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Thermal Management and Control in Hybrid Electric Vehicle Li – ion Battery

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Abstract: This paper presents the thermal management of lithium - ion batteries in electric vehicles that is difficult to achieve better performance and longer battery life. The battery of Li - Ion is the main source of Electric Vehicles and Hybrids Electrical Vehicles. The newly introduced orthosilicate compound Li2MSiO4 is used as a cathode material to improve the thermal behavior of batteries in order to improve thermal efficiency and increase the calendar life of the battery. It is the cheapest material with a high initial load profile and improved ionic conductivity and can withstand better temperatures. The computer fluid flow analysis is carried out using the software ANSYS FLUENT v6.3.2.6 to analyze the battery's thermal system and to investigate the battery's thermal flow during charging and discharge.

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

1. 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 uses 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 examines important parameters such as charging status, battery health.

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].

Different battery pack thermal management systems are similar to air and liquid is used as a 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 a high initial load profile and improved ionic conductivity and is able to withstand better temperature [6]. The main purpose of the study is the thermal flow analysis to investigate the temperature distribution of the Lithium Ion battery module used for an EV at the state of charge and discharge.

2. STRUCTURE OF LITHIUBAM AND PERATION TTERY

2.1 Structure and Operation

The battery of Lithium Ion consists of a negative electrode (or anode), a positive electrode (or cathode), an electrolyte, a separator, a negative and a positive electrode is separated b y a separator, and the electrodes are filled with an electrolyt e 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.

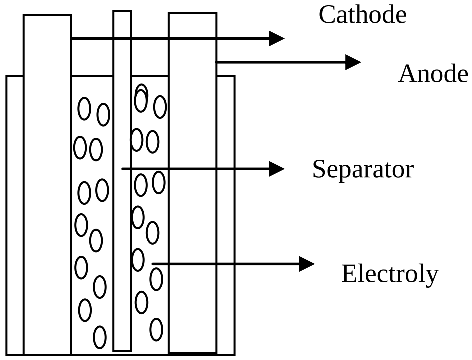

Figure 1. Schematic Diagram of Li-Ion Battery

2.2 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. 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) was selected as the novel Cathode material for the battery of lithium ions. Li2MSiO4 The reversible capacity of orthosilicate cathode material benefited greatly from improved conductivity and reached 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.

Table 1. Characteristics of Li Ion Cathode material

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

3. 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]. A three - dimensional model was therefore developed. The dimensions of different domains (Electrodes domain, Separator and Electrolyte) of the battery are described. The each domain is made of different materials. The thermal flow analysis of the conduction equation is sufficient to describe the thermal emission in the battery and the convective term in 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.

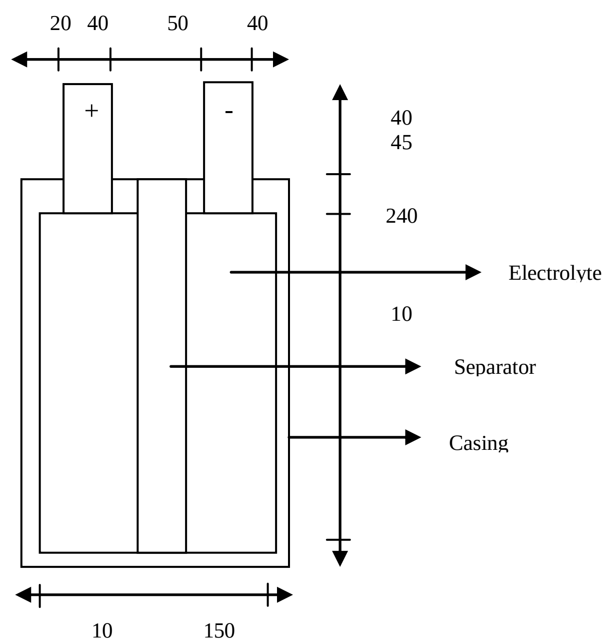

Figure 2. Schematic Model and dimension of Li Ion Battery

The boundary condition and the energy balance equation of the lithium ion battery model make it possible to predict the transient response and temperature distribution for the modeling of 3D fluent flow analysis [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 flow from the battery surface to the surrounding area is determined by both the contribution of radiation and convection heat:

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

Where

$h(W.m^{-2}K^{-1})$ is the heat transfer coefficient, ε the emissivity of the battery cell surface, σ the Stefan–Constant Boltzmann, battery surface temperature T and ambient temperature Ta. The battery is painted black, and the emissivity is 0.95. The battery cools by natural convection in this case. The Rayleigh number controls the flow system in natural convection[13]. The number of Rayleigh 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

Table 1. Thermal Properties of Material model

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	-

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].

Table 2. Radiation of material Properties

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

4. 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

$$\frac{q}{A}=h\Delta T \quad (7)$$

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

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

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

Unit of heat transfer w/m^2k, 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

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

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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

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

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

5. 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. Reduce the battery's internal resistance and rapidly charge the battery and increase the discharge 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 battery's reduced internal resistance, we can show that the battery has 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 am the actual discharge current, K is the constant of Perukerts. 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.

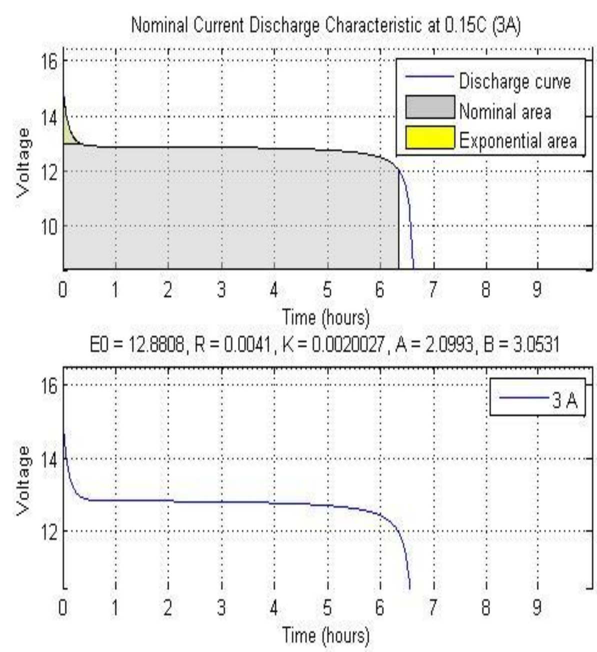

Figure 3. Discharge Characteristics of Conventional battery using LiCoO4 cathode material

Fig 4 shows the discharging characteristics of proposed battery using LiMSiO4. The discharging time 20hour

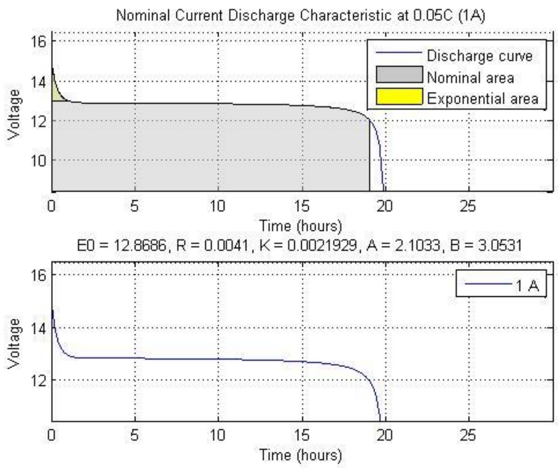

Figure 4. Discharging characteristics of proposed battery using LiMSiO4 cathode material

6. COMPUTATIONAL FLUID DYNAMICS RESULTS

The temperature distribution of the battery of lithium ion using orthosilicate cathode material is shown in Figure 4. The battery initialized starting from minimum of 26 degree Celsius and increased to maximum 59 degree Celsius.

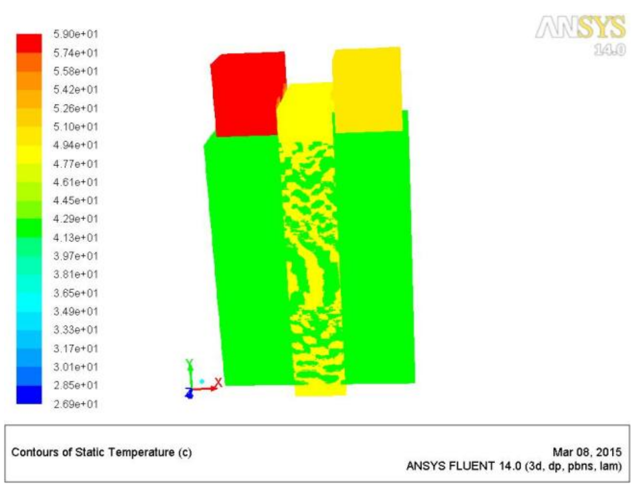

Figure 5.Temperature distribution using conventional material LiCoO4 under steady state condition after 5p discharge rate

Figure 5 shows the temperature distribution of the lithium ion battery using orthosilicate cathode material in a stable state. 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

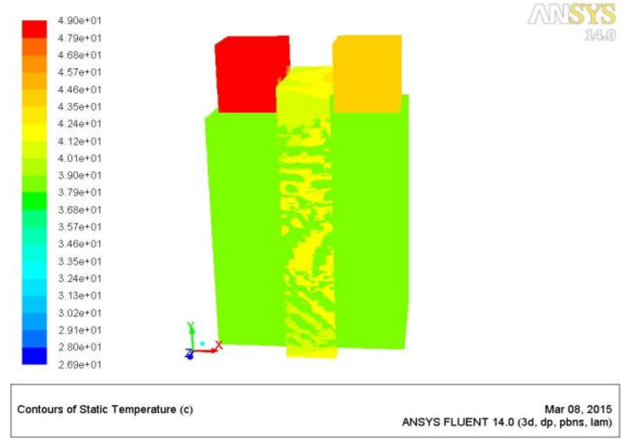

Figure 6. Temperature distribution using proposed material Li2MSiO4 under steady state condition after 5p discharge rate

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.

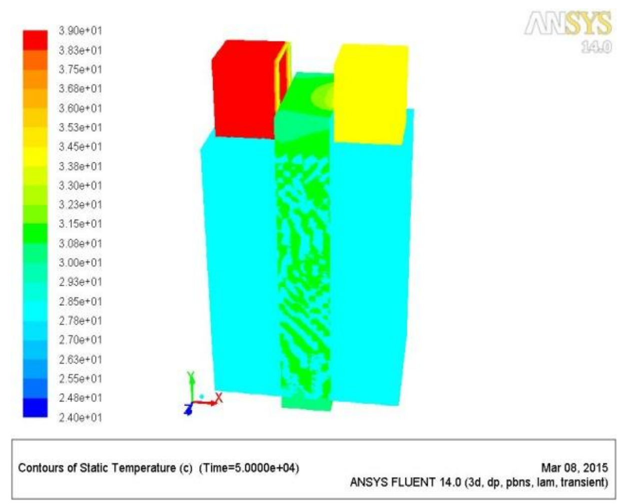

Figure 7. Temperature distribution after 750sec under 5p discharge rate

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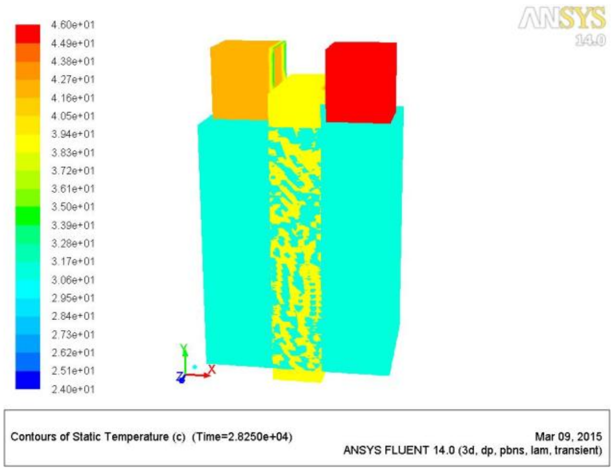


Figure 6. Temperature distribution after 1800sec under 5p discharge rate

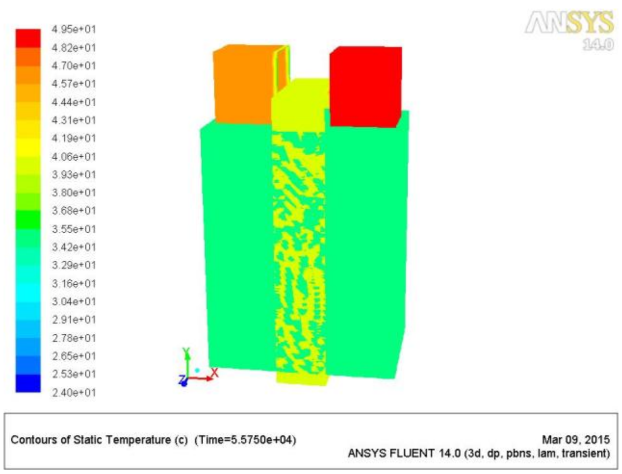


Figure 8. Temperature distribution after 5500sec under 5p discharge rate

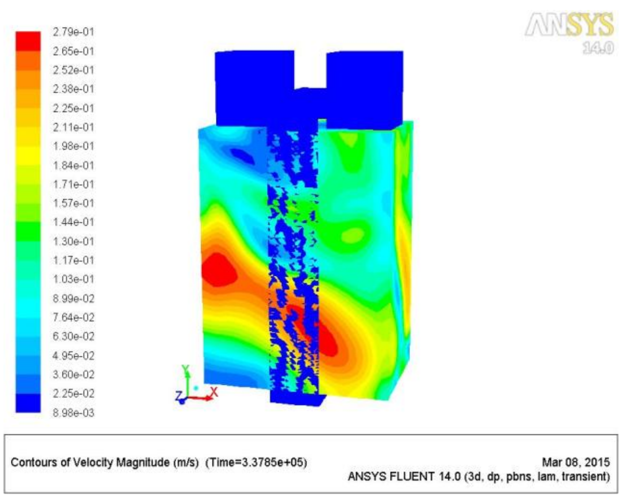
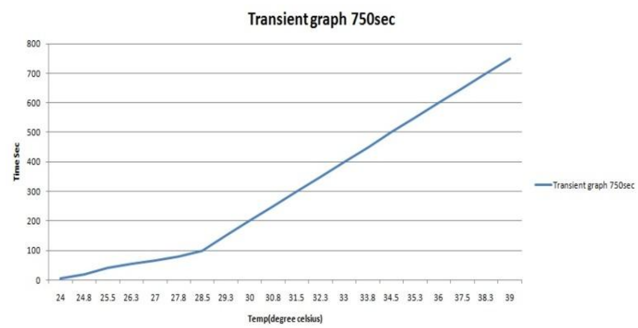


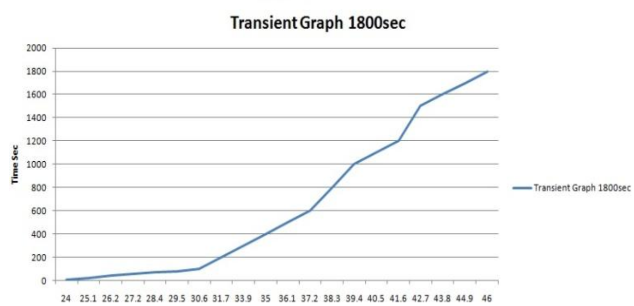
Figure 9. Velocity magnitude of the Fluid inside the battery

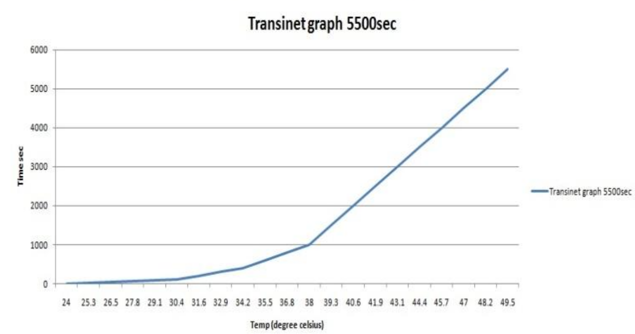
Figure 9 shows the fluid in the battery's velocity magnitude and velocity vector. The batteries during discharge time have reversible reaction. The fluid and ions flows at certain velocity rate at the time charge and discharge. The velocity of the fluid depends on the increase in battery temperature.

7. GRAPH RESULTS OF TRANSIENT THERMAL CONDITION

The transient thermal result of the Lithium ion battery at different discharge times of 750sec, 1800sec and 5500sec at 5p discharge rate. This graph shows the increase in battery temperature during various discharge times.







8. 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

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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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