DESIGN AND DEVELOPMENT OF BATTERY THERMAL MANAGEMENT SYSTEM USING PHASE CHANGE MATERIAL AND FINS TO IMPROVE BATTERY LIFE

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Abstract - *Even though India has seen many advancements in regards to Electric Vehicles, one of the main issues Indian EVs are facing is dealing with the temperature irregularities within the battery pack, effective cooling systems and sudden fires to batteries. Though adapting to new techniques is essential, cost cutting, compactness of the system and optimal weight of the battery should be looked after as well. A battery thermal management system with phase change material with silica, aluminum fins and perforated slots is developed which effectively improves the battery working condition. An intricate system based on multipurpose dry chemical fine powder, which would act on extreme conditions of fire and thus cease the spread of fire and protect the vehicle and the passengers has been developed. An effective battery thermal management system can significantly reduce the chances of an EV battery catching fire, maintain the temperature distribution within the battery pack and thus improve the life of a battery.*

Key Words: *Phase Change Material (PCM), Silica, Battery Pack, Effective Cooling, Battery Thermal Management System, Electric Vehicle, Fins.*

1. INTRODUCTION

Currently in India, Government is enforcing the stringent emission norms for the internal combustion engines driven vehicle. Hence the vehicle manufacturers have to shift their focus to the manufacturing of the electric vehicles. One of the challenges is to develop an efficient battery thermal management system for an electric vehicle. This system also applies to a large number of different vehicle applications, ranging from the compact car to the multi-utility vehicle and from the low-level hybrid vehicle to the entirely electrically-driven vehicle. Thus, it becomes necessary to develop highly efficient energy storage devices for the same. The attraction of the electronics market towards lithium-ion battery as an energy storage device is increasing primarily due to its high energy density, capacity, long cycle life and low self-discharge rate [1].

Li-ion batteries are very sensitive to the temperature. Inside these batteries, during charge and discharge processes, like any rechargeable batteries, heat is generated that causes to increase their temperatures. This increase in temperature has two different effects on the batteries. The beneficial effect is that, by increasing the temperature, Li-ion batteries work more efficiently and their performance becomes better. On the other hand, the unfavorable effect is that, they are closer to thermal runaway that decreases their reliability because of probable explosion [2].

1.1 OBJECTIVES

2. To study the feasibility of phase change material in lithium-ion batteries.
3. To use the phase change material with additives and pin fins heat sinks in batteries for better heat dissipation.
4. To set an experimental setup of a battery pack with PCM, pin fins and fine powder.
5. To analyze the proposed design and compare it with a standard battery pack of an EV bike.

1.2 SCOPE

Battery Thermal Management with PCM presents more effective thermal performance. The pin fins decrease bulk temperature and improve temperature uniformity. Hybrid cooling effect shows an effective rate of heat dissipation. Provision of vent helps protect battery enclosure.

2. MATERIAL & EXPERIMENTAL TECHNOLOGIES

In response to safety concerns surrounding OLA S1 PRO batteries, a scaled-down analysis has been undertaken, with data representing 1/20th of the battery pack. This deliberate reduction aims to facilitate controlled testing and evaluation, given reported incidents of the original batteries exhibiting safety issues, including a notable risk of catching fire.

The consideration of data of 1/20TH of the OLA S1 PRO battery pack is as follows:

The number of battery cells connected in series N_{cs} [-] in a string is calculated by dividing the nominal battery pack voltage U_{bp} [V] to the voltage of each battery cell U_{bc} [V]. The number of strings must be an integer. Therefore, the result of the calculation is rounded to the higher integer.

Ncs =Ubp /Ubc
Ncs = 3V / 3.6 V = 0.83
= 1S

If 1S in series, then the effective voltage would be 3.6 V.

0.195 kWh / 3V = 65Ah
65 / 3.4 = 19.11
= 20P

The required configuration 1S-20P.

Nomenclature		Subscripts	
k	thermal conductivity (W/m k)	BTMS	battery thermal management system
h	heat transfer coefficient (W/m2 k)	BMS	battery management system
ρ	density (kg/m3)	ePTFE	expanded polytetrafluoroethylene
Cp	specific heat (J/mol.k)	PCM	phase change material
T	temperature (k)	s	solid
t	time (s)	l	liquid
C	Capacity of Battery	m	melting

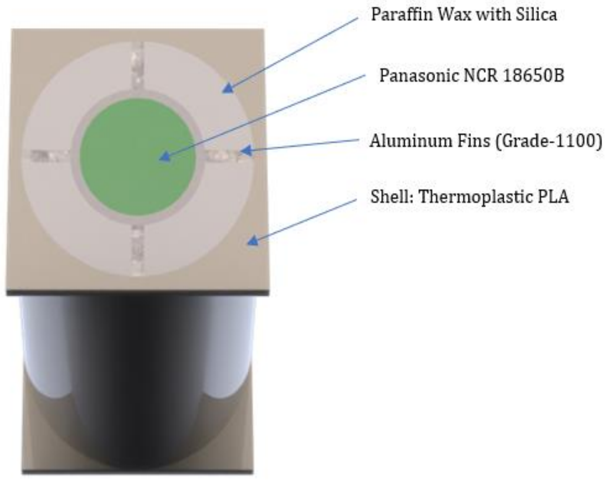

Fig 4.1 Shell with Aluminum Fins, PCM with Silica and Cell

3. PROPOSED BATTERY CONFIGURATION

I. Battery Pack Specifications:
  - 1S – 20P (20 cells in total)
  - Output 0.395 kWh
  - 6 V / 3 Ah

II. Single cell specifications:
  - Cylindrical cells
  - Panasonic NCR 18650B
  - Dimensions- Diameter 18mm, Height 65mm

III. PCM Composition:
  - Primary PCM – Paraffin Wax (Grade RT42)
  - Additives – Silica (SiO2)

IV. Fin Specifications:
  - Material- Aluminum (Grade-1100)
  - Dimensions- 8mm x 2mm x 65mm
  - 4 Rectangular Fins around each cell

V. Shell Specifications:
  - Outer Cover: 2mm, Thermoplastic PLA
  - Inner Cover: 2mm, Thermoplastic PLA

VI. BMS Container with Terminals:
  - 20mm Thickness, Thermoplastic

VII. Sensors:
  - Temperature sensor

4. WORKING

As shown in the figure 4.1, the developed battery thermal management system integrates a phase change material with silica, aluminum fins, and perforated slots to enhance the operational efficiency of the battery. This intricate system is designed to effectively regulate the working conditions of the battery pack. The primary goal of this innovative thermal management system is to substantially reduce the risk of electric vehicle battery fires. It achieves this by maintaining optimal temperature distribution within the battery pack, thereby enhancing the overall lifespan of the battery. The integration of phase change material, aluminum fins, and perforated slots collectively contributes to efficient heat dissipation and temperature control.

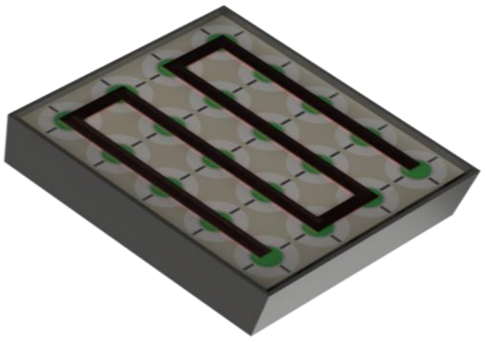

Fig 4.2 Battery Pack with Connections

Thermal runaway is an uncontrolled temperature escalation within a system, particularly concerning in batteries like lithium-ion, where heat generated from internal reactions can trigger a self-reinforcing cycle, potentially leading to catastrophic failure, fires, or explosions. Effective thermal management systems are essential to mitigate the risk of thermal runaway by regulating and dissipating heat within the battery. The vulnerability of battery cells to thermal runaway necessitates proactive measures to mitigate its potential risks. Silica gel, served as a major shape-stability material that could prevent the leakage of melted Paraffin wax. Thermal runaway is a chain reaction within a battery cell that, once initiated, can be challenging to halt. To tackle the challenges of electric vehicle battery packs, a dual-stage venting system has been implemented.

Table 1

Thermophysical properties of Li-ion cell, Paraffin (RT 42), Aluminum, Silica (SiO2) and Thermoplastic (PLA)

Property	Unit	Li-ion Cell	Paraffin (RT42)	Aluminum	Silica (SiO2)	Thermoplastic (PLA)
Dimension	mm	18x65	-	8 x 2 x 65	-	2 x 65
Density	kg/m^3	2720	820	2719	2648	1252
Heat Capacity	J/kg K	300	2000	871	680	1955
Mass	g	44.5	-	-	-	-
Thermal Conductivity	W/m K	3	0.2	202.4	1.5	0.195
Dynamic Viscosity	Kg/m s	-	0.02	-	-	-
Thermal Expansion C.F.	/K	-	0.0001	-	-	-
Melting Heat	J/kg	-	165	-	-	-
Solidus Temperature	K	-	311.15	-	-	-
Liquidus Temperature	K	-	316.15	-	-	-
Nominal Voltage	V	3.6	-	-	-	-
Nominal Capacity	Ah	2.4	-	-	-	-
Internal Resistance	mΩ	30	-	-	-	-

The first stage utilizes passive venting, employing an ePTFE membrane to manage gradual changes in temperature and pressure, ensuring controlled venting for minor variations. In contrast, the second stage, active venting, is designed to swiftly respond to critical situations like thermal runaway. In the event of thermal runaway, the vent enables rapid gas escape, preventing the escalation of the chain reaction. This dual stage venting system offers a comprehensive and tailored approach, safeguarding the safety and integrity of electric vehicle battery packs in various scenarios.

By employing Multipurpose Dry Chemical Fine Powder, the system can respond to extreme fire conditions, swiftly curbing the spread of fire and safeguarding both the vehicle and its occupants. In the event of a fire, the Multipurpose Dry Chemical Fine Powder acts as a proactive measure to mitigate the potential dangers, ensuring the safety of the electric vehicle and its passengers. This comprehensive approach of a robust thermal management system in promoting both the longevity and safety of electric vehicle batteries.

6. MANUFACTURING & EXPERIMENT PROCEDURE

The battery pack is manufactured as shown in fig 5.1, using 3D printing technology and spot welding for the connection of lithium-ion batteries. The design incorporates key features such as a temperature sensor, Paraffin RT 42, silica gel, aluminum fins, and individual cells.

To assess its performance, the battery pack undergoes testing with a load applied by a coil at 3.2 A, complying with a 1C discharge rate. Additionally, each motor connected to the pack draws 0.8 A, aligning with a 0.5C discharge rate. The combined load from both the coil and motors results in a discharge rate of 1.5C. This comprehensive testing approach ensures the battery pack's efficiency and suitability for its intended applications.

The experiment was conducted by ensuring familiarity with safety guidelines for lithium cells and wearing protective equipment. The positive terminal of the lithium cell was connected to the load, linking it to the multimeter. The load was activated, and voltage and current were recorded at intervals during the predetermined test duration. The collected data, including voltage and current profiles, were analyzed. After completing the experiment, the circuit was safely disconnected, the lithium cell was responsibly disposed of, and the equipment was stored securely.

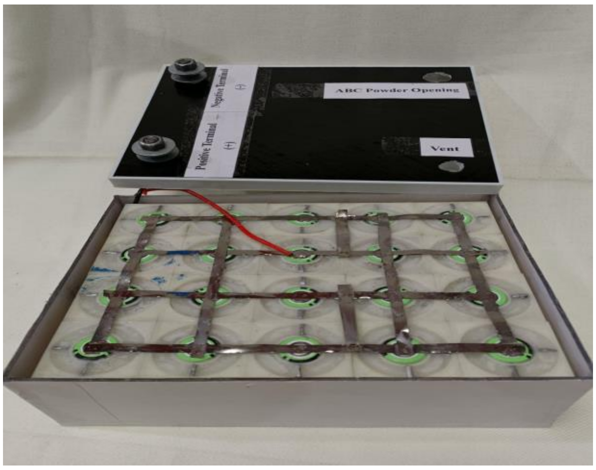

Fig. 5.1 Manufactured Battery Pack (Inside View)

Table 6.1 Comparative results obtained at various discharge rates

TEST MODELS		MEAN OBSERVATION TEMP (K)	
		RESULT AT 1C	**RESULT AT 1.5C**
	ROOM TEMP.	302.72	302.33
1	CELL	312.43	317.66
2	SHELL WITH PCM	311.51	314.33
3	SHELL WITH FINS	311.88	315.11
4	SHELL WITH PCM AND FINS	309.74	313.33
5	SHELL WITH PCM, FINS AND SILICA	309.6	312.77

Individual model performances at 1C and 1.5C discharge rates vary, highlighting the influence of design features on thermal behavior.

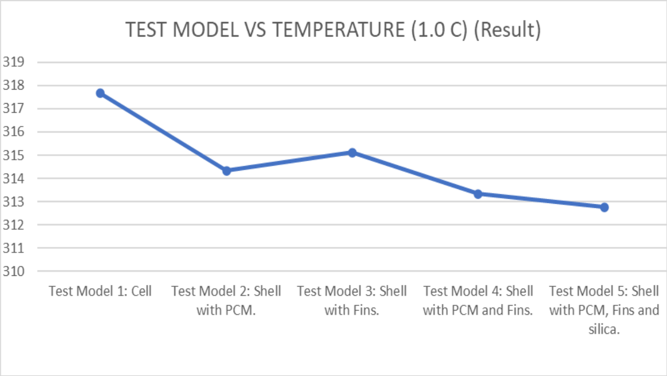

Fig. 6.1 Represents the comparative analysis between Test Model and Temperature variation at 1C

6. RESULTS AND DISCUSSION

The experimental results provide a comprehensive comparison of mean observation temperatures (in Kelvin) for various test models under different discharge rates (1C and 1.5C) compared to the room temperature of 302.72 K.

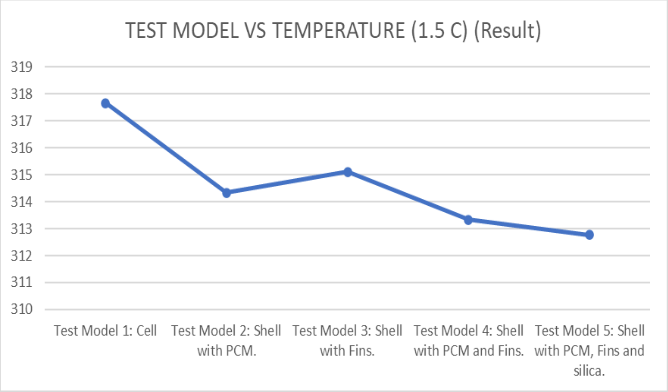

Fig. 6.2 Represents the comparative analysis between Test Model and Temperature variation at 1.5 C

The presence of PCM, fins, and silica in the shell demonstrates a noticeable impact on temperature variations, suggesting their effectiveness in influencing thermal characteristics. Further analysis, considering factors like thermal conductivity and heat dissipation, it is recommended for a more nuanced understanding of the thermal performance of each model.

7. CONCLUSION

In conclusion, this research paper is dedicated to exploring the vital role of temperature reduction in extending battery life, with the primary objective of advancing battery thermal management systems. The methodologies employed include integrating Phase Change Material (PCM) in the module, incorporating aluminum fins, and introducing silica in PCM for leakage protection. The experiments reveal that aluminum fins effectively decrease overall thermal resistance, providing additional heat propagation paths. The Battery Thermal Management System (BTMS) with PCM cooling demonstrates enhanced performance, notably reducing the Lithium-ion battery temperature within its safe operating range, especially at lower current rates of 1C and 1.5C.

Specifically, at 1C, the cell temperature experiences a drop of approximately 1.03%, decreasing from 312.43 K to 309.6 K when utilizing the designed battery pack, showcasing a significant temperature reduction. Similarly, at 1.5C, there is a percentage drop of approximately 3.38%, as the temperature decreases from 312.77 K to 302.33 K, underlining the effectiveness of the proposed BTMS. However, this positive outcome is accompanied by a consideration: the combined integration of PCM and aluminum fins contributes to an increase in the overall weight and area of the battery pack. The inclusion of PCM with Silica and fins, although effective in controlling temperature, raises concerns about the practical implications for weight-sensitive applications, such as electric vehicles and portable electronics. As weight and space are critical factors in these contexts, future research should aim to optimize the balance between thermal management effectiveness and the added weight and volume associated with PCM and fins. Striking a balance in weight reduction while maintaining optimal thermal performance is a crucial aspect for the widespread adoption of these technologies in real-world applications. Despite these considerations, the study's outcomes provide valuable insights into the potential improvements and challenges in enhancing battery performance, emphasizing the need for a holistic approach to battery thermal management system design.

8. REFERENCES

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