Journal of Advanced Engineering Research
ISSN: 2393-8447
Volume 11, Issue 2, 2024, pp.102-109

NUMERICAL AND EXPERIMENTAL INVESTIGATION OF PHASE CHANGE MATERIAL BASED BATTERY PACK COOLING

Samin Mohamed, Fauzan Ahmed, Richu Thomas, Alberto William Donald, Anshul Kashyap, Punit Kongi.

CHRIST-DEEMED TO BE UNIVERSITY, BANGALORE-560060, INDIA
AUTOMOTIVE RESEARCH ASSOCIATION OF INDIA, PUNE-411038, INDIA

samin.mohamed@btech.christuniversity.in, Tel. :8113803736
fauzan.ahmed@btech.christuniversity.in,Tel. : 9790850011
richu.thomas@btech.christuniversity.in,Tel. : 9048120029
akkarakkaran.alberto@btech.christuniversity.in,Tel. : 8788709039
punit.kongi@christuniversity.in,Tel. : 9738819343
anshul.kashyap@btech.christuniversity.in,Tel. : 8851236848

ABSTRACT:

This study examines the use of paraffin as a phase change material (PCM) with various concentrations of graphene nanoparticles for cooling battery packs using numerical and experimental methods. To test their impact on battery cooling, we specifically added 100 grams of paraffin and utilised 1%, 5%, and 10% graphene. The primary objective of the study is to assess the thermal performance of a battery pack using PCM-based cooling at various discharge rates. To simulate the cooling process, a computational fluid dynamics (CFD) model was created, and experiments were run to confirm the numerical findings. The study's findings demonstrated how greatly adding graphene nanoparticles improved the PCM-based cooling system's ability to transfer heat. As the percentage of graphene in the battery pack increased, the CFD simulations projected a drop in temperature, which the experimental data confirmed. The 10% graphene combination in particular produced the finest cooling results. The work offers insightful knowledge into the planning and improvement of PCM-based battery pack cooling systems, with the utilisation of graphene nanoparticles as a potent boost. The findings can be utilised to create battery cooling systems for a variety of uses, such as electric vehicles and renewable energy storage systems

Keywords: Battery pack, Graphene, Paraffin, PCM.

1. INTRODUCTION:

In recent years the EV market has grown enormously ever since the rise in concern towards the global environment and the harm fossil fuels cause not only to the environment but also to the general population that utilises these fossil fuels. Governments worldwide have put forth incentives and regulations to push the countries into adapting EV technology. In the coming years, we can expect to see the EV market grow as the technology advances, and the infrastructure for implementing charging stations becomes more widely available and the costs of the components involved reduce.

Since the advancement In EV technology there has been a sudden increase in the use of lithium-ion batteries. They have emerged as the preferred option for power in electric vehicles owing to their high energy density; extended longevity; and low self discharge rate. Since they store a large amount of energy in a small space they are perfect for the use in electric vehicles. While there are several reasons behind the quick increase in lithium ion batteries, one key contributing factor is the rising demand of electric vehicles, this rise in demand is fuelled by the worries about climate change and the desire to reduce our reliance on fossil fuels, and so the demand of these batteries has grown as more people choose electric vehicles as a more environment friendly mode of transportation.

The lithium ion batteries are more affordable for the general consumer as the advancements till now in the process of manufacturing these lithium ion cells have become more efficient and reliable. Government incentives such as tax breaks and subsidies for EV purchases have also made it easier to encourage the use of EV, causing multiple manufacturers of lithium ion batteries to emerge in the market which overall reduces the price of the batteries. The essential factor towards the use of lithium ion batteries is towards their flexibility to be used in various types of vehicles and their capacity to generate the required amount of power without major losses, one such example of their flexibility are the electric two wheelers, they are often referred to as e bikes or e scooters being a form of vehicle that are propelled by a rechargeable battery. Particularly in urban areas, owing to their lower operating costs and maintenance costs as compared to conventional gasoline powered vehicles, they have gained popularity as an alternate means of transportation. Traditional bicycles, mopeds and scooters are just a few examples of the many designs available for electric two wheelers which are practical and green alternatives means of transportation that are gaining popularity in urban places all over the world. The use of electric two wheelers is projected to increase in the future due to continued advancements in battery technology and the expansion of charging station infrastructure.

A group of identical batteries which is used to power the electric two wheelers is called a battery pack. These battery packs are often made up of many batteries that are in connection to each other either in series or in parallel to supply appropriate voltage and current from its maximum capacity.

The most common and frequently used batteries in the manufacturing of battery packs are the lead acid, nickel-cadmium and lithium ion. While the lead acid batteries are cheaper in comparison to the other batteries they have a shorter life span, the nickel-cadmium battery packs have a longer life span with higher energy density than lead acid batteries but are expensive compared to lead acid or lithium ion batteries. Lithium ion battery packs are smaller in size and require less maintenance, have the highest energy density compared to both nickel cadmium and lead acid batteries and are light weight which is a key factor in the choice for lithium ion cells to be used to create these battery packs. The battery pack's voltage and capacity determine the vehicle's power output and the distance up to which it can cover in a single charge making it an essential part of an electric vehicle.

In the country of India, there are several issues that are faced in recent years.

Lifespan: In India, one of the main issues with electric two wheeler battery packs is that they do not last as long as they should. Many users have stated that the battery pack would fail after a year or two of purchase needing an expensive replacement.

Limited infrastructure: In India, the present infrastructure causes an hindrance in the creation for building further charging stations as it would require the government to change or rebuild existing infrastructure which could be financially taxing.

Lack of standardisation: The battery packs for electric two wheelers being sold by retailers are not uniform as there are no norms or standards present for manufacturers to follow for these vehicles. Users find it difficult to find manufacturers who produce compatible battery packs to their vehicles.

Safety issues: Since the general population has started using electric vehicles there have been reports and complaints regarding the

Thermal runaway is a phenomenon that happens when a battery pack in an electric two wheeler reaches a critical temperature, setting off a series of events that cause a rapid rise in temperature, this could lead to the battery overheating; which could endanger the vehicle and increase the risk of fire. Numerous factors like overcharging, over discharging, short-circuiting, and mechanical damage may cause thermal runaway in addition to the materials used to manufacture these cells and the rate at which they deteriorate.

While these factors exist as barriers towards battery cooling it becomes difficult to find a solution that overcomes all the mentioned factors, but the use of PCM(Phase change Material) is a key step towards finding those solutions. PCMs are substances that can store and release thermal energy by changing their current phase of let's say a solid to liquid. They are used conventionally in building insulation, thermal energy storage and as efficient cooling systems for electronic devices. The use of PCMs in electric vehicle's battery packs is advantageous because of its high thermal energy storage capacity, ability to release heat energy at a stable and consistent temperature, long lasting and the fact that they have low toxicity which makes them accessible to a wide range of applications.

While PCMs show to be a great and viable option there are a few disadvantages that need to be taken into consideration like the fact that they can be expensive making them less cost effective than other thermal energy storage options, the temperature range of a PCM is also limited and may not be the best suited for extreme temperature conditions, while very advantageous it may get tedious to manufacture the PCM and hence is not widely available to find suppliers for the materials

1.1 The limitations of using phase change material (PCM)

Making a battery pack for thermal management can be highlighted as follows:

1.1.1 High Cost:

The use of PCMs in battery packs can increase the cost of production, making it less cost-effective than other thermal management options. This can make it difficult to compete with other battery pack options in the market.

1.1.2 .Limited Temperature Range:

PCMs have a limited temperature range and may not be suitable for use in extreme temperature conditions. This limitation can lead to reduced efficiency and reliability of the battery pack, which can impact its overall performance.

1.1.3 Limited Availability:

The availability of PCMs may be limited, and it can be difficult to find suppliers for certain materials. This can create supply chain issues and lead to delays in production and increased costs.

1.1.4 Limited Usage:

Some PCMs can only be used in specific applications, such as cooling systems for electronic devices, and cannot be used in other applications like building insulation. This limitation can impact the versatility and flexibility of using PCM in battery pack thermal management.

Therefore, while the use of PCMs in battery pack thermal management has its advantages, it is important to consider the limitations and drawbacks to ensure that the technology is practical and cost-effective in the long run.

1.2 The limitations of paraffin wax as a phase change material (PCM)

1.2.1 Low thermal conductivity: Paraffin wax has a low thermal conductivity, which means
that it is not very effective at conducting heat. This can lead to thermal stratification, where there is a temperature gradient across the PCM. This can reduce the overall effectiveness of the PCM in thermal energy storage.

1.2.2 Limited temperature range: The melting point of paraffin wax is typically between 37°C and 70°C, which means that it is not suitable for use in applications that require higher or lower temperatures. This can limit its use in certain thermal energy storage applications.

1.2.3 Super cooling: Paraffin wax can exhibit supercooling, which is when it remains in a liquid state even below its melting point. This can cause issues with the performance of the PCM, as it can delay the onset of melting and reduce the overall energy storage capacity.

1.2.4 Chemical instability: Paraffin wax can degrade over time due to chemical reactions, which can reduce its effectiveness as a PCM. This can be exacerbated by exposure to high temperatures or UV radiation.

1.2.5 Limited lifespan: The repeated cycling of a PCM can cause it to degrade over time, leading to a reduction in its thermal energy storage capacity. This can limit the lifespan of paraffin wax as a PCM, particularly in applications where frequent cycling is required.

3. MATERIAL DEVELOPMENT:

magnetic field and using a ferromagnetic material to generate magnetic forces. In the case of the development of a composite material of paraffin

Ultrasonication is an essential step in the development of the composite material because it ensures a uniform dispersion of the graphene nanoparticles in the paraffin matrix. This is achieved by using high-frequency sound waves to disrupt and break down the particles or materials, resulting in a uniform dispersion.

The use of ultrasonication involves the creation of high-pressure and low-pressure zones within a liquid, which causes cavitation bubbles to grow and eventually collapse. The resulting shockwaves generated by the collapse of the cavitation bubbles are responsible for breaking down and dispersing the nanoparticles.

The resulting composite material of paraffin and graphene is likely to have unique properties that combine the characteristics of both materials. Paraffin is a hydrocarbon-based wax that is known for its excellent heat-retaining properties, while graphene is a two-dimensional material with high electrical conductivity and strength.

The composite material could be used in various applications, including in the field of electronics and energy storage To Create the composite material, different concentrations of graphene nanoparticles were tested with 100 grams of paraffin, namely 1%, 5%, and 10%.

This means that the composite material's properties were tested and evaluated at different concentrations of the graphene nanoparticles. REMI Magnetic steering, specifically the 1 MLH model, was used to steer and manipulate the magnetic pellet containing the dispersed graphene nanoparticles.

This model of magnetic steering is likely a specific type of equipment or device used to generate the magnetic and graphene, magnetic steering was utilised to create a uniform dispersion of the nanoparticles. This is important because a uniform distribution of the nanoparticles ensures that the composite material has enhanced properties, such as improved conductivity or mechanical strength.

3.1 Testing of composite material

Magnetic steering is a useful technique that has many applications in various fields. One of its uses

The composite material was sampled into 1,5 and 10 percent of graphene nanoparticles mixed for 100g weight of paraffin wax. The mixture of 1 percent weight of graphene nanoparticles in 100g of paraffin wax with the melting point of 60 degree Celsius

XRD was performed on the paraffin-graphene nanoparticle composite material with varying percentages of graphene nanoparticles, i.e.As shown in FIG 1 and FIG 2, 5 and 10 percent by weight. The XRD graph shows a distinct and sharp peak, indicating that the composite material has a high degree of crystallinity and well-defined structure. This peak is a result of the highly ordered arrangement of atoms in a specific crystal plane, which is aligned with the incident X-rays. The presence of a high peak in the XRD graph indicates that the graphene nanoparticles are evenly dispersed and distributed in the paraffin matrix, resulting in a well-structured composite material. This inference is significant in understanding the behaviour of the composite material in response to thermal management applications, as a well-structured composite material will have superior thermal properties.

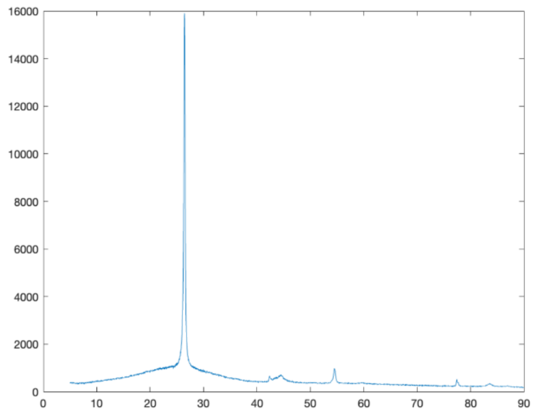

FIG 1. Paraffin with 5 percent of graphene

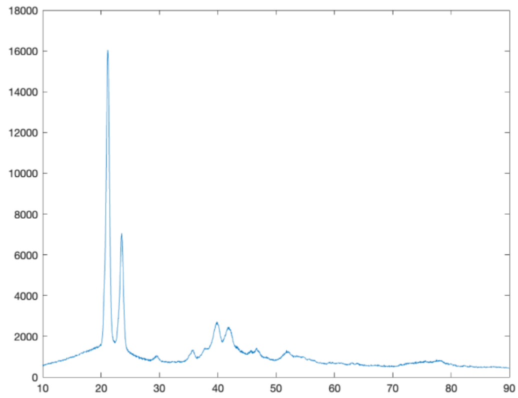

FIG 2. Paraffin with 5 percent of graphene

3.2 Thermal Conductivity of Paraffin with various graphene content.

We conducted a test for thermal conductivity on the composite materials using the laser flash method. This method involves a short pulse of energy being applied to the material's surface and measuring the time it takes for the heat to propagate through it. The laser flash method is a non-destructive testing method that is commonly used to determine the thermal diffusivity and thermal conductivity of materials. It involves the use of a high-energy laser pulse to create a heat flux on the surface of the material. This pulse generates a temperature rise in the material, and the temperature profile is recorded by a detector over a specific time period. The temperature profile is then analysed to determine the thermal diffusivity and thermal conductivity of the material. In the case of composite materials, the laser flash method is used to measure the thermal conductivity of the material. The test involves cutting a small sample of the composite material and preparing it for testing. The sample is placed on a support platform and exposed to a high-energy laser pulse. The laser pulse generates a temperature rise in the material, and the temperature profile is recorded by a detector. The detector records the temperature profile for a specific time period, and the temperature data is analysed shown in FIG 3 to determine the thermal conductivity of the composite material.

Table 1.
Thermal Conductivity

Graphene(percent)	Conductivity(in W/mK)
0	0.2
1	0.242
5	0.266
10	0.29

At various graphene content

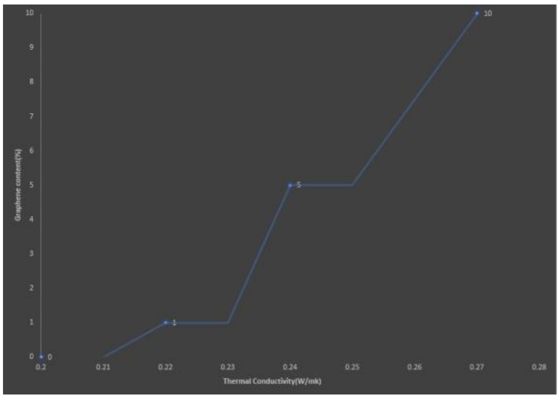

FIG 3. Thermal conductivity result

4. EXPERIMENTATION:

The test bench used in this study is designed to measure the electrical conductivity of a battery pack with and without the PCM material. The test bench comprises four 130W bulbs and two 65W bulbs that are connected to the battery pack to drain it. The components of the battery pack are given in table 2.

Table 2.
Components of the Battery Pack

Components	Specification
Operating Temperature	- 10 - 45 Celsius
Cell type	-Lithium ion
No of cells	- 12 no's
Application	- 2 Wheelers
PCM type	-Paraffin
Nano Particle type	-Graphene
Testing C Rates	-0.25c,0.5c,1c
Outer casing	-Copper plate

The bulbs are controlled by six switches that enable us to regulate the amount of power being drawn from the battery. Additionally,lithium-ion batteries are highly efficient and widely used in various applications, including electric vehicles, renewable

energy storage, and portable electronics. However, these batteries are sensitive to temperature, voltage, and current variations, which can lead to safety hazards and reduced performance. To ensure safe and reliable operation of the battery pack, a Battery Management System
(BMS) is necessary. The BMS monitors and controls the charging and discharging of the battery cells, as well as the temperature and voltage levels. This helps to prevent overcharging, undercharging, and overheating, which can cause damage to the battery and pose a risk of fire or explosion.

In addition to the BMS, an Arduino board is also used to control the entire system. The Arduino board provides a programmable microcontroller that can be customised to meet specific requirements. It allows for real-time monitoring and control of the battery parameters, as well as the integration of additional sensors and actuators for enhanced performance and safety. The testing procedure needs to be developed for the battery pack on the test bench. The battery pack under test is a 3 by 3 combination. The following steps are taken:

1. Connection of the Lithium-ion Battery Management System (BMS) to the battery
pack to monitor the battery voltage, current, and temperature during the tests.
2. Connecting the Arduino board to the BMS and the switches to control the entire system .
3. Connection of four 130W bulbs and two 65W bulbs to the battery pack to drain it.
The bulbs are controlled by six switches that enable us to regulate the amount of power being drawn from the battery.
4. Discharge the battery pack without PCM at a rate of 1 C for 60 minutes.
5. Record the temperature variation at every 10 minute interval.
6. Repeat the test with another battery pack with the PCM and record the temperature variation at every 10 minutes interval.
7. Then we analyse the data and compare the
results between the battery pack with and without the PCM.

By following these steps, we can effectively test the battery pack on the test bench and analyse the data to draw conclusions about the effectiveness of the PCM in cooling the battery pack.The main purpose of this test bench is to perform comparative testing between the battery pack with the PCM and the pack without the PCM. The test bench enables us to measure the battery's discharge rate and determine its operating temperature, which can be used to determine the battery's capacity and efficiency. By comparing the operating temperature of the two battery packs, we can determine the effectiveness of the PCM material in maintaining a consistent temperature and improving the battery's performance. A battery management system (BMS) is crucial for the safe and efficient operation of a
battery pack. The BMS serves as the brain of the battery pack, monitoring and controlling its various functions, such as charging, discharging, and temperature regulation. The BMS helps to prevent overcharging or over-discharging of individual battery cells, which can cause irreparable damage to the battery pack and compromise its safety. It
also ensures that each cell in the battery pack is operating within its optimal temperature range to prevent thermal runaway and other safety issues.

Furthermore, the BMS provides valuable information about the state of the battery pack,
such as its remaining capacity and overall health, allowing for more accurate predictions of its performance and lifespan. This information is important for the proper main-
tenance and replacement of the battery pack, ensuring that it operates efficiently and reliably throughout its lifetime. Overall, the BMS plays a critical role in maximising the performance, safety, and lifespan of a battery pack, making it an essential component of any battery-powered system.Overall, this test bench provides a reliable and accurate method for evaluating the impact of the PCM material on the performance of a Li-ion battery pack. The results of this study can be used to inform future research on thermal management systems for Li-ion batteries and contribute to the development of more efficient and reliable energy
storage systems.

5. RESULTS AND DISCUSSION:

The battery pack without any PCM has an operating temperature of 50 degree Celsius, which is higher than the recommended temperature range for most Li-ion batteries. On the other hand, the battery pack with the paraffin wax mixed with 10 percent graphene nanoparticles as its cooling solution has a significantly lower operating temperature of 38 degree Celsius, which indicates that the PCM is able to effectively dissipate the heat generated by the battery during operation.

The operating temperature of a battery pack plays a crucial role in determining its overall performance and lifespan. When a battery is operated at temperatures above its recommended range, its efficiency decreases, and the battery experiences a reduction in its lifespan. Therefore, it is essential to maintain the operating temperature of the battery within its recommended range. The experiment mentioned here involves comparing the operating temperature of a battery pack with and without PCM. The battery pack without PCM has an operating temperature of 50 degree Celsius, which is higher than the recommended temperature range for most Li-ion batteries. This indicates that the battery pack without PCM is operating at an elevated temperature, which can negatively impact its performance and lifespan. On the other hand, the battery pack with the paraffin wax mixed with 10 percent graphene nanoparticles as its cooling solution has a significantly lower operating temperature of 38 degree Celsius. This indicates that the PCM is able to effectively dissipate the heat generated by the battery during operation,
thereby maintaining the temperature of the battery pack within the recommended range. This not only improves the overall performance of the battery pack but also prolongs its lifespan. PCM-based cooling systems are becoming increasingly popular in various engineering applications, including battery thermal management. PCM offers several advantages over traditional cooling methods, such as low operating costs, high energy storage density, and uniform temperature distribution. Additionally, the use of nanoparticles in PCM, such as graphene nanoparticles, can further enhance its heat transfer performance, leading to more efficient and effective cooling of the battery pack.

TEMPERATURE OF BATTERY PACK

Time(m)	Temperature(in degree C)
10	31
20	32
30	32
40	34
50	36
60	38

FIG 3. With PCM

Time(m)	Temperature(in degree C)
10	32
20	35
30	38
40	42
50	44
60	47

FIG 4. Without PCM

6. Conclusion:

The study found that adding graphene nanoparticles to paraffin as a phase change material greatly improved the cooling performance of battery packs. As the percentage of graphene in the battery pack increased, the computational fluid dynamics (CFD) simulations predicted a drop in temperature, which was confirmed by experimental data. The 5% graphene combination in particular produced the best cooling results. These findings provide valuable insights for the design and development of PCM-based battery pack cooling systems, with the use of graphene nanoparticles as an effective enhancement. This research can be used to create battery cooling systems for various applications, such as electric vehicles and renewable energy storage systems.

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