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Thermal Management of Battery Using Phase Change Material and Air Cooling

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Abstract: Fossil fuels produce large quantities of carbon dioxide when burned. Carbon emissions trap heat in the atmosphere and lead to climate change. Electric vehicles could help diversify the energy needed to move people and goods thanks to their reliance on the broad mix of primary energy sources used in power generation, significantly improving energy security. A battery is an energy storage system in an electric car. The battery of the electric car begins to rise in temperature during its usage. An average optimum battery working conditions varies from 40˚C – 55˚C. Various cooling methods have been implemented to prevent the damage and thermal runaways of the battery cells, such as air, liquid, phase changing materials and a combination of either method. This project has an aim to develop a battery thermal system capable of managing the temperature of the battery within safety limits and providing a cost-effective solution.
Keywords: Battery Thermal Management System, Electric Vehicles, Phase Changing Materials, PCM, Cost effective Solution

I. INTRODUCTION

Human emissions have impacted the carbon cycle by increasing CO2 levels in the atmosphere and depleting natural CO2 sinks such as forests and soils, removing and storing or fixing CO2 concentrations in the air. The surge in fossil fuel prices, environmental pollution, and the finite lifetime of fossil fuels have prompted automotive companies to seek alternative fuels for vehicle propulsion, such as natural gas, hydrogen, and biofuel.

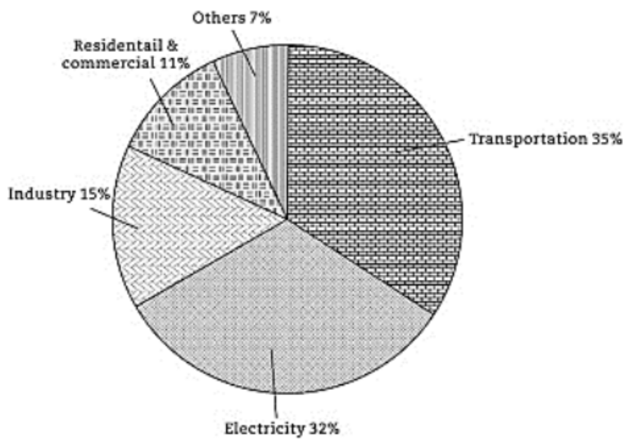

Fig. 1 Usage of Carbon Dioxide (CO2) in Various Industries

The average efficiency of an IC engine vehicle is 25%, which means that only 25% of the fuel is converted into useful energy and the remaining 75% of the fuel is wasted due to heat and friction losses. On the other hand, an electric vehicle has an average efficiency of 80% but has limitations in terms of total mileage and refuelling time when compared to an ICE vehicle. Among some of the different developed technologies, electric vehicles (EVs) have received great attention as an alternative technology and are quickly becoming a component of the modern transportation system. Because of its well-engineered and performance, the traditional vehicle mainly uses an internal combustion engine (ICE), which utilizes fossil fuels such as diesel and petrol and emits pollutants such as hydrocarbons, nitrogen oxides, carbon monoxides, and so on.

Hybrid and plug-in electric cars have the potential to reduce emissions significantly more than conventional automobiles. The benefits of HEV emissions differ depending on the vehicle model and kind of hybrid power system. When driving all-electric, EVs emit no tailpipe emissions and PHEVs emit no tailpipe emissions. The life cycle emissions of an EV or PHEV are determined by the electrical sources utilized to charge them, which vary by area.

Plug-in cars often offer a life cycle emissions advantage over comparable conventional vehicles that operate on gasoline or diesel in geographic locations where electricity is generated using relatively low-polluting energy sources.

Chemical energy storage (lead-acid battery, lithium-ion battery, nickel-metal hydride battery, nickel-zinc battery, nickel-cadmium battery), electrical energy storage (capacitor, supercapacitor), hydrogen storage, mechanical energy storage (flywheel), and generation systems are examples of energy sources (fuel cell, solar PV cell, wind turbines, regenerative braking system). However, each of the energy sources has unique features, size, and efficiency, making them task specific for various sorts of EVs. A lithium-ion battery, often known as a Li-Ion battery, is a form of rechargeable battery in which lithium ions travel from the negative electrode to the positive electrode via an electrolyte during discharge and back again during charging. Li-ion batteries employ an intercalated lithium compounds as the positive electrode material and commonly graphite as the negative electrode material. The negative electrode of a standard lithium-ion battery is typically constructed of carbon. The positive electrode is usually made of metal oxide. A lithium salt in an organic solvent serves as the electrolyte.

EVs are the latest buzzword in the automotive industry. EVs may be powered through a collector system by electricity from off-vehicle sources or self-contained with a battery, solar panels, fuel cells, or an electric generator to convert fuel to electricity. The source of energy and electrical storage are essential aspects to power EVs. Lithium-ion batteries produce a lot of heat during working (charging and discharging), which increases the temperature and temperature difference in the battery module. Increased temperature decreases the electrical performance of Li-Ion batteries and balance of systems. Temperature is thus the main parameter that needs to be controlled in a battery. Hence, an effective thermal management system is needed to control the temperature of the batteries, reducing the energy consumption and cost.

There are various kinds of cooling methods such as air cooling which can be natural or forced, liquid cooling which can be direct or indirect liquid flow and finally PCM, which change its phase to take in the heat and dissipate it. Compared with such conventional thermal management methods, the PCM can absorb or release a lot of latent heat by phase transition (solid to liquid and vice versa) and maintain almost constant temperature (near isothermal) during the process. PCM with other cooling methods is useful to achieve a better heat transfer and effective thermal management of batteries.

A PCM absorbs and releases thermal energy to maintain a regulated temperature. Now in its liquid phase, the PCM can release the heat it absorbed as the external temperature decreases. During this time, the PCM solidifies and provides a warming effect. PCM cooling systems can meet the cooling requirements of the battery pack, however, the volume change that occurs during a phase change restricts its application. PCMs have a very high potential to be a low-cost, effective, and simple thermal solution if mainly the conductivity of these materials can be improved. The enduring effectiveness of PCM battery thermal management system for long term high-rate charge/discharge operation, hybrid cooling method was reviewed as a promising system since the whole thermal system had better performances by controlling the temperature in the range of the latent heat of the PCM. Air cooling is simple and easy, but not very efficient and relatively crude compared to liquid cooling.

This research aims to design an effective battery thermal management system (BTMS) at a cheap and effective price that can be implemented in real time operations. This project closes the gap of thermal energy storage using PCM and natural conventional air cooling. A specified design made up of stainless-steel grade 304 with minimal area coverage for easy melting of PCM is provided. The key outcomes of the projects are to understand the importance and functioning of BTMS in EVs, to conduct an experimental study on BTMS using OM-42 which is a PCM and to selected PCM along with combination of conventional cooling technology should bring down the temperature of battery less than 50˚C which is an optimal working condition.

II. LITERATURE REVIEW

The problem occurred because the lithium-ion battery generates a lot of heat while working, which ultimately increases the temperature of the battery module, affecting the battery's capacity and life. The optimal working temperature of lithium-ion battery is 40°C. To maintain the temperature of the battery and the safety of the battery, an effective thermal management system must be implemented.

Wang et al. [1] investigated that using PCM can decrease the maximum temperature and maximum temperature difference of the cell at the discharge point also PCM has good heat storage capability where temperature retaining function can also be achieved. This was analysed by a numerical model using Catia and Ansys. Various parameters such as thickness of PCM, viscosity, latent heat and thermal conductivity were investigated. It was found that PCM has good heat storing capability and can effectively reduce the maximum temperature and temperature difference. PCM can improve the thermal management performance by increasing the latent heat, thermal conductivity, and thickness of the PCM unit and reducing PCM viscosity. The rapid increase in temperature of the battery threatens passenger safety and the EV's performance.

[2] The development of hybrid battery management system was done by considering micro heat pipe array, intermittent spray water and convective air. The heat piper extracts heat from the battery pack and delivers it outside, convective air is used to dissipate heat and when the high-power operations is taken placed it is cooled by spraying of water. This system reduces the temperature of 75 Ah battery pack from 41.9°C to 29.6°C and the temperature difference is reduced from 4.8°C to 2.9°C during dynamic operations. This system is said to consume 62% less energy to achieve better cooling performance, and the saved energy can elongate the driving range of EVs. Passive and hybrid techniques are used in battery pack to study the thermal management issue occurred in EV.

[3] Multiple jets were introduced to enable the air flow to change its directions and pass through the dead air regions, hybrid technology was also put in which the liquid jacket is added to each of the cells. The liquid comes in contact with the cell which maximize the contact surface area to improve the heat transfer. To study the effects of these computational fluid dynamics simulation were performed. It has been seen that the temperature variance at the cell level is reduced from 3.29◦C to 0.36◦C. This resulted in temperature uniformity at pack level and cell level. The mathematical model of the batteries is described. It is concluded that EV are effective to reduce the pollutants and save energy.

[4] At stressful conditions, especially at heat discharge operating at high temperature or ambient temperature, traditional methods such as air cooling and liquid cooling don't meet the requirements. Further process was carried out using pulsating heat pipe which is found to be more effective. It was found that the conflict must be solved between large heat storage capacity and low thermal conductivity. A lot of researchers are focussed more on heat dissipation. EVs are known for their light weight; therefore, the BTMS is in demand.

[5] The development of novel liquid cooling with thin cooling plates took place to meet the requirement. Various simulation was conducted on the proposed batter such as three-dimensional transient and two pair battery is selected. Calculation on coolant inlet velocity, tube inner diameter and battery discharge rate were found. It was concluded that cooling tube which was in contact with pair of battery increases with coolant flow direction. The maximum temperature of the battery reduced was 38.28◦C and the temperature difference was reduced to 4.23◦C. For the second pair of battery the cooling tube is evenly distributed to pair of battery and the maximum temperature reduced was 34.97◦C and the temperature difference was reduced to 4.04◦C. The weight ratio of BTMS of this design was found to be 1.88% and 2.00%, respectively. This study was found to be effective in terms of battery temperature uniformity and better BTMS weight ratio.

[6] Batteries are treated as the heart of EVs. They release heat during charging as well as during discharging process. Hence BTMS design is very important in controlling the heat and the temperature rise within the battery pack. Maintaining temperature is very important to have a better life span of battery, efficiency, and safety of battery. In recent years, exciting characteristics such as low parasitic power and uniform temperature distribution are managed using PCM and justified as efficient control of BTMS. Currently research has been started with the introduction of hybrid thermal management system and with the combination of PCM for effective cooling. A revies on various paraments such as cell spacing, specific heat capacity, thermal conductivity, Mass of PCM, Thickness of PCM is reviewed. The conclusion arrived is that hybrid BTMS with combination of PCM serves as best BTMS as it controls the maximum temperature raise and maintain uniform temperature throughout the cells. The future scope of electric vehicle is to design a system for efficient waste heat recovery, so that the energy released to environment is minimal. 18 Various cooling methods has been summarized in the vision of safety problems caused by thermal stress.

[7] This performance degradation caused by abnormal temperature occurrence must be solved. A design must be implemented in such a way that the EVs must adapt to both hot and cold temperature, which requires battery to perform well in both conditions. It has been concluded that the natural air-based cooling is simple in structure with low maintenance cost whereas, forced convection cooling system is complex which require additional energy to drive, but comparing with liquid cooling, it is more efficient than air cooling because it serves best in keeping the battery temperature in normal range. Although the performance of cooling gradually decreases along the direction of liquid flow. Having a mineral oil or silicon oil in liquid cooling system is appropriate for high instantaneous heat generation. It is also better in terms of leak proofness and much better, complex, and heavier than air cooling.

[8] Further development of a numerical model of Li-Ion battery package with PCM took place [8]. The model developed was based on energy balance of battery cell and the heat generation source. To obtain the phase transition phenomena in PCM the specific heat capacity is denoted by temperature-dependent function. The verification of the model was done by comparing the numerical value by theoretical value and the relative error obtained is 6%. The usage of PCM shows that the maximum battery temperature was reduced by 3% comparing with that of battery without PCM. By improving the air flow of the around the system automatically improves the thermal management performance of PCM and reduces the max temperature of battery by 2.5◦C. The study also proved that using PCM A-32 H is better than using other PCM due to transition temperature and high latent heat fusion.

PCM with high latent heat fusion is suggested for the mentioned battery pack as it reduces the battery maximal temperature and maintains battery under normal working operating temperature.

III. METHODOLOGY

The model is designed to achieve all the objectives and understand the problems and parameters in mind. The important objective of the model was to achieve optimal heat transfer rate as well as to offer a good amount of electrical resistivity with a factor of battery friendly. The design is made compact and made sure that it doesn’t occupy a lot of space. Since battery and its cooling system are important contents in an EV, we made sure that it doesn’t occupy a lot of space and energy. Comparing with other cooling method designs, our design stands budget friendly and size friendly. The design was initiated with a battery tank at the centre of the base plate. The battery tank was designed accurately to the size of the battery. Since the battery is not ideal to contact a liquid, we made sure that the battery tank design is liquid proof. To facilitate a place for PCM which is supposed to be kept nearby battery to cool it down we designed triangular fins around the battery tank.

The battery tank was designed at a dimension of 230mm length and 78mm width in order to fit 14.8v lithium-ion battery into it. The triangular fins on vertical sides and horizontal sides differ a little. We designed nine triangular fins on the vertical side whereas 3 triangular fins were designed on the horizontal side. The triangular fins had a height of 68mm and length of 20mm and a width of 25mm on both vertical and horizontal sides. On the vertical side, 2.5 mm of gap was left on the both the edges in order to weld and make a joint. On the horizontal side, 1.5 mm of gap was left on both sides to weld and make a joint. These fins are welded to battery tank as well as base plate. In general, it covers from base plate to top of the battery tank. Triangular fins are the only structure in the entire model that is going to carry a liquid. So, we made sure that there is no leakage on the fins. Fins are designed to these extents to withhold required PCM quantity. Also, to justify the use fins, non-dimensional parameter fin calculation was derived.

A. *Fabrication of Casing*

The designed model must be fabricated for experimentation purpose. Fabricating such a complex and compact structure was a difficult task. After analysing various materials, we concluded on using Stainless steel. This decision was made keeping in mind factors like thermal conductivity, electrical resistivity, thickness, and the cost of fabrication.

Stainless steel grades were also analysed and decided to use SS Grade 304. The ss grade 304 sheets have a thickness of 1.6mm. The sheet cost is at 293 rupees per kg. We also considered its yield strength, elongation, tensile strength and durability. The sheet is then bought, and base plate is constructed for the entire structure. At the centre of the base plate the battery tank was constructed. The battery tank is of the same dimension as battery.

Fig. 2 Battery Casing

The battery tank is then welded and joined to the base plate. Laser cutting and welding used in this process for precision and accuracy. The remaining sheet is then Bended as per triangular fins dimension. Each fin is carefully bent with precision and according to the designed dimension. For the vertical portion of battery tank, nine fins were constructed whereas 3 fins were constructed for horizontal portion. These constructed fins are then welded to the base plate as well as battery tank. The vertical portion had 2.5 mm of gap left on both the edges for welding and joining. The horizontal portion had 1.5mm of gap on both the edges for welding and joining. The triangular fins were constructed at a height of 68mm same as battery tank and has a length of 20 mm width of 25mm.The final product is available within a short period of time. Several other testing parameters like fluid leakage and thermal conductivity and stability of the final model were tested for a shorter period of time.

TABLE -1 Properties of Stainless Steel SS304 (Casing)

S.NO	PROPERTIES	VALUES	UNITS
1	Density	8.03	g/cc
2	Maximum Operating Temperature	900	°C
3	Melting Point Temperature	1371	°C
4	Specific Heat	420	J/(kg°C)
5	Heat Transfer Coefficient	25	W/m2K
6	Thermal Conductivity	16.2	W/m.K
7	Electrical Conductivity	9.9×10^{8}	Ω·m
8	Electrical Resistivity	0.072 x 10-6	Ω·m

B. *Selection of Battery*

Battery is the powerhouse of electric vehicle. EV batteries go through discharge and charge cycles while driving and when the car is plugged in. The quantity of charge the battery can hold is affected by repeating this process over time. This reduces the range and time required to charge between trips. Lithium-ion (Li-Ion) batteries are rechargeable batteries that are utilized in electric cars and a variety of portable electronics.

TABLE -2 Properties of the Lithium-Ion Battery Used

S.NO	PROPERTIES	VALUES	UNITS
1	Battery Type	Lithium-ion	-
2	Nominal Voltage	14.8	Volts (V)
3	Typical Capacity	24	Ampere Hours (Ah)
4	Number of Cells	48	-
5	Dimensions	230 x 78 x 68	Millimetres (mm)
6	Operating Temperature	Charge: 0 - 50 & Discharge: 0 - 65	Celsius
7	Charge Voltage	16.8	Volts (V)
8	Maximum Discharge Current	10	Amperes (Amp)
9	Individual Cell Voltage	3.7	Volts (V)
10	Individual Cell Capacity	2000	Milliampere Hours (mAh)
11	Cell Configuration	4S and 12P	Series & Parallel
	Charge Voltage	16.8	Volts (V)
12			
13	Maximum Continuous Discharge Current	10	Amperes (Amp)
14	Operating Temperature	Charge: 0 - 50 Discharge: 0 - 55	Celsius
15	Storage Temperature	20 - 45	Celsius
16	Maximum Charge Current	9	Amperes (Amp)
17	Upper Cut-off Voltage	16.8	Volts (V)
18	Lower Cut-off Voltage	12	Volts (V)

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They have a higher energy density than standard rechargeable lead-acid or nickel-cadmium batteries. This allows battery makers to save space, resulting in a smaller battery pack overall. Because of their high energy per unit mass compared to other electrical energy storage methods, lithium-ion batteries are currently employed in most portable consumer gadgets such as cell phones and laptops. They also have a high power-to-weight ratio, excellent high temperature performance, and low self-discharge.

Although most lithium-ion battery components may be recycled, the expense of material recovery continues to be a problem for the business

Another limitation is its heating, since battery carries the majority of work in electric vehicle it gets heated up a lot in shorter period of time which actually reduces its lifetime and working quality. To overcome this challenge and limitation is what we are working towards in this project

C. PCM Utilized

PCMs are substances which absorb or release large amounts of so-called "latent" heat when they go through a change in their physical state, i.e., from solid to liquid and vice versa. In a heating or a cooling process, this phase change takes place as soon as the material reaches its specific phase change temperature.

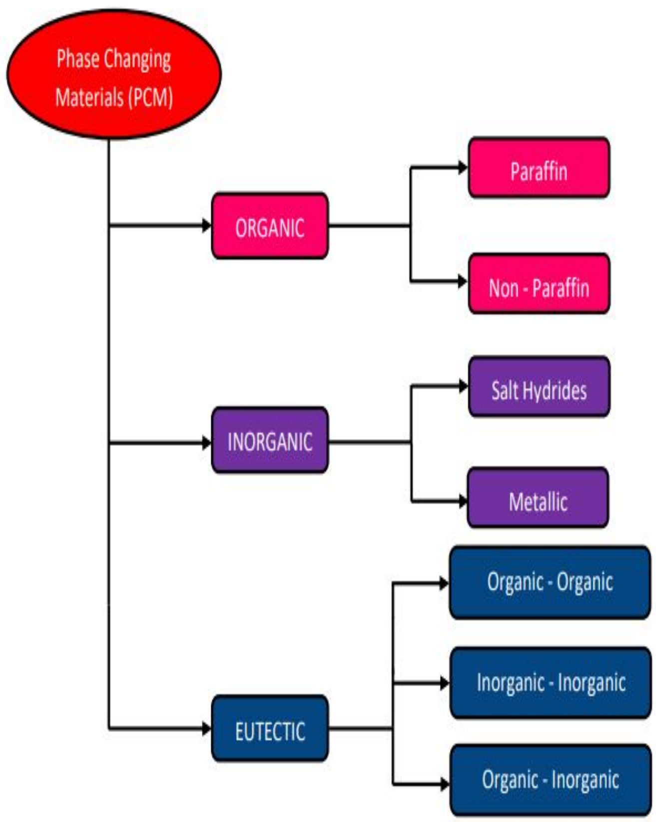

Fig. 3 Schematic Flowchart of Various Varieties of PCM

During the latent heat absorption or latent heat release, the temperature of the PCM remains constant. The PCM's property of absorbing and releasing large amounts of heat in a controlled way can be utilized to improve the thermal performance of various end-use products to which the PCMs are applied. The latent heat absorbed by the PCM can be stored therein. Therefore, PCMs are considered to be highly efficient thermal storage means. PCMs have a very high potential to be a low-cost, effective, and simple thermal solution if mainly the conductivity of these materials can be improved.

In this project, we used an industrial organic PCM OM-42. OM42 is an organic chemical based PCM having nominal freezing temperature of 41C. On changing phase latent heat is released or absorbed, allowing the ambient temperature within the system to be maintained. OM42 is constituted of the right mix of various additives allowing equilibrium between solid and liquid phases to be attained at the melting point.

TABLE -3 Properties of OM-42 PCM

S.NO	PROPERTIES	VALUES	UNITS
1	Melting temperature	44	(◦C)
2	Solidification temperature	33	(◦C)
3	Latent heat	199	(kJ/kg)
4	Specific heat capacity	2.78 (liquid) & 2.71 (Solid)	(kJ/kg.K)
5	Density	863 (liquid) & 903 (Solid)	(kg/m^3)
6	Thermal conductivity	0.1 (Liquid) & 0.19 (Solid)	(W/m.K)
7	Dynamic viscosity	0.01979	(Pa.s)
8	Maximum operating temperature	120	(◦C)

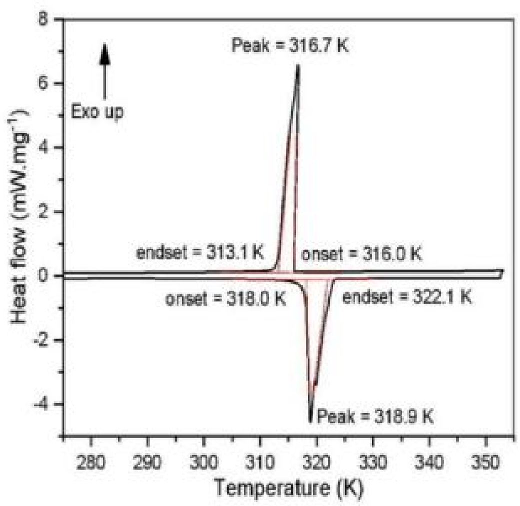

Fig. 4 PCM Properties Graph

The graph shows sharp melting and solidification peaks, and zero slopes of the heat flow curves signify sensible heating in a solid and liquid state. The sudden change of slope indicates a transition region, and the heat flow peak signifies maximum endothermic and exothermic reactions during the phase transition process. Besides, it was noteworthy that OM 42 has a narrow range of melting peaks at 318.9 K (DSC instrument).

D. Environmental Characteristics

Rising fuel prices and a push for greener initiatives have led many organizations to adopt EVs for their fleets. Notable for their fuel efficiency, EVs can be a cost-effective way to reduce operating expenses. Besides lower fuel costs, EVs also serve as a greener alternative to gas or diesel vehicles. By eliminating exhaust, they can reduce a fleet's greenhouse gas emissions. This advantage helps businesses stay sustainable and compliant with government guidelines.

Fig. 5 Experimental Setup

The PCM has been filled inside the triangular fins, as the temperature of the battery rises, the heat is transferred from the battery to the side walls of the container and then it is utilized for melting of the PCM (convection). EVs use one or more electric motors powered by rechargeable lithium-ion batteries, the same kinds of batteries that power smartphones and laptops. And like electronic devices, EVs plug into external power sources for charging. Other types of batteries rely on regenerative braking for charging or generating electricity from the vehicle's frictional energy. In addition to being less polluting than fuel engines, lithium-ion batteries often work more efficiently. Many have a guaranteed life span of 8-10 years. Because EVs do not rely on fossil fuels for power, they may not have certain components that ICE vehicles do. For instance, parts such as fuel lines, fuel tanks, and tailpipes. This means that most EVs do not emit carbon dioxide emissions (CO_2), which helps reduce air pollution. An EV's driving range between stations is dependent on its battery life. Extreme driving conditions or weather can also affect an EV's range as they use more energy to compensate.

In this project, we understood the limitations an electric vehicle faces in the society, and we made sure that these limitations are solved with an apt solution. Since electric vehicle is highly dependent on the battery, we tried to increase its lifetime and working quality by introducing a new and efficient cooling method to it. We also tried to bring the solution under an affordable budget and solution better than the existing ones. The compound we used for cooling is "Phase changing material". We used an organic phase changing industrial material which gave us a perfect solution for the problem we faced with our battery. This certainly can break the limitations that current generation electric vehicle faces. We also made the battery pack and its casing in a very compact way. Since battery occupies the larger portion in electric cars along with a complex cooling system. We designed and implemented a simple, compact and cost-efficient battery and its cooling system. This certainly would change the face of electric vehicle world by decreasing its production cost and increasing its reliability as well as its number of users in the society.

IV. RESULTS AND DISCUSSION

By using PCMs to absorb heat, the temperature of a battery pack could be kept within the normal operating range for a long time without using any external power. PCMs could greatly improve the heat dissipation efficiency of BTMS by combining with air cooling either natural or forced convection.

Cooling fins rely on conduction to diffuse the heat away from what is being cooled. The heat transfer surface area is a function of fin dimensions and fin shape, as the surface area increases the amount of heat transferred increases. Cooling fins speed up the heat transfer as they create a much larger surface area with the liquid than would otherwise be available.

The non-dimensional parameter for the designed triangular fins were calculated and it was found to be greater than one ($m>1$), which proves that the conceptual design of the fins is effective for heat transfer.

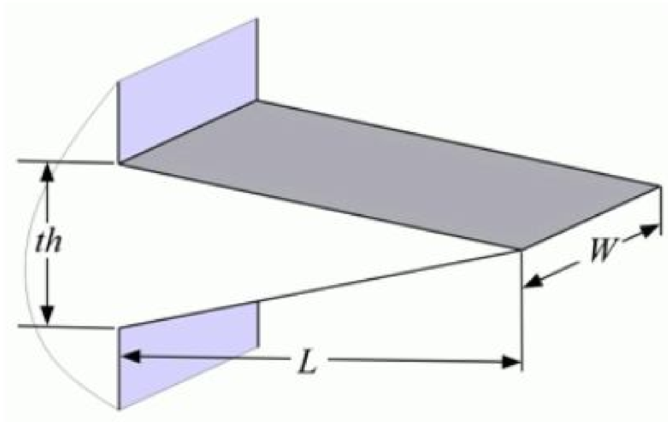

Fig. 6 Non-Dimensional Parameter Nomenclature

$$m = \sqrt{\frac{2h}{k\,th}}$$

Where the abbreviations and values are as stated below:
Th = thickness of the fin = 25 x 10^{-3} mm
K = thermal conductivity of stainless steel (SS304) = 15W/mK
H = heat transfer coefficient of air = 5W/m^2K

A. Experiment with Triangular Fins

Firstly, the temperature of the battery was measured using the concept of fins and natural air cooling. The variations of temperatures were made a note of after every 5 minutes up to 30 minutes. The initial results of this experiment are tabulated in Table 4 below.

TABLE -4 Experimental results with the presence of triangular fins

Temperature (˚C)	0 mins	5 mins	10 mins	15 mins	20 min	25 mins	30 mins
Battery	60.0	57.2	55.4	52.5	51.6	49.7	48.8
Side Wall	48.5	54.6	52.2	50.1	47.0	46.7	45.5
Fin 1	43.1	42.0	41.7	40.5	40.4	40.2	40.1
Fin 1 Centre	43.3	42.4	41.9	40.95	40.0	39.9	39.8
Fin 2	43.6	42.6	42.0	41.7	41.4	41.3	41.2
Fin 2 Centre	42.4	42.25	41.8	41.4	40.9	40.5	40.1
Fin 3	45.5	43.7	42.1	41.7	41,4	40.3	39.5
Fin 3 Centre	45.2	43.3	41.9	42.1	42.4	40.8	39.3

At the beginning of the experiment the battery was discharged using a discharging load, CPU fan of 12V. The temperature of the battery was noted to be 60C. After 5 minutes the battery temperature dropped down up to 2.8C and became 57.2C, at 10 minutes the battery temperature was 55.4C, at 15 minutes the temperature was 52.5C and finally at the end of this observation at 30 minutes the temperature of battery was noted to be 48.4C. When compared to the initial setup, it was found that there was a temperature drop of 21.2C.

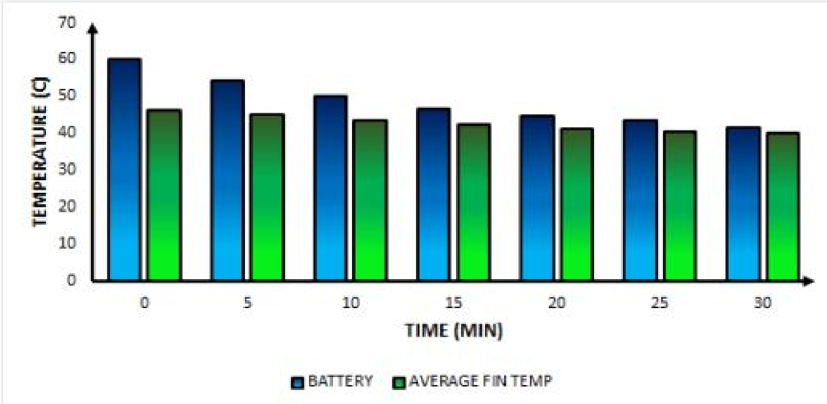

Fig. 7 Graphical illustration of battery cooling using triangular fins

The calculation for fins temperature was taken such that, the three fins, one at the beginning, one at the middle and finally one fin at the end were recorded and then the average of these three fins were taken. At the beginning of the experiment, the average fin temperature was noted to be 46.6C and declined gradually after every 5 minutes from 46.6C to 45.0C, then 43.7C. after 30 minutes it was noted that the end average temperature of the fins were 40.1C. The temperature rise and decline have been plotted in a bar graph illustrated in the above figure 7.

B. Experiment With Triangular Fins and Water

The second experiment was performed in such a way that the triangular fins were filled with water at room temperature (34C). This was done in order to allow the system to transfer heat in convection mode. The system was overserved for every 5 minutes up to 30 minutes and the readings are tabulated in table 5.

TABLE -5 Experimental results with the presence of triangular fins filled with water

Temperature (˚C)	0 mins	5 mins	10 mins	15 mins	20 min	25 mins	30 mins
Battery	60.0	54.4	50.4	48.6	47.3	45.3	44.7
Water	34.0	53.1	50.3	47.6	46.7	45.6	43.5
Side Wall	48.5	49.6	48.3	45.1	44.0	43.3	41.1
Fin 1	43.1	43.9	45.4	45.1	42.8	41.4	41.2
Fin 1 Centre	43.3	42.3	45.2	44.7	40.9	40.2	39.8
Fin 2	43.6	46.7	46.9	45.7	44.7	42.9	42.1
Fin 2 Centre	42.4	46	46.7	44	43.3	42.7	41.8
Fin 3	45.5	46.7	46.8	46.3	44.5	43.3	41.9
Fin 3 Centre	45.2	47.1	46.6	43.5	43.3	43.1	42.1

From this experiment it was observed that the cooling of battery was much quicker compared to using only triangular fins. This is because heat was allowed to transfer in both conduction and convection method. The battery temperature dropped from 60C to 44.7C in 30 minutes very quickly. The temperature of the water inside the fins had a sudden increment after 5 mins from 34C to 53.1C and the gradually dropped down to 43.5C after 30 minutes. Similarly, the average temperature of the fins varied from 43.9C to 41.4C as shown in fig 8.

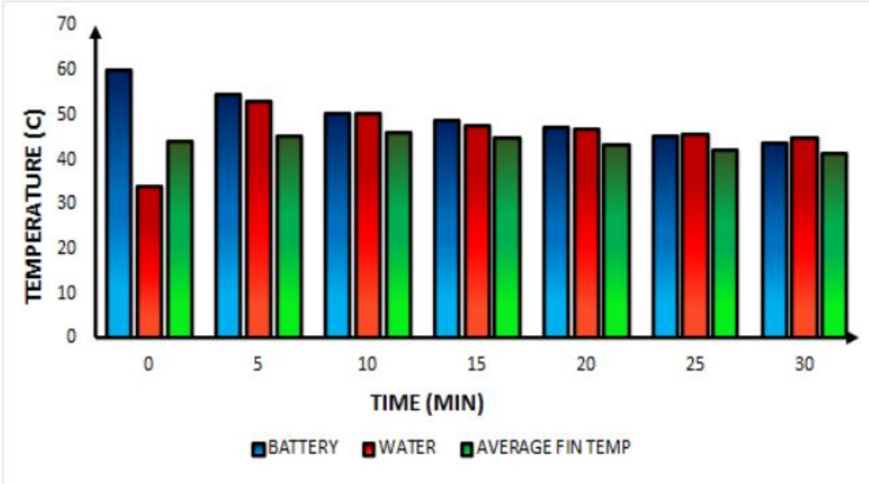

Fig. 8 Graphical illustration of battery cooling using triangular fins filled with water

C. Experiment With Triangular Fins and PCM

The third experiment was performed in such a way that the triangular fins were filled with OM42 PCM at room temperature (34.3C). This was done in order to allow the system to transfer heat in convection mode. The system was oberseved for every 5 minutes up to 30 minutes and the readings are tabulated in table 6.

TABLE -6 Experimental results with the presence of triangular fins filled with OM42 PCM

Temperature (˚C)	0 mins	5 mins	10 mins	15 mins	20 min	25 mins	30 mins
Battery	60.0	54.4	50.2	46.7	44.9	43.7	40.8
PCM	34.3	54.3	40.2	40.7	39.3	38.1	37.6
Side Wall	48.5	41.5	40.7	39.2	41.1	39.6	38.5
Fin 1	43.1	37.8	39.7	39.1	39.4	38.1	38.1
Fin 1 Centre	43.3	39.5	39.3	37.8	38.6	38.4	37.2
Fin 2	43.6	37.6	39.4	39.3	40,4	40.2	39.1
Fin 2 Centre	42.4	37.7	39.7	39.1	39.8	39,7	39.1
Fin 3	45.5	39.7	39.8	41.6	40.3	39.6	39.2
Fin 3 Centre	45.2	40.9	40.2	41.5	40.1	40.2	39.3

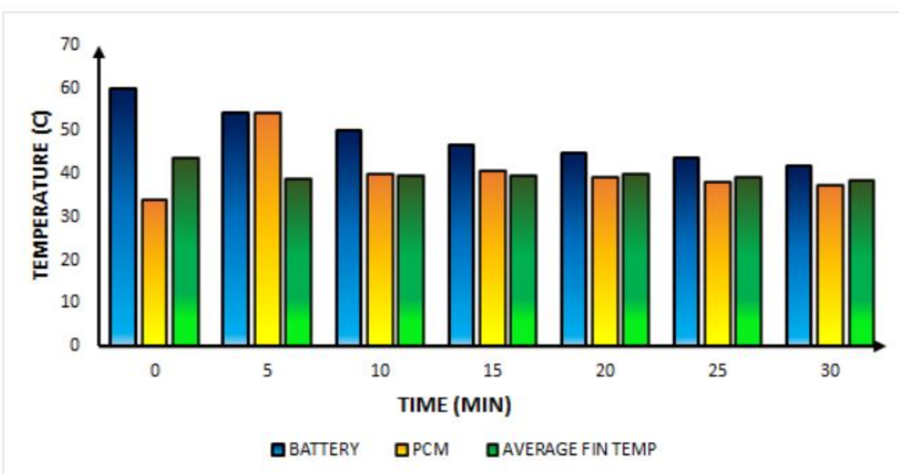

Fig. 9 Graphical illustration of battery cooling using triangular fins filled with OM42

From the final experiment, the temperature drop was highest compared to the other two methods. The OM42 PCM had the capacity to withdraw heat from the system quickly. The temperature of battery came down from 60C to 40.8C in 30 minutes. The temperature of PCM was 34.3C initially and had a sudden upsurge to 54.3C and immediate decline after 10 minutes from 40.2C to 37.6C at the end of the experiment. The OM42 PCM was transformed from solid state to liquid state within 5 minutes of the experiment beginning and it became solidified at the end of the experiment at 30 minutes.

D. Thermal Fluke Image with PCM

The thermal image of the system consisting of both Phase Changing Materials (PCM) as well as natural convection were observed. The following figures: figure 10, figure 11, and figure 12 indicate the thermal variations and changing noted during the experiment. It was noted that the temperature of PCM gradually upsurged during the discharge of the battery and reduced after 10 minutes by dissipating the heat to the metal plate (SS304) and air from the surrounding. Hence, these images signify the heat transfer from the lithium-ion battery to the surrounding metal and PCM utilized in this experiment.

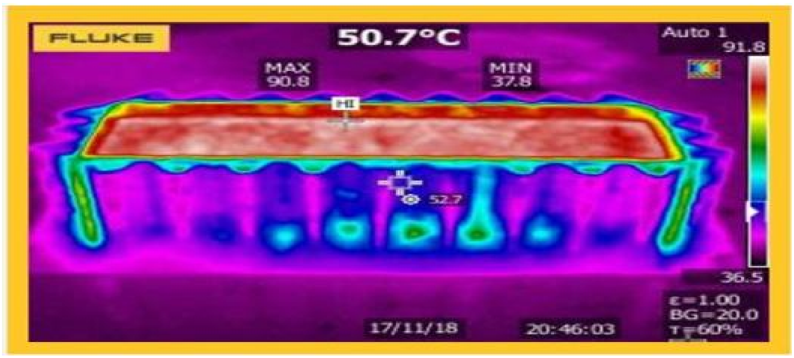

Fig. 10 Thermal Image of the System in the Initial 5 Minutes of Experiment

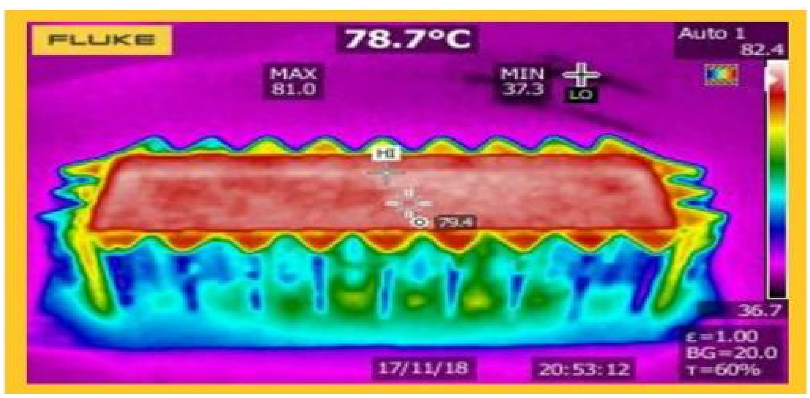

Fig. 11 Thermal Image of the System in the Initial 10 Minutes of Experiment

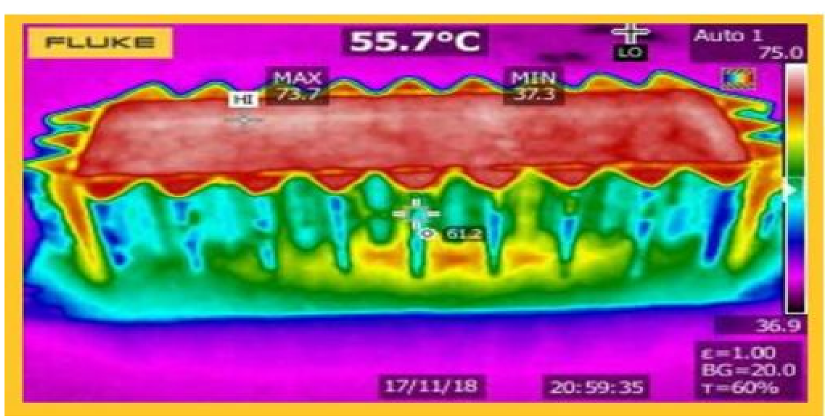

Fig. 12 Thermal Image of the System in the Initial 15 Minutes of Experiment

V. CONCLUSION

In this project, a combination of two cooling methods has been used: air cooling and PCM cooling to design an effective and inexpensive BTMS for Li-Ion batteries and other electric vehicle batteries. The effectiveness of the designed triangular fins along with the combination of cooling systems were experimentally tested and observed. The parameters taken while designing the setup are compactness, simplicity in design, light weight, reliable and easy maintenance. It was noted that the system was more effective with the input of fins, PCM, and natural air cooling. The cooling system designed can be implemented in real time application. Nevertheless, the objective and purpose of this project has been achieved along with bridging the research gap with novelty. However, the manufacturing of this proclaimed design is a bit complex due to the triangular fins assisted for PCM cooling as well as the necessity to make them leakproof to prevent the overflow of PCM as it can corrode the battery system.

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