

# Experimental Investigation on the Performance Improvement in the Lithium-Ion Battery for the Electric Vehicle

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## ABSTRACT

Lithium-ion batteries are the most commonly used as power source for many portable applications due to its high energy density, high nominal voltage, less maintenance, and low self-discharge rate. In this experiment, the thermal behavior of Li-ion batteries was analyzed at different state of charge (SOC) levels. The results of SOC estimation are demonstrated by using single cell of Li-ion battery. For the safe packaging of the battery, sand, vermiculite and absorbent are tested as a packing material by keeping these materials at distances of 15mm, 30mm, 45mm and 60mm from the cell of Li-ion battery. The result shows that the cell having 100% SOC level showed the highest peak temperature at around 579°C. The next peak temperature is showed around 539°C for the battery which contained 50% SOC level. The lowest temperature attained is 371°C when the battery SOC level is around 10%. By maintaining the SOC levels which is 50% and below at the cell level can improve battery performance, life and safety of the vehicle. In the electric vehicle, the effect of SOC needs to be considered when designing the battery pack and level of SOC should be maintained and monitored by the BMS at all the time. Also, for packaging materials, sand is the best among all three tested insulating materials due to its highest thermal conductivity and lowest thermal diffusivity.

**Keywords:** *Lithium-ion battery, 18650 type Li-ion cells, SOC, Packaging materials, Vacuum furnace*

## 1. INTRODUCTION

The current energy economy based on fossil fuels is at risk due to increase in demand for oil and depletion of non-renewable resources. Another factor for dominant the energy economy is the continuously generation of various emission by combustion of fossil fuel. These emissions are almost double from last thirty years and creating upward thrust in earth temperature that associated with a series of dramatic weather changes. So, the controlling these emissions is necessary. The alternate for this is to replace these resources with ideally zero emission fuel i.e. with renewable energy resources, electric powered vehicles (EVs) or, at least, by using controlled emission vehicles, i.e. complete hybrid electric powered vehicles (HEVs) and/or plug-in electric powered vehicles (PHEVs). In accordance with the development of new technologies for the use of renewable energy resources and energy generating plants based upon these resources are increasing worldwide. The intermittence of those assets requires excessive efficiency strength storage systems.

Electrochemical systems, such as batteries and brilliant capacitors that can properly store and distribute energy on demand. The electric vehicle which require power from battery and require batteries which is capable to deliver high energy efficiency and high power output in order to compete with current IC engines. The efficiency of batteries in REPs is directly associated with their content material in power performance and lifetime. Indeed, Lithium batteries are expected to deliver an energy go back factor better than traditional batteries.

In contrast to simpler batteries, lithium-ion batteries have been developed into electronic controls which regulate how they charge and discharge. They prevent overloading and overheating which in some circumstances can cause lithium-ion batteries to explode

A review of the literature suggests that considerable efforts have been made in the performance improvement of lithium ion batteries and thermal management of Li-ion battery. The literature review is categories in two sections such as thermal management for the battery, improvements in performance of Li ion battery.

### 1.1 Improvements in Performance of Lithium Ion Battery

The literature shows that considerable efforts have been made in the performance improvement of lithium ion battery. *Zhang et. al. [1]* investigated the performance and studied the safety characteristics of the anode with alloys to increase their high energy capacity. The result of this experiment showed that the anodes with alloy material gave 20% extended life with very minimal capacity loss when compared to other anodes. *Chan et. al. [2]* experimented about the silicon nanowires anode material for high performance. The result of added silicon over the anodes gave 30% of more charge capacity than the graphite-based anodes which can improve the efficiency of the battery three times more than the existing one. *Scrosati & Garche [3]* did a wide research on lithium batteries for future to improve performance characteristics of lithium battery. The results show that batteries are also being used by hybrid and electric vehicles and electric vehicle popularity in market taken by storm as it gives more miles range, high torque and power by electric motors using lithium ion batteries. *Jia et al. [4]* investigated about the new three-dimensional mesoporous silicone content for high-power lithium-ion battery anode. Renewable energy storage and EV applications attracts next generation li-ion batteries with power performance and high energy density. As the demand for these growing days by day, result shows that anode material had the highest theoretical capacity if it uses the mesoporous silicon and that too in three dimensional to achieve it. *Kovalenko et al [5]* studied about a significant component of brown algae used in li-ion batteries with high capacity. Result shows that silicon has high capacity when compared to graphite, but it can exhibit drastic volume movements while electrochemical changes with lithium happen. *Wu et. al. [6]* studied and experimented on graphene doped sheets for large capacity in the anodes. Study gives result as such concentrates more on doped graphene sheets as replacing the old one to witness improvement of the performance of

characteristics of lithium battery *Liu et. al. [7]* studied and experimented on graphic carbon conformal mesoporous treatment of TiO<sub>2</sub> hollow spheres for high-performance lithium ion battery anodes.

## 1.2. Thermal Management of Li-ion Battery

The literature shows that considerable efforts have been made in the thermal management of lithium ion battery. *Khateeb et. al. [8]* proposed an electric scooter thermal management for getting more performance by changing PCM. The thermal management of this battery can achieve novel phase change material (PCM) through designing a lithium ion battery for an electric scooter. *Chen et. al. [9]* studied the thermal analysis of Lithium-ion batteries. By introducing 3D model of thermal to examine the batteries thermal runaway behavior and to achieve a great simplified model for thermal in order to get the most high-performance characteristics for the battery. This helps in the elimination of the heat even in various temperature changes in atmosphere. *Balakrishnan et. al. [10]* investigated the safety mechanisms of lithium-ion batteries. In order to avoid incidents which can be fatal sometimes, safety mechanisms are introduced such as shutdown separators, temperature coefficient elements, coatings and non-flammable electrolytes. *Khateeb et. al. [11]* investigated the thermal handling of Li-ion battery for electric scooters with phase change material. In this study, we are going to compare the experiment which is done by the PCM for changing the thermal management in the system. This helps us to identify the major changes that could lead to any minor variations in the electric scooter. *Yoshino et. al. [12]* studied about development of battery related electronic products such as notebook computers, video cameras and cell phones. The conventional rechargeable batteries with reduced size, greater capacity and weight for a given capacity compared to other batteries, lithium ion is the best among all of them. *Mahamud et. al. [13]* carried out experimental examinations on vehicle dynamic efficiency, long-term reliability and battery system costs directly affect the thermal control of electric vehicle traction battery systems. *Wua and Cui [14]* was designing nanostructured Si anodes for high energy lithium ion batteries. Result shows that the nano particles are becoming more popular in the world right now as it is very small and produces more energy than any other big materials in the world. Extending to other battery materials that undergo large volume changes the nano scale design principles that are meant for silicon. *Karimi et. al. [15]* investigated the thermal power of electric vehicle that uses Lithium-ion batteries. Lithium ion battery efficiency and life cycle depend on the thermal problems associated with battery in electric vehicle. *Chunnian et. al. [16]* studied about the carbon material which uses encapsulated Fe<sub>3</sub>O<sub>4</sub> in nano particles for high rate Li-ion battery which is doped in the anode material. The result of that particular experiment gave the idea of encapsulated nano particle helps create powerful battery *Pan et. al. [17]* Performed investigation on packaging materials for safe transport of spent Li-ion batteries. Result shows that Li-ion batteries contain highly flammable components and are still partly charged, the number of fire incidents reported has been growing since then. To avoid this, we need to package the materials safely through some wooden packaging or steel packaging with sand or vermiculite as packaging material to shipping the batteries thorough air or ship. *Khan et al. [18]* investigated for the battery thermal management system. The

available scientific literature and enormous standards gives a broad view to the promising future hi technology batteries in the thermal management and existing standards of BTMS. The result shows that the best BTMS would be with the high standards thermal system which monitors the battery thoroughly within the range of operating limit.

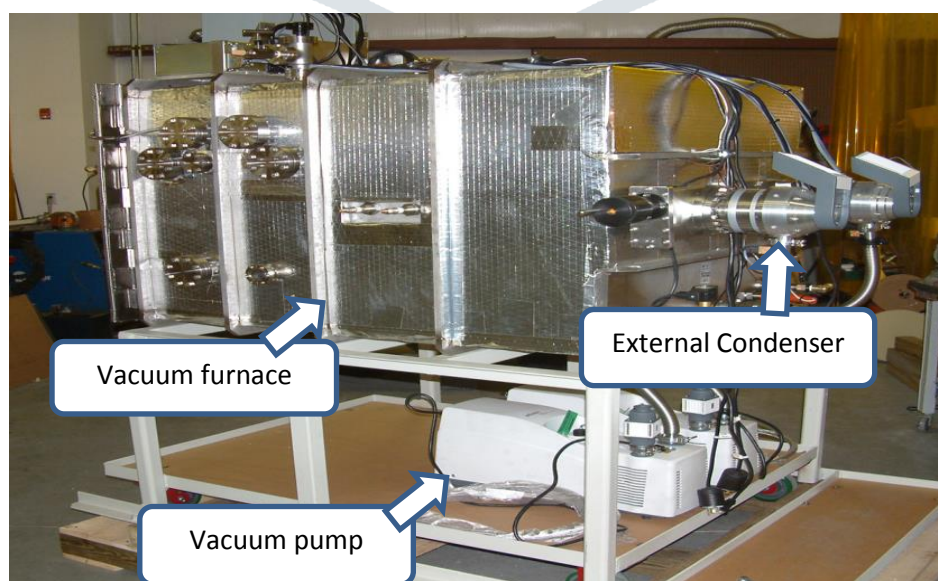
The most of the researchers have done their work on either on materials of cathode and anode or battery electrolytes. They concentrated mainly on battery power, heat transfer rate and cycle life. In order to increase the performance of battery, the battery management system should maintain the SOC of individual cells in a battery pack containing hundreds of cells to check for uniform SOC distribution among cells. In this experimental study, the experiments were carried out on three different condition of SOC level on Single 18650 type of li-ion battery cell. The performance comparisons and weight and voltage drop behaviour of single 18650 type cell used in lithium-ion battery pack at three different SOC levels have been studied. Also study the different types of three battery packing materials used in Li-ion battery for safe transporting.

## 2. EXPERIMENTAL SETUPS

In order to understand and define standard conditions of thermal runaway behaviour of Li-ion batteries, 18650-type Li-ion cells, which are widely used in laptops and electric tools, have been tested by heating in vacuum furnace.

### 2.1 Components of Experimental Setups

The 18650 type Li-ion cells have been used in this thermal testing process which is conducted to test the thermal behaviour of Lithium ion batteries. It is going to be heated in a vacuum furnace which gives us the accurate measurement of thermal values. The setup was carried out with all the required devices like temperature controller and measurement, pressure measurement device, vacuum pump, and external condenser. Everything is kept in a vacuum furnace closed so that to perform the test without any hindrance.



**Figure 1:** Vacuum Furnace for Thermal Testing of Batteries



### 2.1.1 Vacuum furnace

A vacuum furnace is a type where a vacuum covers the metal in the furnace during manufacturing. The lack of air or other gases avoids decay, heat loss by convection and eliminates a source of pollution. Maximum furnace temperatures and levels of vacuum depend on the melting points and heated substance vapor pressures. Vacuum furnaces are used to conduct high quality and low contamination processes including annealing, brazing, sintering, and heat treatment.

Characteristics of a vacuum furnace are:

- Temperatures at standard scale. 800–3,000 °C (1,500–5,400 °F)
- In a hot environment, temperature can be regulated, usually enclosed by heat shielding or insulation.
- Low carbon, oxygen and other gaseous contamination of the product.
- Vacuum filtering systems eliminate by-products from plant materials at low temperatures while heating, resulting in a higher quality end product.
- Fast commodity refrigeration (quenching) may be used to reduce plant cycle times.
- Computer controlled process to ensure repeatability.

### 2.1.2 Vacuum pump

The main function of vacuum pump function is to extract gas molecules from a sealed volume and leave behind a partial vacuum. Through suction, it eliminates the air from the sealed structure to gradually decrease the air pressure within the confined space to create vacuum. It evacuates the air contained within a device which converts a rotating shaft's mechanical input energy into pneumatic energy. The amount of energy emitted depends on the volume of gas or air extracted and the difference within pressure between internal and external air.

### 2.1.3 External condenser

A condenser is designed to transfer heat to a secondary fluid or ambient air from a working fluid (e.g., water in a steam power plant). The vapor normally enters the condenser at a temperature above the secondary fluid. As the vapor cools, it reaches equilibrium temperature, condenses in liquid and absorbs significant amount of latent heat. When this cycle takes place in the condenser, the amount of fluid decreases and the quantity of liquid increases. Many condenser structures have an extra duration to sub cool this concentrated liquid below the threshold for saturation.

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

In this chapter, obtained results from the experiments are conceded. The experiments are carried out in a vacuum furnace under different SOC level on single cell of 18650 type. The thermal behaviour of the single cell is investigated by measuring the temperature with respect to time and study this variation for thermal runaway temperature and time. Also study the heat generation rate from single cell to pack level and controlling this heat by maintaining the battery state of charge. The experiment

tested on three different 18650 type cell having 0%, 50% and 100% of SOC level. The single lithium ion 18650 type cell is forced to achieve the peak temperature and by letting the cell to go on a thermal runaway, the material's performances is being monitored. The sand, absorbent and vermiculite were being tested with connection of six thermocouples which is used to measure the cell temperature, heater temperature and other four temperature variants at different distances away from the cell (in mm).

### 3.1 Experimental Results

The experiments are carried under different cases to evaluate the thermal behaviour of single 18650 type cell at different SOC level and with different packaging material. The total six cases have been studied.

**Case 1:** Voltage and weight drop behaviour of single 18650 type cell at three different SOC level.

**Case 2:** Temperature and pressure change behaviour with respect to time at three different SOC level.

**Case 3:** Temperature differences in sand at different distances from single 18650 type cell.

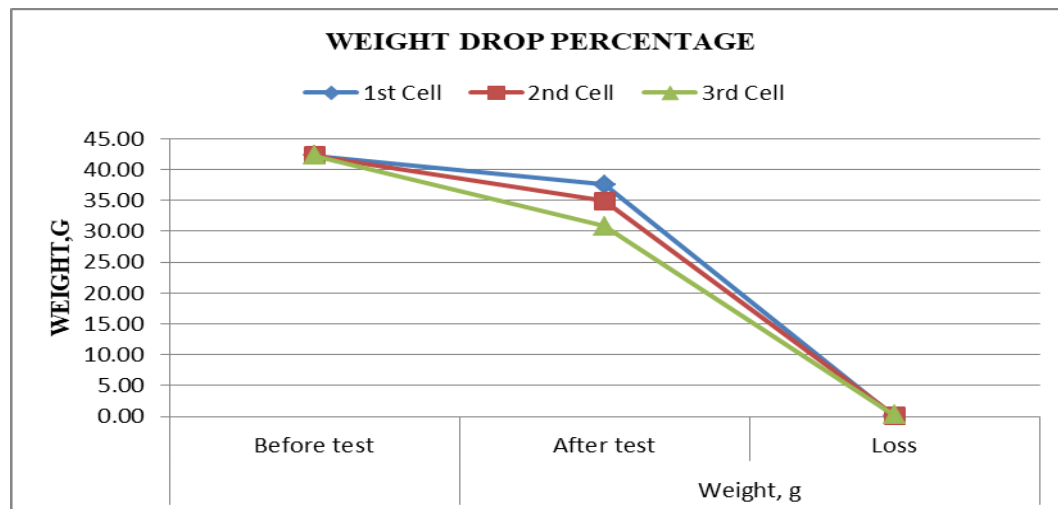
**Case 4:** Temperature differences in vermiculite at different distances from single 18650 type cell.

**Case 5:** Temperature differences in absorbent at different distances from single 18650 type cell.

**Case 6:** Comparison of three materials sand, vermiculite and absorbent temperature differences at 15mm distance from the single 18650 type cell.

### 3.1.1 Case 1: Voltage and weight drop behaviour of single 18650 type cell at three different SOC level.

The weight loss and voltage drop of the three different single 18650 type cell at three different SOC level have been calculated.



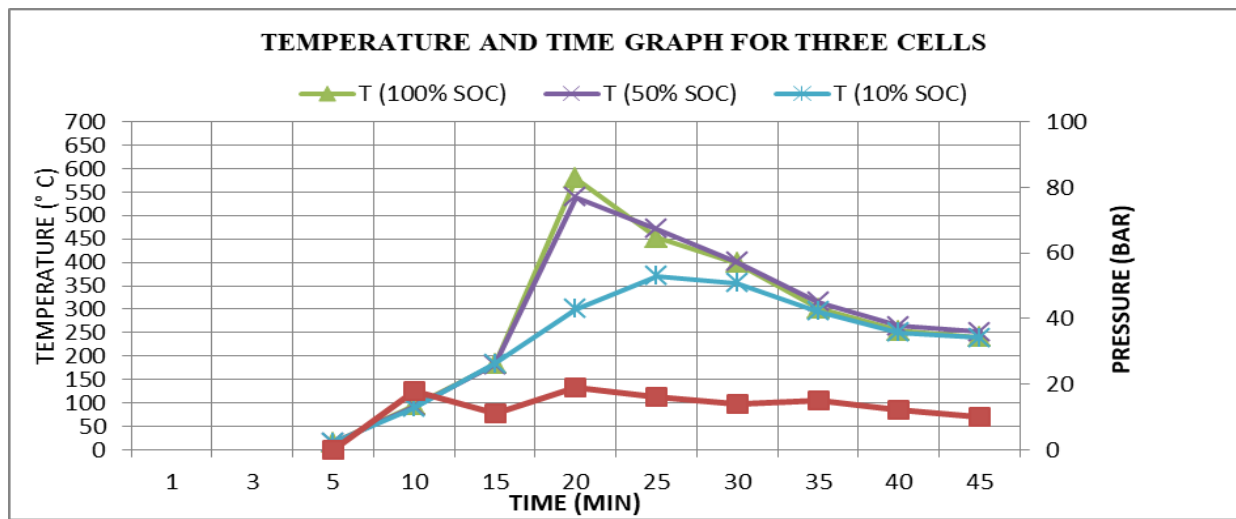
**Figure2:** Percentage in weight drop of three single 18650 type cell at different SCO level

The loss of weight in percentage for three different cells are 11%, 17% and 27% respectively. The weight loss percentage in the cell with 10% SOC level was very low as compared with other two higher SOC level cell due to release of large amount of gases from the cell surface with higher SOC levels. The voltage, at the end of each test being conducted becomes zero as the thermal runaway occurred at peak temperature and releases all the gases from the cell surface.

### 3.1.2 Case 2: Temperature and pressure change behaviour with respect to time at three different SOC level.

The thermal behaviour of the lithium ion battery is being analysed by performing cycle of furnace heating with three cells that are at different SOC level (10 %, 50 %, and 100 %). The experiments show that the thermal behaviour absolutely based on the SOC level in the cells. It is very important to maintain the SOC level in the battery pack attains peak temperature and thermal runaway occurs at high temperature. The cell which have 100% SOC level showed the highest peak temperature of 579°C. The next peak temperature is around 539°C for the cell have 50% SOC level. The lowest temperature is 371°C for cell having SOC level is 10%. So, the electrical energy is very high at the cells which contain high percentage of SOC.

The thermal runaway happens at high temperatures in the batteries, where it bursts freely at higher SOC-level rather than in the low SOC-level. The pressure and temperature of the lithium ion battery differs at different SOC levels and this is shown in the graph below.

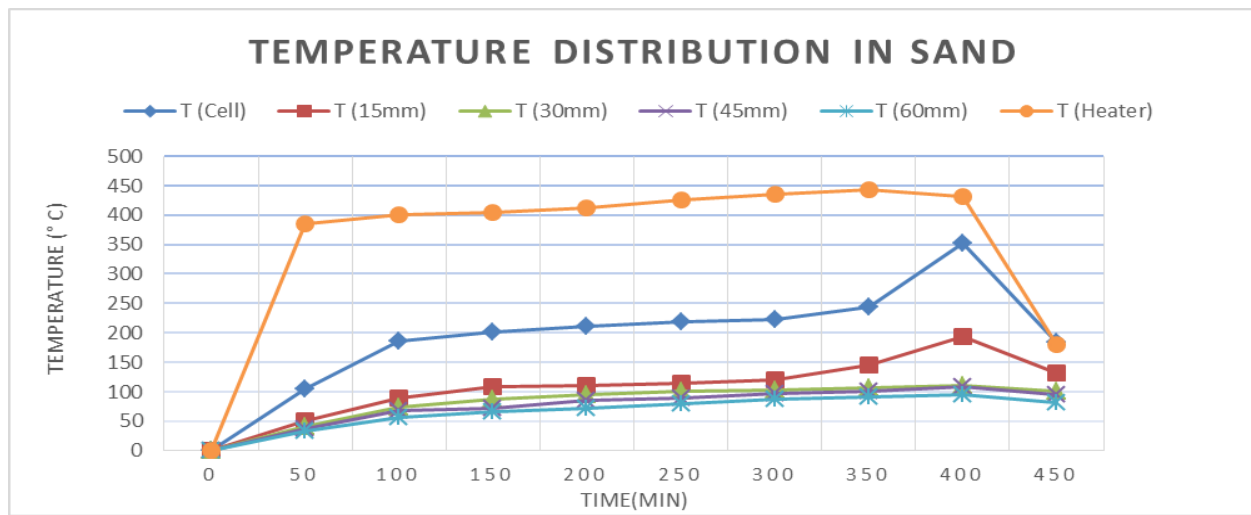


**Figure 3:** variation of temperature, pressure with respect to time for three cells maintained at different SOC level

### 3.1.3 Case 3: Temperature differences in sand at different distances from single 18650 type cell.

For the packaging the battery safely, different materials have been tested and studied at different temperatures. The procedure of the doing the experiment is same and additionally sand is added to it separately. In this case variation of temperature of cells and packaging material as sand placed at different distances from heater with respect to time have been studied. The behaviours of sand as a packaging material is tested and placed at distance of 15mm, 30mm, 45mm and 60mm from the cell and heater. The temperature variation of cell with respect to time for various distance of sand from heater is measured with the help of six thermocouples. The temperature is being noted down as T1, T2, T3, T4, T5 and T6. The thermocouple T1 and T6 is used to monitor the temperature of the surface of the cell and heater temperature. The other thermocouples T2, T3, T4 and T5 used to measure the temperature at distances from the cell of 15mm, 30mm, 45mm and 60mm. The maximum temperature of the cell(T1) and heater temperature(T6) is noted in this case is 353°C and 443°C after the time duration of 400 minutes and 350 minutes respectively. The Maximum temperatures (T2, T3, T4 and T5) at distances of 15mm, 30mm, 45mm and 60mm is 194°C, 110°C, 108°C and 96°C respectively after the time duration of 400 minutes.



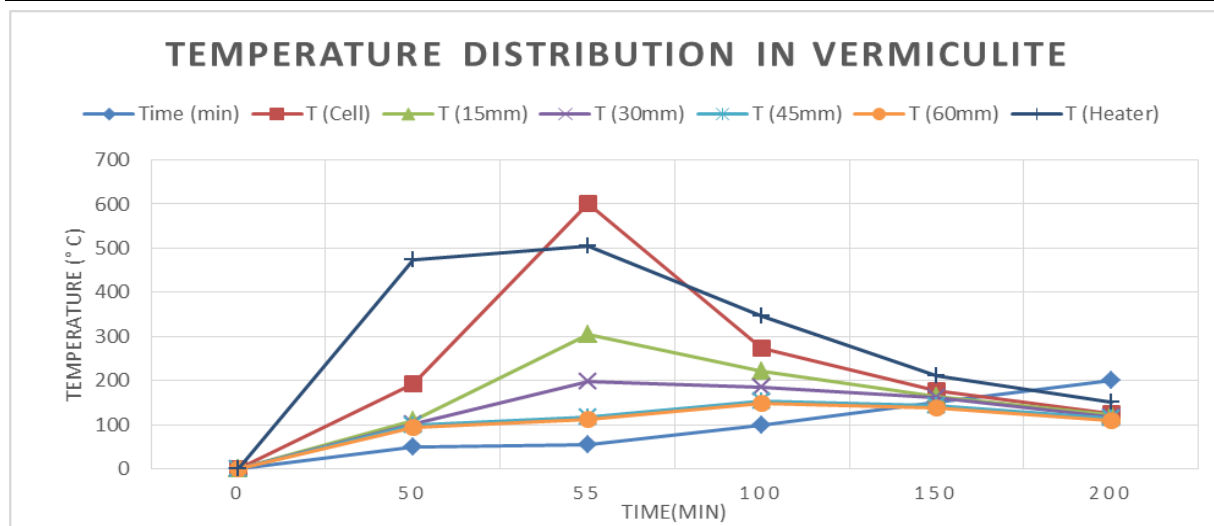


*Figure 4: variation of temperature of cell and sand placed at different distances from heater with respect to time*

### 3.1.4 Case 4: Temperature differences in vermiculite at different distances from single 18650 type cell.

In this case variation of temperature of cells and packaging material as vermiculite placed at different distances from heater with respect to time have been studied. The experiment is carried out using the same procedure and additionally, vermiculite is added to it separately. Three times the thermal testing was done for each material in order to see the variations in the behaviour of these materials by heating the cell up to the maximum temperature and letting the cell to go on thermal runaway. This is done to calculate the cell thermal behaviour with selected packaging materials.

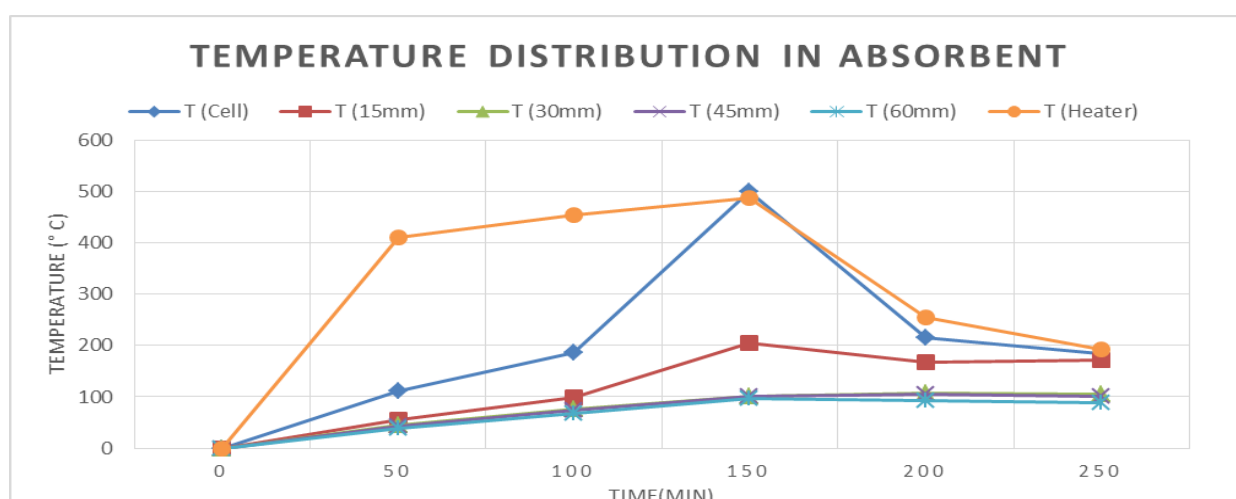
The behaviours of vermiculite as a packaging material is tested and placed at distance of 15mm, 30mm, 45mm and 60mm from the cell and heater. The temperature variation of cell with respect to time for various distance of vermiculite from heater is measured with the help of six thermocouples. The temperature is being noted down as T1, T2, T3, T4, T5 and T6. The thermocouple T1 and T6 is used to monitor the temperature of the surface of the cell and heater temperature. The other thermocouples T2, T3, T4 and T5 used to measure the temperature at distances from the cell of 15mm, 30mm, 45mm and 60mm. The single type 18650 cell is heated by an external heater up to 560°C and made to go on a thermal runaway, which travels through the materials used for packing. The maximum temperature of the cell(T1) and heater temperature(T6) is noted in this case is 600°C and 505°C after the time duration of 55 minutes. The Maximum temperatures (T2, T3, T4 and T5) at distances of 15mm, 30mm, 45mm and 60mm is 304°C, 198°C, 154°C and 148°C respectively in the time duration between 55-100 minutes.



**Figure 5:** variation of temperature of cell and vermiculite placed at different distances from heater with respect to time

### 3.1.5 Case 5: Temperature differences in absorbent at different distances from single 18650 type cell.

In this case variation of temperature of cells and packaging material as absorbent placed at different distances from heater with respect to time have been studied. The experiment is carried out using the same procedure and additionally, absorbent is added to it separately. The behaviour of absorbent as a packaging material is tested and placed at distance of 15mm, 30mm, 45mm and 60mm from the cell and heater. The temperature variation of cell with respect to time for various distance of absorbent from heater is measured with the help of six thermocouples. The temperature is being noted down as T1, T2, T3, T4, T5 and T6. The thermocouple T1 and T6 is used to monitor the temperature of the surface of the cell and heater temperature. The other thermocouples T2, T3, T4 and T5 used to measure the temperature at distances from the cell of 15mm, 30mm, 45mm and 60mm. The single type 18650 cell is heated by an external heater up to 560°C and made to go on a thermal runaway, which travels through the materials used for packing. The maximum temperature of the cell(T1) and heater temperature(T6) is noted in this case is 501°C and 488°C after the time duration of 55 minutes. The Maximum temperatures (T2, T3, T4 and T5) at distances of 15mm, 30mm, 45mm and 60mm is 205°C, 108°C, 105°C and 96°C respectively in the time duration between 150-200 minutes.



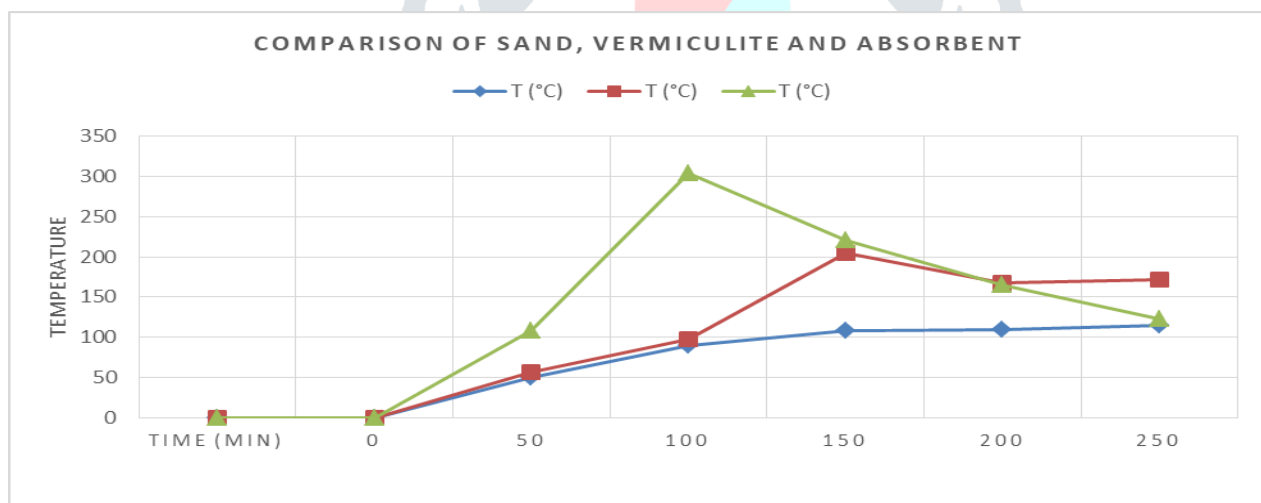
**Figure 6:** variation of temperature of cell and absorbent placed at different distances from heater with respect to time

### 3.1.6 Case 6: Comparison of three materials sand, vermiculite and absorbent temperature differences at 15mm distance from the single 18650 type cell.

The temperature distributions in all the three packaging materials at 15mm distance from the 18650-type cell is measured and compared. It can be seen that, at same experimental setup, it took much longer time to ignite the cell in sand. After the occurrence of thermal runaway, the temperature of packaging material at 15mm distance from cell raised significantly in vermiculite, while in absorbent and sand it raised slightly. This is due to their thermal diffusivity properties of materials. Sand, which has the smallest thermal diffusivity, will always have the minimum heat effect from the main source and will have least heat impact on the surrounding.

The maximum temperature is significantly lower in sand at T (15mm) than in other materials (sand: 114 °C, Absorbent: 205 °C, vermiculite: 221 °C). This is due to the thermal conductivity of the materials. The heat from the cell is easily transmitted to the surrounding materials in sand due to its highest thermal conductivity and therefore the cell surface temperature is reduced.

The maximum temperature of sand, vermiculite and absorbent is 114°C, 205°C and 304°C respectively in the time duration between 100-250 minutes



**Figure7:** Variation of temperature with respect to time for sand, vermiculite and absorbent place at a distance of 15 mm from the cell.

## CONCLUSIONS

In this study, we put our emphasis on SOC at cell-level. Since the EV / HEV battery packs often contain thousands of cells, it is therefore of vital importance to maintain the appropriate level of SOC in all the cells of battery pack by monitoring and modifying the SOC levels by BMS to the safe level. The following conclusions have been made from the experiments conducted.

1. The testing conducted in the vacuum furnace, with three different 18650 type lithium cells shows that the thermal behavior of the cell changes when the cell surface temperature reaches above 320°C.

2. The cell having higher the state of charge (SOC) begins the thermal runaway faster and has higher peak temperature and weight loss than the lower state of charge cells.
3. Maintaining the SOC levels which is 50% and below at the cell level can improve battery performance, life and safety of the vehicle.
4. In the electric vehicle, the effect of SOC needs to be considered when designing the battery pack and level of SOC should be maintained and monitored by the BMS at all the time. In case of any accident, the thermal runaway even if occurred, it should be controlled in the cell and pack level, otherwise it may lead to a fatal incident.
5. When thermal runaway of a Li-ion battery occurs; the battery surface temperature can rise explosively to 340-687°C. The SOC reflects the usable cell capacity and is one of the most important states to be tracked in order to optimize battery performance and extend battery life.
6. With highest thermal conductivity and lowest thermal diffusivity, sand is the best among the tested insulation materials to prevent “chain reaction” of batteries thermal runaway and hence can be considered as the safest packaging material. Absorbent and vermiculite have lower in rank packaging materials as compared with sand.

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