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Improvement in Efficiency of Battery of Electric Vehicle by Analyzing the Heat Transfer Enhancement of Lithium Ion Battery Pack

Pranav Salvi[1], Rahul Patil[2], Swapnil Nehe[3], Taranjyot Singh Birdi[4]

[1-3]Student, Mechanical Engineering, K.K. Wagh Institute of Engineering Education and Research, Maharashtra, India
[4]Student, Mechanical Engineering, Guru Gobind Singh College of Engineering and Research Centre, Maharashtra, India

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Abstract - *Electric vehicles are being developed to address the looming energy crisis and air pollution concerns. Because of its high power density and current efficiency, cylindrical lithium-ion batteries are widely employed. Internal temperature and temperature fluctuations between individual batteries have a significant impact on battery performance. The temperature of the battery changes during operation due to internal heat generation caused by electrochemical processes and the Joule effect. This self-sustaining process can result in an unregulated temperature increase, which can eventually lead to a deadly thermal runaway if heat is not removed as it is generated. We can either enhance the heat transfer coefficient or increase the surface area to increase the heat transfer rate. The heat transmission coefficient of a certain medium, on the other hand, is constant. As a result, increasing the surface area by adding fins can improve the heat transfer coefficient.*

Key Words: Efficiency, Fins, Battery pack, CFD, Joules effect.

1. INTRODUCTION

A number of critical industrial sectors, including portable devices (laptops, cell phones, etc.) as well as the automotive and power industries, rely heavily on the ability to store significant amounts of energy at high density (energy per unit mass or volume). A strong interest is focused around Lithium-ion batteries because of their high-energy density and good performance. However, despite these benefits, this technology still has a number of unresolved challenges that require additional research and development to improve their characteristics and performance. Lithium secondary cells, in particular, are very sensitive on the temperature at which they operate: excessive heat is a major battery killer, thus temperature control is critical. The temperature of the battery changes during operation due to internal heat generation caused by electrochemical processes and the Joule effect. This self-sustaining process can result in an unregulated temperature increase, which can eventually lead to a deadly thermal runaway if heat is not removed as it is generated. The chemistry utilized for the cathode, the types most typically employed by the car sector, is one way to classify Li-ion cells.

1.1 Problem Statement

The „Li-Ion batteries" has become an increasingly important segment of electric mobility. But due to its temperature rise issue it becomes hazardous and less efficient. Addressing this problem, to have efficient heat transfer rate, it requires research into more effective cooling strategies. This project is about „an Investigation of Heat Transfer Enhancement of Lithium Ion Battery Pack".

1.2 Objective

1. To maintain the battery temperature within its optimum value.
2. To design a lightweight cooling system.
3. To enhance the efficiency of battery pack.

1.3 Scope

This research details a series of experiments conducted to better understand the thermal behavior of Lithium-ion batteries under load, as well as the ability of alternative cooling systems to keep operating conditions within a safe range for the cells. Despite the fact that there are various theoretical models available in the literature, there are extremely few experimental data reports.

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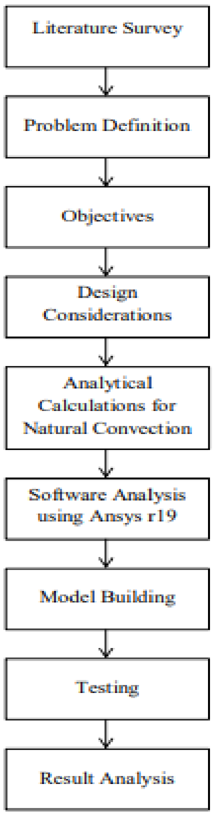


igure 1 – Flow of project

2. Literature Survey

I

Title- Effects of fins geometries, arrangements, dimensions and numbers on natural convection heat transfer characteristics in finned-horizontal annulus.

Author- S.A. nil and M.A. aforesaid Journal- International Journal of Thermal Sciences (2019)

• Natural convection heat transfer in closed enclosure exists during a wide selection of engineering applications.

• within the gift results natural convection air flow and warmth transfer characteristics in un-finned and finned annulus fogbound between 2 concentrical horizontal cylinders are numerically investigated.

• the consequences of the physicist numbers, annulus width, fins geometrical dimensions, fins numbers, fins shapes and fins arrangements were investigate.

II

Title- Thermal management of lithium-ion batteries: AN experimental investigation.

Author- Carla Menale and Francesco D'Annibale and Barbara Mazzarotta and Roberto Bubbico. Journal- Energy (2019)

• This paper describes a collection of experimental tests administered to raised perceive the thermal behavior of Lithium-ion batteries below load.

• The temperature increase looks to be correlate with the increasing internal resistance of the cells.

• To assess the potency of various cooling systems under a spread of in operation conditions of the battery pack, AN experimental facility (hardware simulator) has been set up, capable of simulating the thermal behavior of battery pack, wherever electrically heated components replaced real Li-ion cells.

III

Title- Study on the thermal interaction and warmth dissipation of cylindrical Lithium-Ion Battery cells

Author- Yuqi Huang and Yiji Lu and Rui Huang and Junxuan subgenus Chen and Fenfang Chen and Zhentao Liu and Xiaoli Yu and Anthony Paul Roskilly Journal- Energy Procedia (2017)

• Cylindrical Lithium-Ion Batteries are wide used as power supply for electrical and hybrid vehicles attributable to their compact size and high power density.

• as a result of the gap among battery cells is simply a number of millimeters, the thermal standing of battery would directly influence this potency and battery life.

• Researchers have developed some models of the transient temperature distribution in Lithium-Ion battery throughout the discharge cycle and therefore the thermal management on numerous forms of battery packs has been studied.

IV

Title- Enhancing Heat Transfer of Rectangular Fins Implementing Constructal improvement Approach **Author-** Fadi Alnaimat, Muhammad Ziauddin, policeman Mathew Journal- Thermal Science (2019)

• Fin form optimization is important to boost heat transfer by maximising the warmth flux and reducing material.

• This study examined rectangular fin shape optimized through material reduction and increasing effective surface area to boost a lot of heat flux.

• Simulation approach was adopted mistreatment ANSYS bench effecting a Steady-State Thermal Analysis.

3. Design

The satisfying the objectives, test will be performed in three ways:

1. Natural Cooling

2. Cooling with fins

3. Forced Cooling

The test setup consists of Li-Ion battery pack, Battery Management System, Various Sensors & Cooling System.

The structure of a model will be as follows:

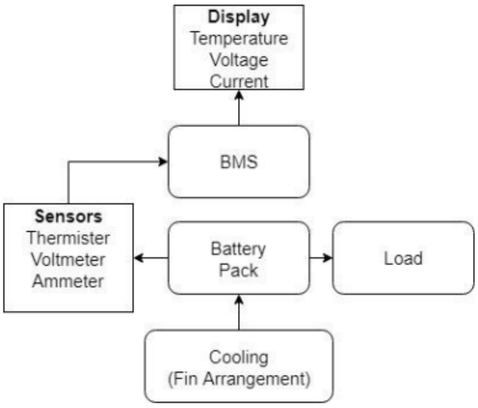


Figure 2 – Block Diagram of Setup

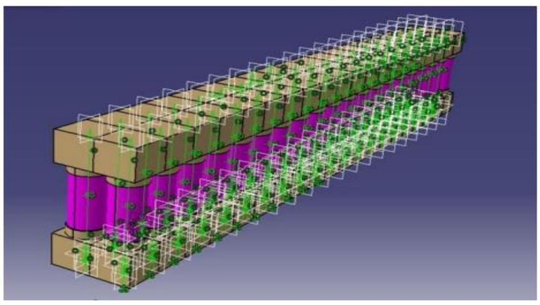
Cell considered for design is Li-Ion 18650 cylindrical cell.

Specifications-

2600 mAh (3.7V / 13-15 A) Allowable Temperature Range-

- During Charging- 0 to 45°
- During Discharging- -20 to 60°

As application of the battery pack is „Auxiliary Battery" used in a vehicle. So, the capacity of a battery pack considered is 12 V, 26 A-h (312 W). This capacity is achieved by arranging such cells in 4s10p configuration.



Picture 1 - CAD of battery arrangement

3.1. Calculations

3.1.1. Without Fin

Length=0.167m, Height=0.095m, Width=0.107m

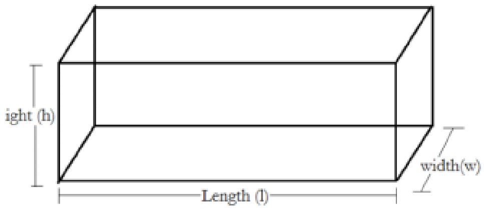


Figure 3 – Pack Casing

Given:

ρ = 1.145 kg/m^3

Cp = 1007 J/kgK

k = 0.02625 W/mK

α = 2.277 x 10-5 m^2 /s

μ = 1.895 x 10-5 kg/ms

ϒ = 1.655 x 10-5 m^2 /s

Pr = 0.7268

$$T_{mf} = \frac{Tg+T\infty}{2} = \frac{45+25}{2} = 35\,^{\circ}C$$

$$A_s = 2 \times (0.167 \times 0.107) + 2 \times (0.107 \text{ x } 0.095)$$

$$\mathbf{A_s = 0.056068\ m^2}$$

$$\rho = 2 \times (0.107 + 0.167) + 2 \times (0.107 + 0.095)$$

$$\boldsymbol{\rho = 0.952}$$

$$L_c = \frac{A_s}{\rho} = \frac{0.056068}{0.952}$$

$$L_c = 0.05889\ m$$

$$\beta = \frac{1}{T_m} = 3.24 \times 10^{-3}\ /^{\circ}C$$

$$G_r = \frac{g\beta\Delta T L_c{}^3}{\gamma^2}$$

$$\mathbf{G_r = 4.74 \times 10^5}$$

$$Ra = G_r \times Pa$$

$$Ra = 4.74 \times 10^5 \times 0.7268$$

$$\mathbf{Ra = 3.4458 \times 10^5}$$

$$Nu = 0.59 \times Ra^{0.25}$$

$$\mathbf{Nu = 14.29}$$

$$Nu = \frac{hL_c}{k}$$

$$14.29 = \frac{h \times 0.05889}{0.02625}$$

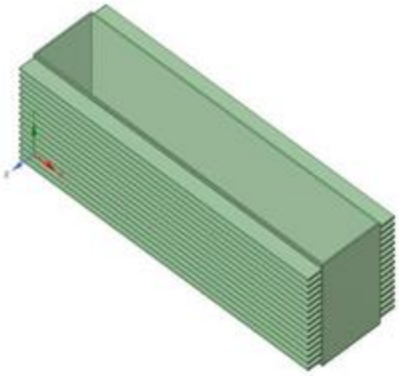
$$\mathbf{h = 6.3714\ W/m^2K}$$

$$Q = h \times A_s \times \Delta T$$

$$Q = 6.3714 \times 0.056068 \times 20$$

$$\boxed{\mathbf{Q = 7.1446\ Watt}}$$

Considering horizontal fins



Picture 2 - Horizontal Fin Arrangement

Length=0.167m, Height=0.002m, Width=0.020m

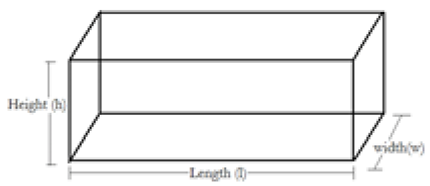


Figure 4 – Horizontal Fin

Considerations:

Perimeter (P) = 2(b + t) = 2(0.167+0.002) = 0.338 m

$A = b \times t = 0.167 \times 0.002 = 0.334 \times 10^{-3}\ m^2$

$$m = \sqrt{\frac{h \times p}{k \times A_{cs}}} = \sqrt{\frac{6.3714 \times 0.338}{205 \times 0.334 \times 10-3}}$$

$$= \mathbf{5.608}$$

$$Q = \sqrt{h \times p \times k \times A_{cs}} \times (T_s - T_\infty) \times \tanh ml$$

$$= \mathbf{0.857784\ W\ (with\ one\ fin)}$$

According to the dimension of the casing has height of 95 mm. So, we can fit 15 fins of 2 mm thickness with 4 mm of spacing between them.

$$\mathbf{Q = 0.857784 \times 15 = 12.8667\ Watt}$$

Providing fins on the both sides:

$$\mathbf{Q_{Fin} = 2 \times 12.8667 = 25.73\ Watt}$$

Un-fined Area= = 0.02171 m^2

$$Q_{unfin} = \sqrt{h \times p \times k \times A_{cs}} \times (T_s - T_\infty)$$

$$= \mathbf{2.7664\ Watt}$$

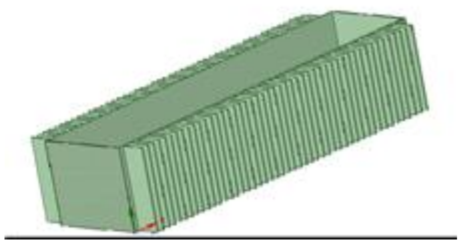
Total heat transfer after putting the fins:

$$= Q_{fin} + Q_{unfin}$$

$$= \mathbf{28.49\ Watt}$$

$$\boxed{\mathbf{Effectiveness = \frac{Q_{Fin}}{Q_{without\ fin}} = 4}}$$

3.1.3 Considering vertical fins



Picture 3 - Vertical Fins Arrangement

$$R_{al} = \frac{g\beta\Delta T L^3}{\gamma^2}$$

$$R_{al} = \frac{9.81 \times 3.24 \times 10^{-3} \times 20 \times 0.095^3}{(1.655 \times 10^{-5})^2} = \mathbf{1.9898 \times 10^6}$$

$$S_{opt} = 2.714 \frac{L}{R_{al}^{0.25}}$$

$$S_{opt} = 2.714 \frac{0.095}{(1.9898 \times 10^6)^{0.25}} = \mathbf{6.864\ mm}$$

Number of fins:

$$n = \frac{w}{s+t} = \frac{0.167}{6.864 \times 10^{-3} + 0.002} = 18.83$$

$$\mathbf{n \approx 19}$$

$$h = N_{u\ opt} \frac{V}{S_{opt}}$$

$$= 1.307 \frac{0.02625}{6.864 \times 10^{-3}}$$

$$\boldsymbol{h = 4.9983 \frac{W}{m^2 K}}$$

Then the rate of natural convection heat transfer becomes:

$$Q = h \times A_s \times (T_s - T_\infty)$$

$$Q = 4.9983 \times (2 \times 19 \times 0.095 \times 0.02) \times 20$$

$$Q = 7.2175 \text{ Watt}$$

If we provide same fins on opposite side then,

$$\boldsymbol{Q_{Fin} = 14.435\ \text{Watt}}$$

Un-fined Area= 0.03135 m^2

$$Q_{unfin} = \sqrt{h \times p \times k \times A_{cs}} \times (T_s - T_\infty)$$

$$= \mathbf{3.9948\ Watt}$$

Total heat transfer after putting the fins:

$$= Q_{fin} + Q_{unfin}$$

$$= \mathbf{18.4298\ Watt}$$

$$\boxed{\mathbf{Effectiveness} = \frac{Q_{Fin}}{Q_{without\ fin}} = \mathbf{2.57}}$$

3.2 Software Analysis

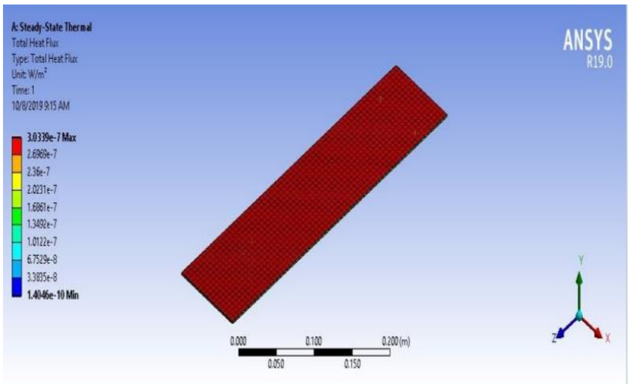
Steady State Thermal Analysis

- Thermal Material- Aluminum
- Meshing- 1mm element size, Tetrahedrons
- Boundary Conditions:

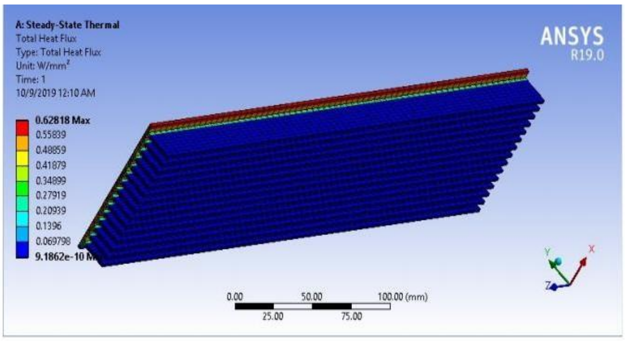
Initial Temperature of 45° on side of battery pack Convection on fin side

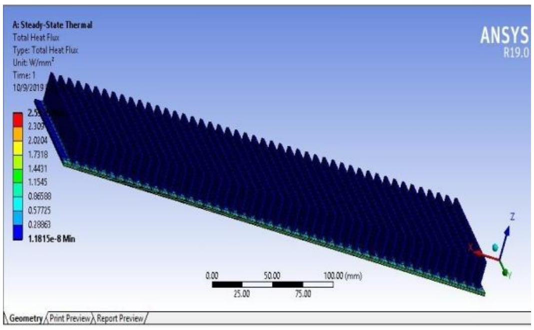
- Solution: Temperature
- Total Heat Flux

Picture 4 – Without fin analysis



Picture 5 – Horizontal Fin analysis





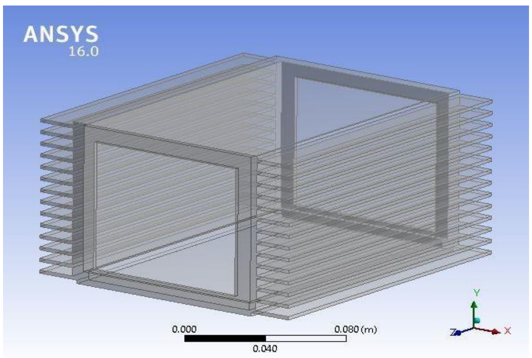
Picture 6 – Vertical fin analysis

3.2.1. Machine Fluid Dynamics:

machine Fluid Dynamics (CFD) may be a field of hydraulics that solves and analyses problems involving fluid flow exploitation numerical strategies and algorithms. CFD modelling relies on the basic governing equations of fluid dynamics: mass, momentum, and energy conservation. CFD aids within the prediction of fluid flow dynamics utilising computer code tools and mathematical modelling. 3 primary steps structure the CFD process:

1. Pre-Processing: this is often the primary step of the CFD simulation process that helps in describing the pure mathematics in the absolute best manner. One must determine the fluid domain of interest.

2. Solver: Once the matter physics has been identified, fluid material properties, flow physics model, and boundary



conditions are set to unravel employing a computer. There are widespread business computer code obtainable for this including: ANSYS FLUENT, ANSYS CFX, Star CCM, CFD++, OpenFOAM etcetera of these software have their distinctive capabilities. exploitation this software; it's doable to solve the governing equations relating to flow physics issues .

3. Post-Processing: successive step once obtaining the results is to analyse the results with totally different strategies like contour plots, vector plot, streamlines, knowledge curve etc. for appropriate graphical illustrations and reports. a number of the popular post-processing computer code include: ANSYS CFD-Post, EnSight, FieldView, ParaView, Tecplot 360 etcetera

3.2.2 Geometry:

The pure mathematics was created on CATIA. it had been then foreign in Ansys. the various surfaces were named in order that they will be simply recognized whereas applying boundary conditions. The battery pack was drawn by a separate surface within the geometry. This reduced the complexness of the geometry in Ansys software.

image 7 – Geometrical representation of battery Pack

3.2.3 Meshing:

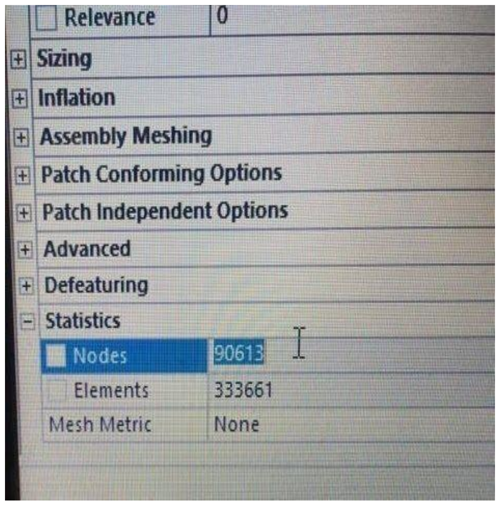
The meshing was done in Ansys Fluent. Fine meshing was selected. As shown in the image, meshing is maximized near the fin area as its scope of importance in the result is high. This allowed in reducing the computation time without compromising the accuracy.

Number of nodes generated= 90613

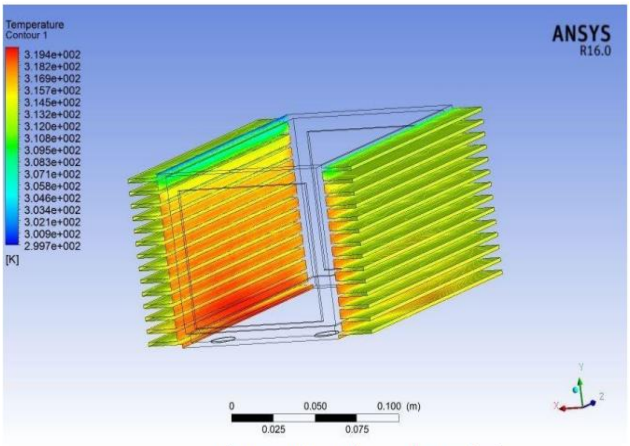
Picture 9 – Statistical Representation of Nodes and Elements

Solver:

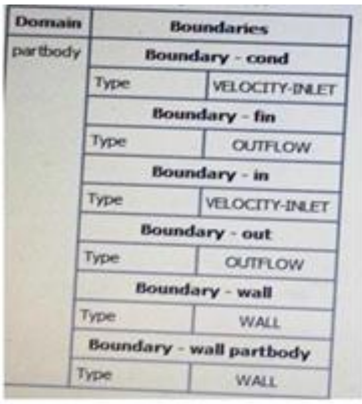
Ansys Fluent was used to simulate the CFD. In solver, the



energy equation was used to perform CFD thermal analysis. The laminar viscous model was chosen while solving the problem assuming that the heat dissipation by the batteries will be a laminar flow. The boundary conditions were applied to different surfaces.



Picture 10 – Thermal Analysis



Domain	Boundaries	
partbody	Boundary - cond	
	Type	VELOCITY-INLET
	Boundary - fin	
	Type	OUTFLOW
	Boundary - in	
	Type	VELOCITY-INLET
	Boundary - out	
	Type	OUTFLOW
	Boundary - wall	
	Type	WALL
	Boundary - wall partbody	
	Type	WALL

Picture 11 - Boundary Physics

Models

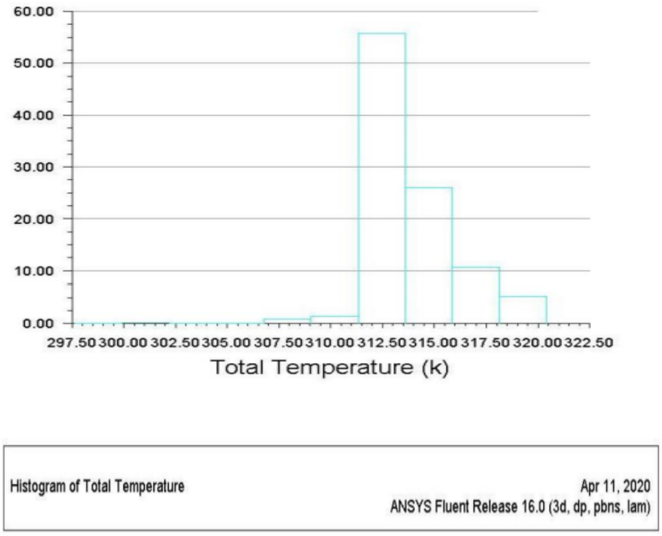
Models

- Multiphase - Off
- Energy - On
- Viscous - Laminar
- Radiation - Off
- Heat Exchanger - Off
- Species - Off
- Discrete Phase - Off
- Solidification & Melting - Off
- Acoustics - Off
- Eulerian Wall Film - Off

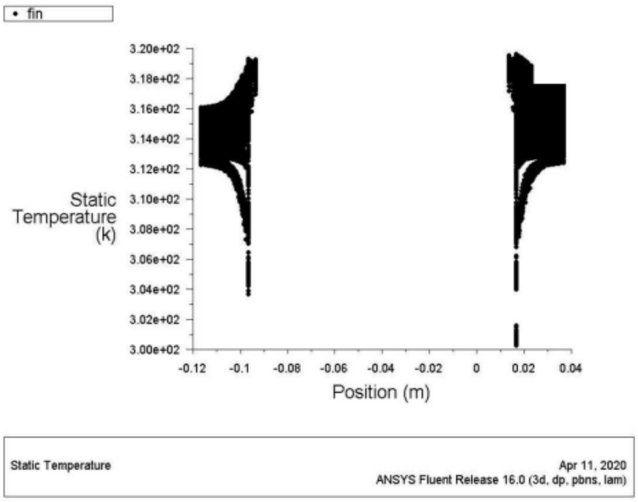
Picture 12 – Models selected

The simplec solution scheme was chosen over simple and coupled scheme as it has less approximation as compared to simple model and it is less complex than coupled model, thus saving computation time. The green Gauss cell based spatial discretization gradient was used as it evaluates the results in a complete cell.

3.2.5. Result



Picture 13 – Histogram of Total Temperature



Picture 14 – Static Temperature

4. MANUFACTURING AND TESTING DETAILS:

The manufacturing stage consisted of assembling of the cells into the required designed structure. The cells were arranged together with the help of a Cell Holder. The cells were arranged in a 4s10p structure which consisted of 4 in series and 10 in parallel. These bundles were packed together and a pack was formed. A Nickel Strip is used to make cell to cell connection. These battery packs were then bound together and were aluminum cased. A Battery Management System was used in order to see the results of current, voltage and power consumed. The various apparatus used in the Manufacturing stage are listed below: Cells, Strip Connection Nickel, Battery Management System, Wires, Cell Holder, Arduino, Temperature Sensors, LM35, Thermistor (NTC/PTC), Heat Sink (Fins), Aluminium (Casing).

Picture 16 – BMS

Different parts had to be selected across the variety of products that the market offers. We have divided them into Readily available parts and the Selected ones based on our requirement.

Table 1 – Selection of Parts

Selected	Readily Available
Cells	Strip Connection Nickel
BMS	Wires
Temperature Sensor	Cell Holder
Aluminium (Casing)	Arduino
	Heat Sink (Fins)

5. COSTING:

The tentative costing for the equipments required throughout the work will be discussed in this section.

i. Cells:

	Panasonic NCR18650B	Samsung 18650	Playrun 18650
Voltage	3.7	3.7	3.7
Capacity(mAh)	3400	2600	2600
Price(Rs.)	450	200	274

ii. Temperature Sensors:

	LM35	LM35DZ
Range	-40 to 100 °C	-40 to 110 °C
Accuracy	0.5°C	0.5°C
Current Drain	60000 mA	40000 mA
Price(Rs.)	450	200

iii. Arduino Uno Rev3: Code: A000066 Price-Rs. 1700 Specifications: Microcontroller- ATmega328.

Operating Voltage- 5V Supply Voltage (recommended)-

7-12V Maximum supply voltage (not recommended)- 20V The Overall costing for the cells was Rs. 12500. A Battery Management System worth Rs. 500 was ordered for smooth functioning. Aluminum Casing is used in the project work which cost 3500 Rs. Other expenses which were included in the project work which come under miscellaneous was worth of 3500 Rs. In such a way the costing of the project work completed is a total of Rs. 20000.

6. RESULTS:

Table 4 - Comparison between analytical and software values

Table 4 - Comparison between analytical and software values

	Without Fins Q (Watt)	With Horizontal Fins Q (Watt)	With Vertical Fins Q (Watt)
Analytical Calculations	7.1446	28.49	18.4298
Ansys	10.1	71.25	61.39

7. CONCLUSION

This chapter expects to through a light on the various conclusions with scientific justification drawn out of your project work.

- Cell Selection and Battery pack configuration
- Heat transfer in three cases:

1. without fins
2. with Horizontal Fins
3. with Vertical Fins

- Difference between Analytical Calculation values and Steady State Thermal Analysis result

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