COMPARISON STUDY ON COOLING MANAGEMENT OF COMPOSITE PHASE CHANGE MATERIAL BATTERY PACK
Two Different Cases

by

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Lithium-ion batteries have become more and more recently. Because of their more density of energy and extended life cycle. In this research investigate the paraffin wax and composite phase change material (CPCM) were used to make a hexagonal and trapezoidal-shaped lithium-ion battery pack. Because thermal conductivity of paraffin wax is very low, to increase thermal conductivity adding carbon-based material of graphite powder. Without cooling, PCM cooling, and CPCM cooling studies on the battery module were all done. This investigation found that environment temperature of 28-32 °C, the experiment utilized three different discharge rates of 1C, 2C, and 3C. At all discharge rates, the CPCM with hexagonal battery pack has demonstrated good performance by keeping its temperature below 50 °C. In related to PCM cooling, the peak temperature was decreased by 6.7%, 9.1%, and 8.9% at 1C, 2C, and 3C. The CPCM-with trapezoidal based battery pack lowered the high temperature increase by 14.2% when related to the PCM-based battery pack. Additionally, it reduced the temperature variance of the trapezoidal battery pack.

*Key words: thermal conductivity, PCM, lithium-ion batteries,
CPCM, paraffin wax*

Introduction

People are continuously looking for green and clean energy because of the ecological damage and climate change brought on by the wide spread usage of fossil fuels. Currently, there is a world- wide consensus on the two-carbon strategy of carbon peaking and carbon neutrality, which causes the vehicle and linked industrial chain to spark a push toward carbon reduction. New energy cars have received a lot of attention in this campaign because of their distinctive benefits for energy conservation, pollution reduction, and environmental friendliness [1]. Demonstrated that using electric cars might potentially cut ozone-depleting gas emissions by 40%. Lithium-ion batteries areextensively employed as a key component of electrical vehicles (EV) and hybrid electric vehicles (HEV) because of their benefits of more density of energy and consistent service life [2]. The temperature has a significant impact on the safety and performance of power batteries, especially in EV. Maintaining an appropriate operating tempera-

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ture range is crucial to ensuring the optimal balance between battery performance and lifespan [3, 4]. Poor heat dissipation in power batteries can lead to several detrimental effects on battery performance and lifespan. When heat cannot effectively dissipate from the batteries, it results in a continuous rise in temperature, leading to several issues [5, 6]. Hence, the battery thermal management system (BTMS) is needed to enhance the protection, reliability, then overall achievement of power batteries, especially in EV and HEV. An effective BTMS aids in regulating and maintaining the battery's temperature within a safe and beneficial working range [7].

The following four types of thermal management systems (TMS) are mostly created on the various working mediums of heat dissipation. Air cooling is a BTM strategy that uses ambient air to manage battery temperature. In this approach, fans or ventilation systems direct air over the battery cells to remove heat. Air cooling systems can be either passive (using fans or blowers) or active (using nature air-flow) [8-10]. Liquid cooling is known for its high efficiency in heat dissipation, making it effective in maintaining stable battery temperatures during various driving and charging conditions. It is particularly useful for managing temperature spikes during fast charging or intense usage scenarios. However, liquid cooling systems may add weight and complexity to the battery pack [11-13]. Heat pipe cooling is another effective BTM strategy that has gained attention in recent years. Heat pipes are passive heat transfer devices that can efficiently transport heat from one location another using the principles of phase change [14]. The PCM are substances that can store and release thermal energy as they change from one state to another, within a specific temperature range. In PCM integrated into the battery pack to absorb and release heat during charge and discharge cycles, helping regulate the battery temperature [15]. The paraffin wax, an organic phase transition substance, has been chosen in the field of heat dissipation because of its non-corrosion, high latent heat, and high stability [16]. Paraffin wax thermal conductivity is very low, to enhancing by adding nanoenhanced phase materials like expanded graphite (EG), metal foams, multiwall carbon nanotubes (MWCNT), nickel foams [17]. A light weight material with superior mechanical and thermal abilities is foam metal. It performs better at heat transmission because of its intricate interior geometry and high surface area per unit volume [18]. The investigation into the thermochemical behavior of copper foam – paraffin wax CPCM for lithium-ion batteries has yielded promising results. The findings indicate that using CPCM in lithium-ion batteries can significantly lower the cell temperature during discharge, providing potential benefits for battery performance and safety [19]. Carbon-based substances with high thermal conductivity are frequently used to improve the thermal conductivity of paraffin wax in heat dissipation applications. By incorporating these additives into the paraffin wax, the overall thermal performance of the material is improved, making it more efficient in absorbing and dissipating heat [20, 21]. Because of its light texture, good thermal conductivity and high stability, expanded graphite is most common and utilized frequently [22]. Cooling management system performance on a laptop battery pack was assessed utilize a composite PCM/EG. The findings showed that TMS with PCM is smaller and lighter than conventional TMS [23, 24]. Evaluated the different concentrations of the carbon nanotube and graphene powder based on CPCM for energy storage use in a heat sink. Based on the results, at a concentration of 3 wt.%, the authors found that the composite PCM exhibited a reduction of 5.3% in latent heat fusion when incorporating carbon nanotube and a reduction of 7.3% when incorporating graphene nanoplatelet [25, 26].

In the proposed study, the focus is on investigating temperature variation and the development of a lightweight battery module using high thermal conductivity particles. Specifically, the researchers plan to use multi-wall carbon nanotubes (MWCNT), graphite-synthetic powder as the exclusive materials for this purpose. The choice of high thermal conductivity particles, such as MWCNT, graphite-synthetic powder, indicates the researchers' intent to increase the thermal properties of the battery pack. By incorporating these particles into the battery's design, they aim to improve heat dissipation and temperature management during the charging and discharging processes. In this study we tested two different battery thermal management systems.

Experimental details

The current experiment made use of Samsung 18650 cylindrical lithium-ion cells to produce a trapezoidal and a hexagonal battery pack. The lithium-ion batteries are 18 mm in diameter and 65 mm height. Table 1 displays the battery module specifications. Six modules, each with four cells, make up the two different battery packs. The 24 lithium-ion batterie cells with cylindrical shapes are interconnected in six series and four parallel arrangements. Verma *et al*. [27] tested several thicknesses of 3 mm, 7 mm, and 9 mm and the conclusion that 3 mm was the ideal thickness for lowering the highest temperature of the battery pack. At the top and bottom of the trapezoidal battery pack, plates made of hardwood hold a circle made of a 2 mm thick aluminum sheet. The experimental test carried out 28 °C atmospheric conditions.

Table 1. Specifications of the battery module

Characteristics	Details
Type of the battery	18650
Current of the module	10 Ah
Voltage of the module	24 V
Maximum charge rate	1C
Maxiumum discharge rate	3C

Methodology

The lithium-ion batterie cells with a 24 V, 10 Ah capacity make up the battery pack, which is shaped like a trapezoid. The cooling performance of a trapezoidal battery module is evaluated at several rates of discharge, 1C, 2C, and 3C. To measure temperature, the battery module is attached to the thermocouple, which serves as the temperature sensor. When PCM is included in the trapezoidal battery pack, cooling behavior is evaluated under various loads. The PCM is the melting temperature of paraffin wax, which is 47 °C. The thermo physical characteristics of paraffin wax and graphite powder are shown in tabs. 2 and 3. Figure 1 representation diagram of the hexagonal battery module and trapezoidal battery module.

Table 2. Characteristics of the paraffin wax [28]

Properties	Specification
Temperature of the melting range	46 °C
Heat energy of the material	226 kJ/kg
Material density	802 kg/m^3
Material specific heat	2510 J/kgK

Table 3. Characteristics of the graphite powder [28]

Properties	Specification
Density	2.93 kg/m^3
Thermal conductivity	2.7 W/mK
Material specific heat	710 J/kgK

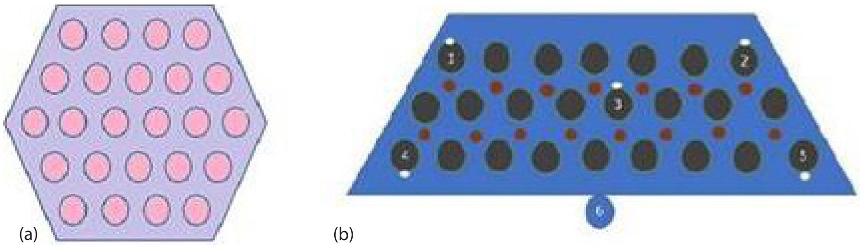

Figure 1. Schematic diagram represents comparison of; (a) hexagonal and (b) trapezoidal battery module

Preparation of PCM and CPCM

Grade C paraffin wax, from the eastern Petro chem form, has a melting point of 46 °C. Due to its latent heat, availability in a range of melting temperatures, and chemically less reactive nature, paraffin wax was preferred over all other PCM. The graphite-synthetic powder with a thickness of 11-15 nm, purchased at Sisco Research Laboratories Pvt. Ltd. in India. As seen in fig. 2, the CPCM is a type of material that combines a PCM with additives or particles that have a high thermal conductivity. In this instance, paraffin wax, which has a large latent heat capacity, is chosen as the PCM. Graphite particles are further to the PCM to rise its thermal conductivity. There are various phases involved in creating CPCM. First, a warm plate is utilized to melt the paraffin wax until it ranges a temperature of 100 °C. Graphite is added to the mixture after the paraffin wax has completely melted. Using a magnetic stirrer, the fluid is equally stirred once the graphite particles have been added. To ensure that the graphite and paraffin are well mixed, the stirrer is set to revolve at a speed of 1000 rpm. This mixing aims to ensure that the paraffin is equally coated with graphite particles. After mixing is complete, the paraffin combined with the different compositions of graphite particles is gathered and put into a mold. Due to the incorporation of graphite particles, the resultant CPCM will have improved thermal conductivity, making it more effective for heat absorption and storage.

Figure 2. Preparation of composite phase change material; (a) pure paraffin wax and (b) graphite powder with paraffin wax

Experimental procedure

An apparatus for charging and discharging batteries, a information collection unit, then a display make up the testing equipment for evaluating battery module performance. Applying a weight on the pack caused the cells to discharge. By connecting resistors, the appropriate electric load is used to the module. The measurement's accuracy is 0.1 V. The temperature range, which is normally 30 °C, was determined to be the ambient temperature. A data logger with 0.1 °C precision serves as the data gathering device that transmits temperature sensor data to the computer. The *K*-type thermocouples serve as a temperature sensor to transmit the cell pack's warmth to the data recorder. Initially, the module was charged in the experiment at a rate of discharge 1C. The module then has twelve hours to reach the desired ambient temperature. Final discharge rates for the battery pack included 1C, 2C, and 3C. To confirm the protection of the cells, the research is conducted for one charge and discharge cycle, however it is manually stopped when the temperature hits 60 °C. The two different battery module lay-outs are appeared in fig. 3.

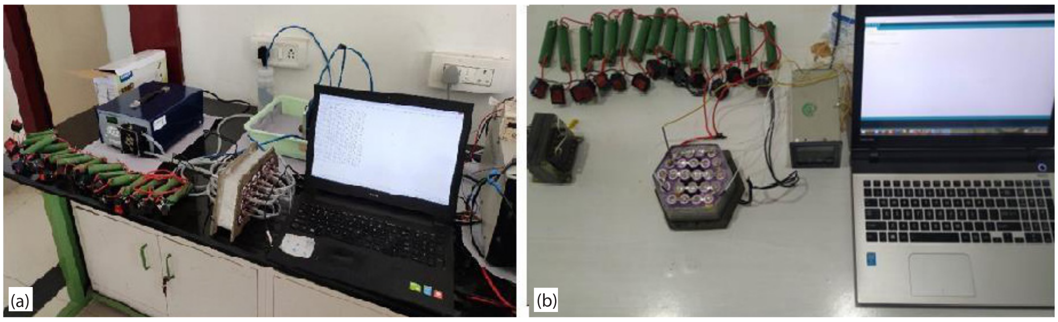

Figure 3. Experimental lay-out of the two different battery module; (a) trapezoidal battery module and (b) hexagonal battery module

Result and discussion

Comparison of two different battery module without cooling

At three different discharge rates, the experiment on the hexagonal module is first run without any cooling medium. The lithium-ion batteries module's temperature profiles at 30 °C. At the 1C discharge, the peak temperatures are 54.27 °C, 53.36 °C, and 48.56 °C, correspondingly. Figure 4(a), the corner battery's temperature steadily rose. In addition, the temperature of batteries 1 and 2 quickly rose as a result of additional heat growth in the middle of the lithium-ion batteries module. This caused the lithium-ion batteries module to operate above its safe operating temperature (50 °C) and caused an uneven distribution of temperature throughout the battery pack. Similar to fig. 4(a), batteries 1, 2, and 3 can withstand temperatures of 59.24 °C, 55.21 °C, and 43.14 °C, respectively.

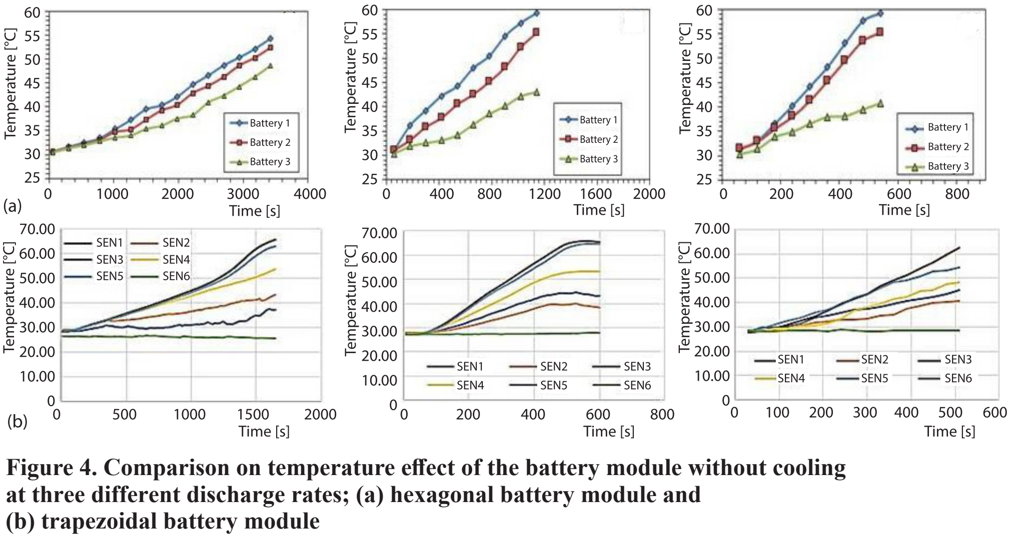

Figure 4. Comparison on temperature effect of the battery module without cooling at three different discharge rates; (a) hexagonal battery module and (b) trapezoidal battery module

An analysis of the cooling behavior of a battery module with a trapezoidal form discharged at varied rates of 1C, 2C, and 3C. The study keeps track of the battery pack's thermal performance throughout a range of time periods to look for temperature increases that go over the permitted limit of 65 °C. According to the study, for all three discharge rates, temperature rises are greatest in the center of the battery pack. The battery module's extreme temperature without the usage of phase change is 65.47 °C after 1200 seconds of continuous discharge at a 1C rate of discharge. When the discharge is 600 seconds of continuous discharge, the warmth continues to climb until it reaches its greatest point at 65.53 °C. When the discharge increased to 3C, the extreme temperature also climbs over 65 °C within 500 seconds of continuous discharge, drastically changing the temperature behavior from 2C. Natural air convection is used to conduct the test at a temperature of 28 °C. In order to attain high precision, the test is repeated several times. It is found that under the same working circumstances, the temperature rise remains constant. Figure 4(b) displays the trapezoidal battery pack's temperature curves.

Comparison of two different battery module with PCM cooling

The hexagonal battery module with PCM cooling had a lower extreme temperature than the battery module without cooling, as revealed in fig 5(a). At a 1C rate of discharge, the maximum warmth drops from 54.27 °C to 49.18 °C. At 2C and 3C discharges, the temperature rises of 52.12 °C and 54.37 °C. When paraffin wax was injected at a distance of 5 mm between cells, it seems that the extreme warmth increase of the trapezoidal battery module was reduced by 8 °C. However, even with the paraffin wax, the battery pack's highest temperature rise occurred at 55.63 °C after 1200 seconds at a 1C discharge rate as displayed in fig 5(b).

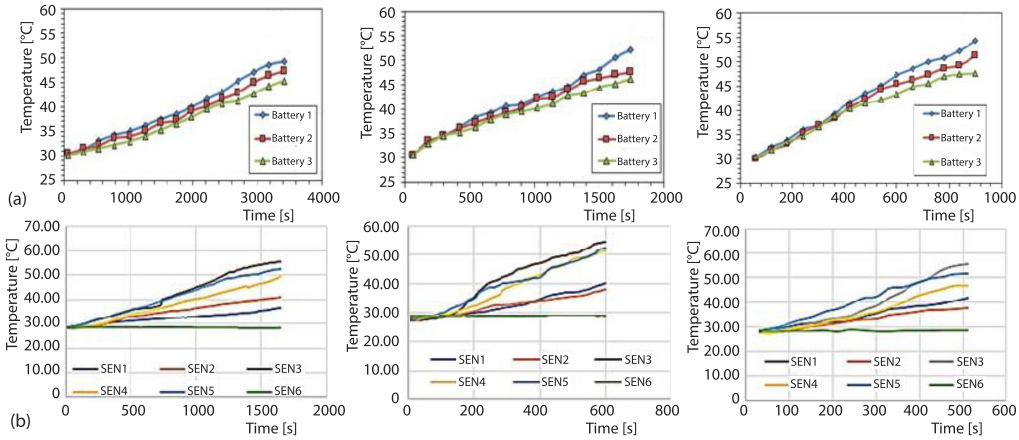

Figure 5. Comparison on temperature effect of the battery module with PCM cooling at three different discharge rates; (a) hexagonal battery module and (b) trapezoidal battery module

Comparison of two different battery module with CPCM cooling

Based on the temperature profiles of the hexagonal battery module under various discharge rates and utilizing CPCM cooling, the results depicted in fig. 6(a) indicate significant temperature reductions. At a 1C discharge rate, the module's maximum temperature decreased by 49.18 °C, reaching 45.88 °C. Similarly, at a 2C discharge rate, the peak temperature decreased from 52.12-47.73 °C. At a 3C discharge rate, the maximum temperature was lowered from 54.37-49.53 °C. Notably, the CPCM battery pack performed effectively across all discharge rates, keeping the temperature below 50 °C. Comparing the CPCM cooling approach with PCM cooling, the maximum temperature reductions were 6.7%, 9.1%, and 8.9% at 1C, 2C, and 3C discharge rates, respectively. These findings demonstrate that a CPCM-based battery thermal management system outperforms a pure PCM cooling method, improving the cooling rate significantly. Through the implementation of CPCM, the battery pack's peak temperature was successfully lowered from 55.63-48.68 °C, as evidenced in fig. 6(b).

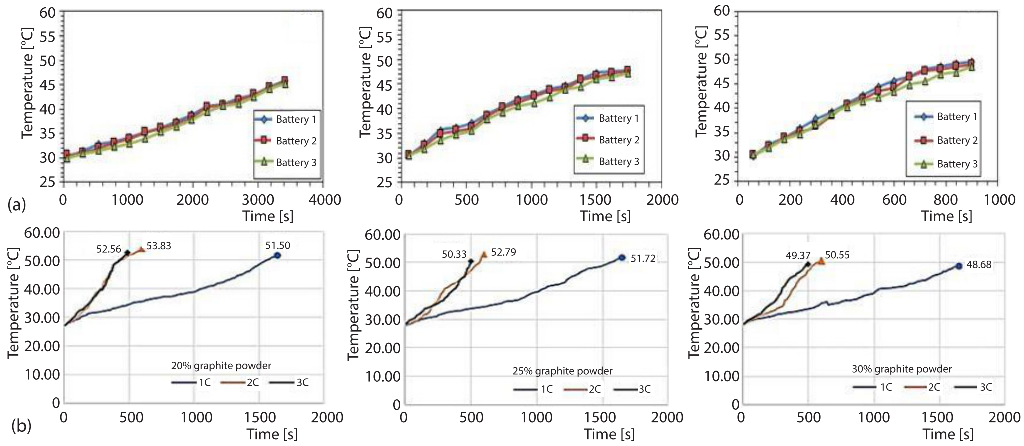

Figure 6. Comparison on temperature effect of the battery module with CPCM cooling at three different discharge rates; (a) hexagonal battery module and (b) trapezoidal battery module

Conclusions

- The incorporating CPCM into a battery pack, a distinctive trapezoidal-shaped and hexagonal shaped cooling system is effectively created. Increasing the heat transfer rate using CPCM improves cooling effectiveness. The production of CPCM, which is improved for high thermal conductivity, use the paraffin wax and graphite-synthetic powder compositions. The efficiency of cooling a trapezoidal battery pack is also contrasted with that of other technologies, including free convection, pure PCM, and CPCM. By highlighting the advantages of each technique, this comparative study aids in increasing efficiency.
- At a 1C discharge rate, the hexagonal battery module with PCM achieved a maximum temperature below 50 °C, indicating successful thermal management. However, when subjected to higher discharge rates, the PCM cooling approach proved inadequate in maintaining a safe operating temperature range for the module.
- The CPCM battery module demonstrated successful performance by effectively keeping the temperature below 50 °C across all discharge rates. The peak temperature was lowered by 6.7%, 9.1%, and 8.9% at 1C, 2C, and 3C in comparison PCM cooling*, etc.*
- In comparison the PCM-based battery pack, the CPCM-based battery pack reduced the high temperature rise by 14.2%. Furthermore, it helped keep the trapezoidal battery pack's variation in temperature.
- The CPCM-based battery pack with a liquid cooling system is intended to utilize the PCM, which has a melting point of 46.7 °C. The trapezoidal battery pack must reach 44.29 °C and there can only be a temperature differential of no more than 4-5 °C.

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