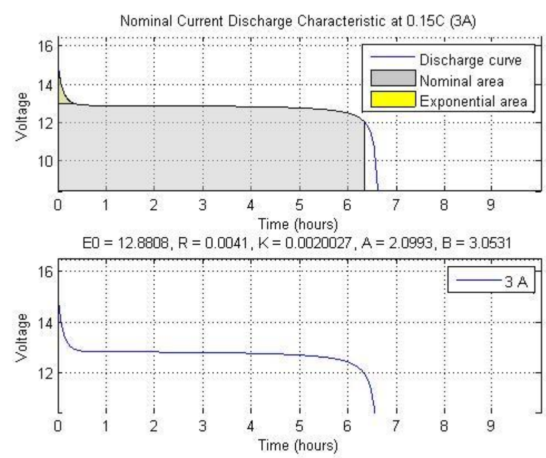

Fig 3: Discharge Characteristics of Conventional battery using LiCoO4 cathode material

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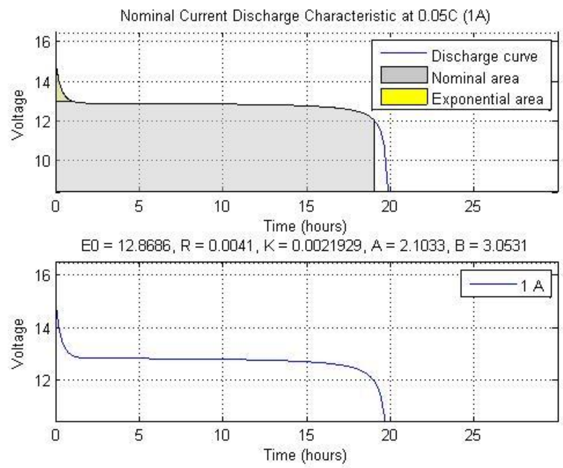


Fig4: Discharging characteristics of proposed battery using LiMSiO4 cathode material.

V.COMPUTATIONAL FLUID DYNAMICS RESULTS

The temperature distribution of the Lithium ion battery using orthosilicate cathode material under steady state condition is shown in the Fig 4. The battery initialized starting from minimum of 26 degree Celsius and increased to maximum 59 degree Celsius.

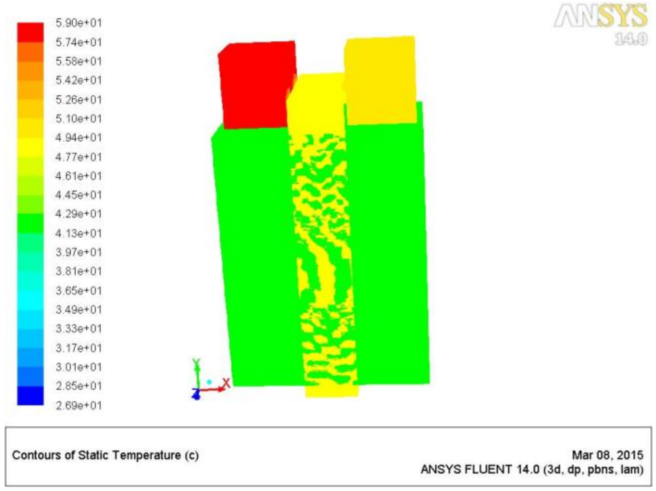


Fig 5: Temperature distribution using conventional material LiCoO4 under steady state condition after 5p discharge rate. The temperature distribution of the Lithium ion battery using orthosilicate cathode material under steady state condition is shown in the Fig 5. The battery initialized starting from minimum of 26 degree Celsius and increased to maximum 49 degree Celsius. The temperature distribution under transient condition after 750sec, 1800sec and 5500sec under 5p discharge rate of battery is analyzed. The temperature rise in the battery after 750sec under 5p discharge rate in shown in the Fig 6 the temperature starts from the minimum of 24 degree Celsius and increased to maximum of 39 degree Celsius.

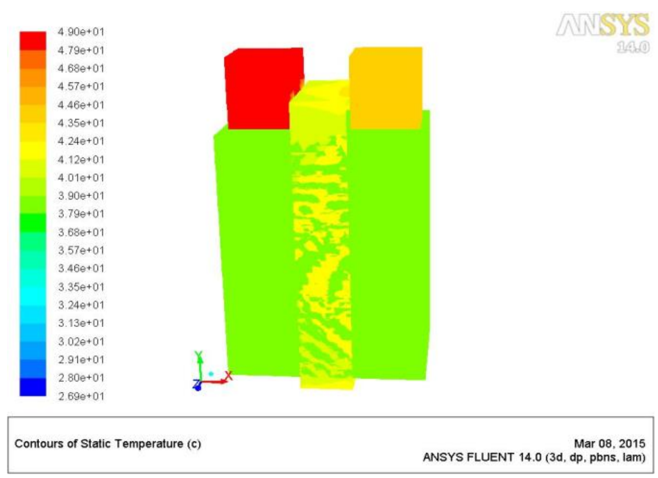


Fig6: Temperature distribution using proposed material Li2MSiO4 under steady state condition after 5p discharge rate. The temperature start increased when the operating time of the battery increased the temperature distribution in the battery after 1800sec and 5500sec is also shown in the Fig 7 and Fig 8. Under 5p discharge rate the temperature after 1800sec are 24 degree Celsius to 46.5 degree Celsius, temperature after 5500sec are 24 degree Celsius to 49.5 degree Celsius.

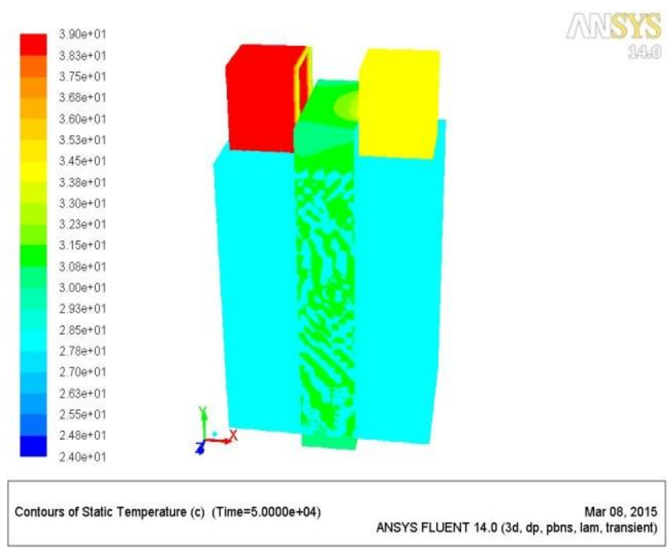


Fig 7: Temperature distribution after 750sec under 5p discharge rate

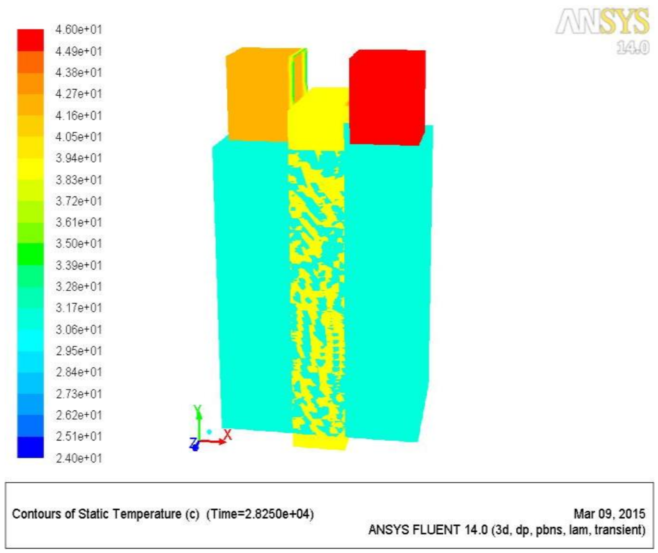


Fig 8: Temperature distribution after 1800sec under 5p discharge rate

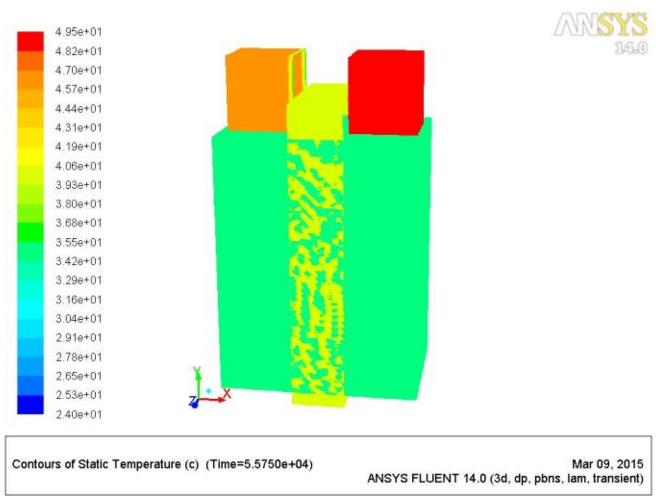


Fig9: Temperature distribution after 5500sec under 5p discharge rate

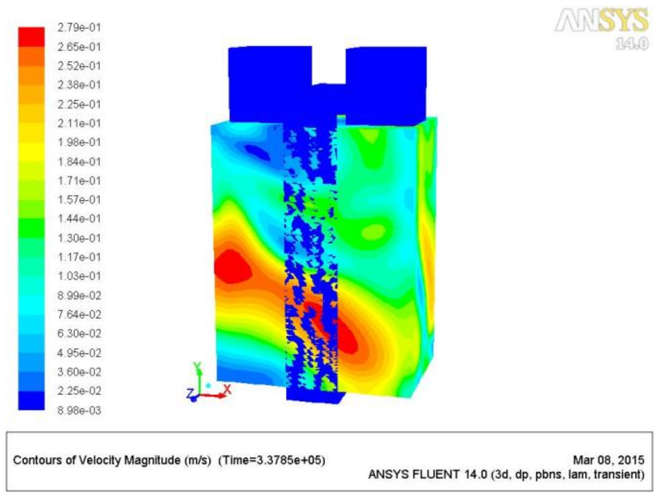
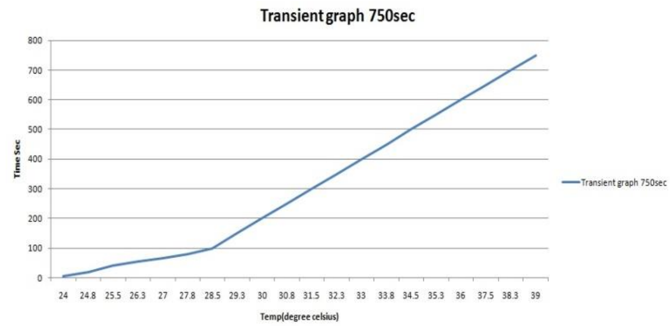


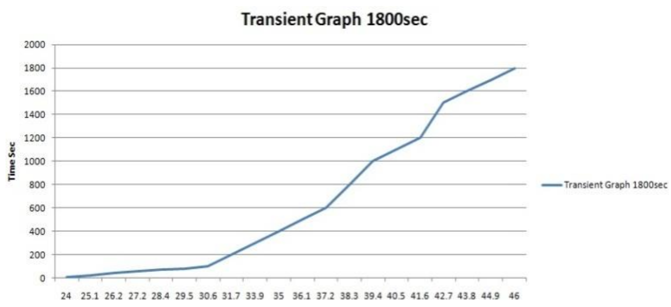
Fig 10: Velocity magnitude of the Fluid inside the battery

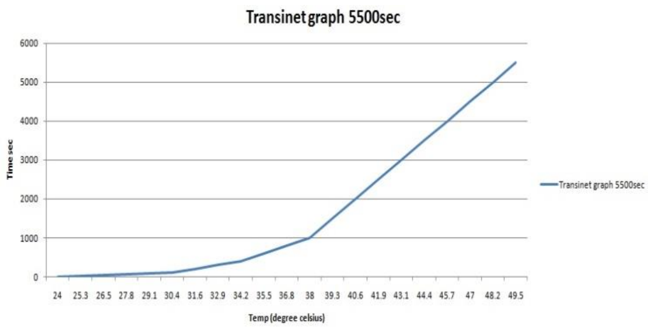
The fig 9 shows the velocity magnitude and velocity vector of the fluid inside the battery. The batteries during discharge time have reversible reaction. The fluid and ions flows at certain velocity rate at the time charge and discharge. The velocity of fluid depends on the temperature rise in the battery.

VI. GRAPH RESULTS OF TRANSIENT THERMAL CONDITION

The transient thermal result of Lithium Ion Battery under 5p discharge rate at different discharging time 750sec, 1800sec and 5500sec. This graph result shows the temperature rise in the battery during different discharging time.







VII.CONCLUSION

The simulation was done to determine the thermal run away problems in the battery pack and to find the better solution for battery management system. The CFD simulation model had done to 12v 20ah Lithium battery pack under worst case loading condition to find maximum temperature rise at transient condition. This analysis reveals that conventional battery reaches maximum temperature of 59 degree Celsius at peak usage of power. In this case the battery heated more and leads to thermal runaway problem, the air convection cooled not protected the battery properly, the model was adapted to stimulate a cooling system by changing the cathode material in the battery. The Orthosilicate cathode material used the maximum temperature reduction 10 degree Celsius, a 16.5% reduction in the temperature rise. The maximum battery temperature was reduced to 49 degree Celsius for the maximum power drawn in electrical vehicle operating condition.

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