Phase Changing Material (PCM)

CL-204: Heat Transfer

Group 7(Project No.5)

By

Ankit Singh (22110025)

Chanchal Yadav (22110055)

Kaushik (22110113)

Om Gupta (22110174)

Pankaj (22110177)

Under the guidance of

Prof . Biswajit Saha

Indian Institute of Technology, Gandhinagar

Objective:

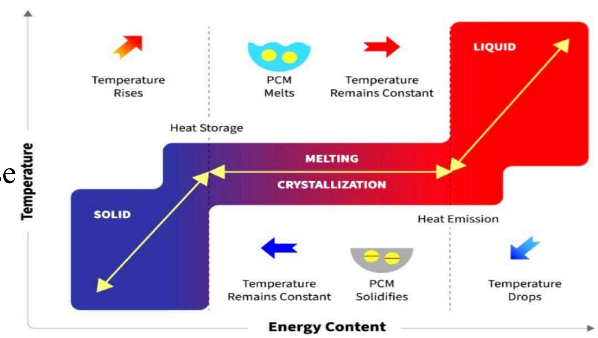
Our objectives for this project are twofold. Firstly, we aim to compare the temperature profiles between setups with and without the phase-changing material (PCM). Through careful experimentation and data collection, we will analyze and contrast the temperature trends in each setup to assess the impact of PCM on temperature regulation.

Secondly, we seek to evaluate the efficiency of the experimental setup. By quantifying factors such as temperature stabilization, thickness of PCM material, heat retention, and energy storage capacity, we will assess the overall effectiveness of the PCM-based thermal storage system compared to conventional setups. This analysis will provide valuable insights into the practicality and performance of PCM technology in thermal management applications.

Basic Introduction & Theory:

Introduction:

Phase-changing materials (PCMs) are innovative substances that undergo a phase transition, such as melting or solidification, at specific temperature ranges. This unique property allows them to store and release large amounts of thermal energy during these phase transitions, making them highly effective in temperature regulation applications. PCM technology has garnered significant interest in various industries, including construction, automotive, electronics, and energy storage, due to its ability to enhance thermal comfort, improve energy efficiency, and mitigate temperature fluctuations.



Theory:

The principle behind phase-changing materials lies in their ability to absorb or release thermal energy as they transition between different phases, typically solid and liquid. This phenomenon occurs at a constant temperature known as the phase change or melting/freezing point. During the phase transition process, the material absorbs or releases energy in the form of latent heat while the temperature remains constant until the transition is complete.

When a PCM absorbs heat, such as from its surroundings or an external heat source, it undergoes a phase change from solid to liquid, storing the absorbed thermal energy within its molecular structure. Conversely, when the temperature decreases, the PCM solidifies, releasing the stored energy into the environment. This thermal energy exchange enables PCMs to act as thermal batteries, effectively buffering temperature fluctuations and maintaining stable thermal conditions within their surroundings.

The choice of PCM depends on various factors, including the desired operating temperature range, heat capacity, thermal conductivity, and compatibility with the application requirements. Common PCM materials include paraffin waxes, organic compounds, hydrated salts, and eutectic mixtures, each offering distinct advantages in specific temperature regulation applications.

In practical applications, PCMs are often encapsulated or integrated into building materials, textiles, energy storage systems, or thermal management devices to harness their thermal energy storage capabilities. By strategically incorporating PCMs into the design of temperature regulation systems, it is possible to achieve enhanced thermal comfort, energy efficiency, and environmental sustainability across a wide range of industries and applications.

Experiment:

The primary objective of the experiment was to compare the temperature changes while we use PCM and while we don't. The methodology involved the construction of two containers with dimensions 30cm x 30cm x 30cm each, utilizing MDF sheets. One incorporated PCM-based insulation, while the other served as a control without insulation.

Paraffin wax was chosen as the PCM for experimentation. To facilitate the vertical placement of PCM, substructures with dimensions 4.5cm x 4.5cm x 0.7cm were designed, and aluminum foil was utilized on the walls of the container. Each container was equipped with a 100-watt bulb serving as a heat source to simulate real-world conditions. Temperature sensors were strategically installed in both containers to monitor internal temperature variations accurately throughout the experiment.

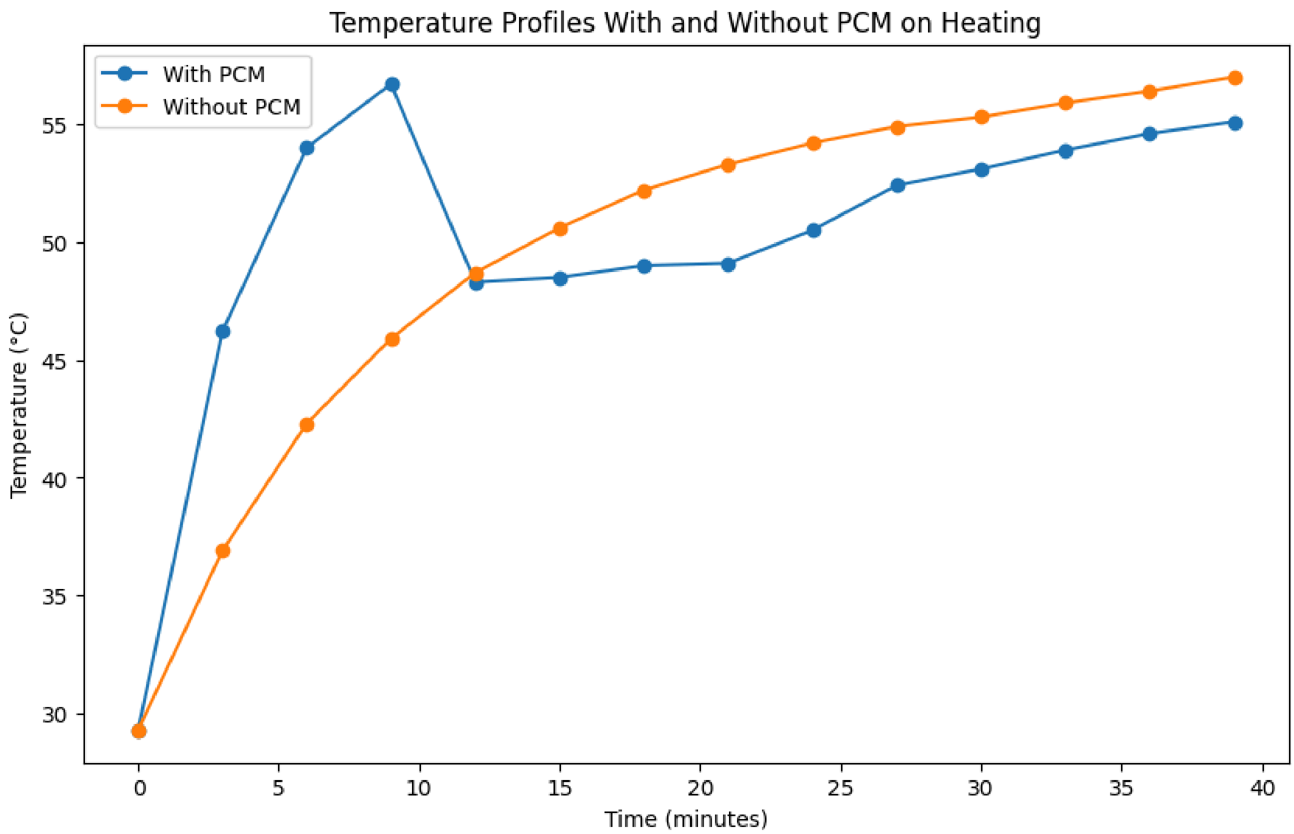
The experiment began with ensuring equal starting conditions in both containers, initiating them at the same temperature. Consistent heating was achieved by utilizing standardized 100-watt bulbs in both containers. Temperature measurements were recorded regularly using a digital thermometer to monitor temperature changes over time. We recorded data for heating and then switched the bulb off to allow the containers to cool.

The recorded temperature data was used to plot temperature profiles for both containers, allowing for visual comparison and analysis of temperature variations. By comparing these profiles, the effectiveness of PCM-based insulation in maintaining temperature stability was assessed. Through the experiment, insights were gained into the thermal performance of PCM-based insulation, providing valuable data for concluding its efficiency in practical applications.

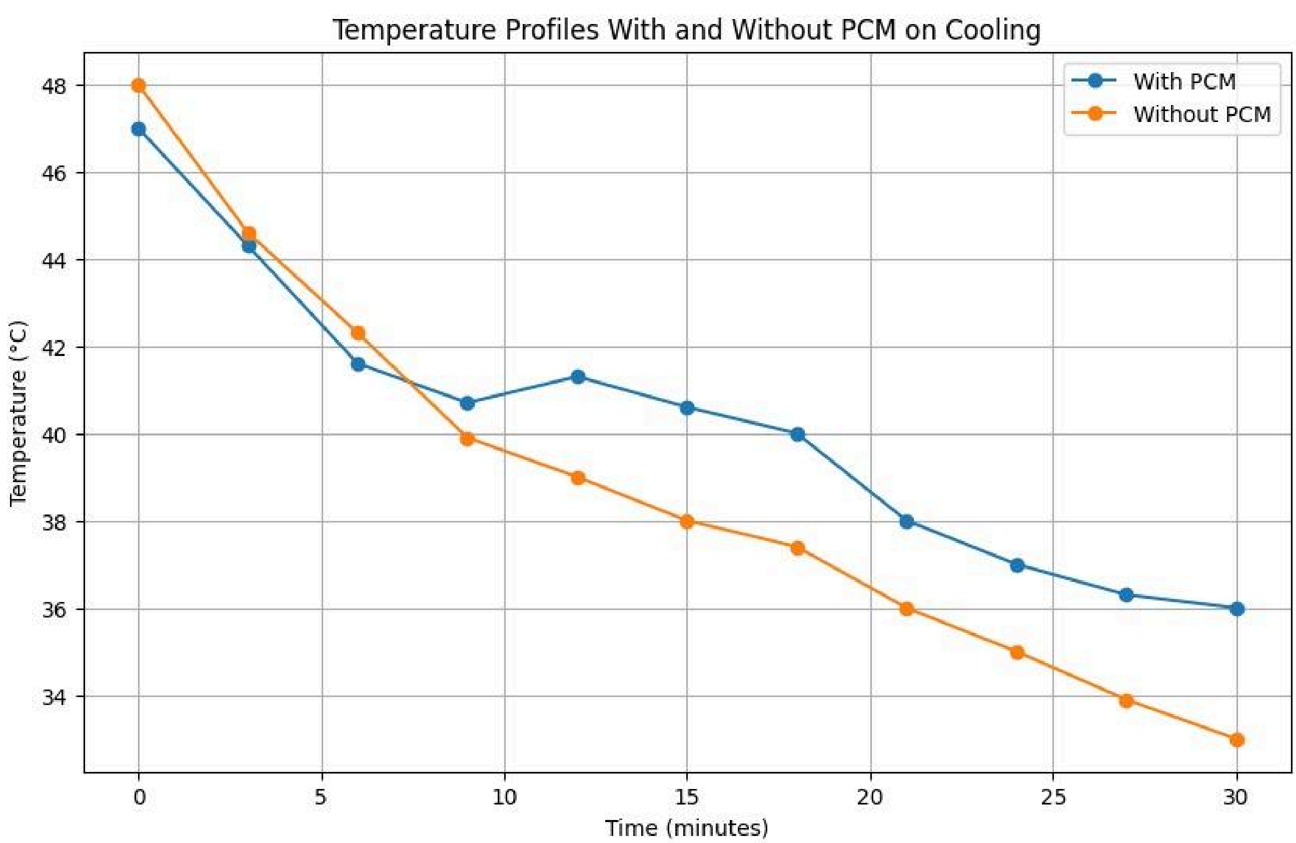
Observation:

We plotted graphs for both the conditions - heating and cooling for both the curves using matplotlib library of Python.

These are the temperature profiles we got experimentally for both containers.



Temperature Profiles With and Without PCM on Heating
With PCM
Without PCM
Temperature (°C)
Time (minutes)
30
35
40
45
50
55
0
5
10
15
20
25
30
35
40



Temperature Profiles With and Without PCM on Cooling
With PCM
Without PCM
Temperature (°C)
Time (minutes)
34
36
38
40
42
44
46
48
0
5
10
15
20
25
30

Heating -

At first, we can see that both containers' temperatures are rising rapidly. However, it has been noted that the temperature of the container containing PCM is rising faster than that of the other container. This is because aluminum foil has a high degree of reflection, which raises the temperature inside the container by reflecting back a significant amount of heat.

However, the temperature of the PCM-containing box rapidly drops and even approaches the temperature of the other container after a specific point—the melting point of paraffin wax. This is because paraffin wax changes phases, and it takes a lot of energy to break the bonds between molecules in order to change the phase. As a result, the container's temperature dropped, and heat was absorbed. The temperature of the PCM-containing box begins to rise once the phase shift is completed. However, it stays below the other container until the temperature reaches a saturation point. The condition approaches stability.

Cooling -

The initial observation in the experiment highlights the significant temperature decline in both containers as they are cooled down. After some time, the PCM reaches its melting point. It is at this pivotal temperature that the PCM undergoes a transformation, transitioning from a liquid to a solid state. This solidification process triggers a controlled release of heat, influencing the rate at which the temperature decreases within the PCM-containing container.

Moreover, the unique thermal properties of PCM play a pivotal role in making it an ideal candidate for acting as a heat storage reservoir. This characteristic allows the PCM to release stored heat as needed efficiently, demonstrating its versatility in various applications that require precise heat management. Once the solidification process is complete, the temperature decline in the PCM container resumes its accelerated pace, highlighting the dynamic nature of this material's thermal behavior. The distinct phases of the PCM, from liquid to solid and back, showcase its ability to modulate heat transfer effectively, showcasing its importance in practical heat storage solutions.

.

Calculation:

Without PCM

Assumptions:

1) one dimensional Heat transfer (radially outward)
2) Thermal properties are considered as constant
3) After some time, the temperature inside the box reaches almost steady state.
4) Air inside the container is stagnent

Initially the temperature will keep rising (unsteady state) and after some point the temperature start saturating (Reaches steady state)

- Unsteady State Analysis

$$P - \dot{Q} = m C_p \frac{dT}{dt} \quad \text{—(1)}$$

$P \rightarrow$ power of bulb (W) = 100 Watt

$\dot{Q} \rightarrow$ heat transfer through the walls

- ~~Unst~~ Steady State

$$R_{net} = R_{air} + R_{mdf} + R_{inside}$$

$$= \frac{1}{h_o A} + \frac{t}{K_m A} + \frac{L}{K_a A}$$

$$\frac{dT}{dt} = 0$$

$$P = \dot{Q} \quad \text{(from eqn (1))}$$

$$\dot{Q} = \frac{\cancel{KA}\,\Delta T}{R_{net}}$$

$K \Rightarrow$ Thermal Conductivity of MDF.

Integration to find $T(t)$

from eqn ①

$$P - \frac{(T(t) - T_{surrounding})}{R_{net}} = mC_p \frac{dT}{dt} \quad -②$$

$m = \rho V$ $\quad\quad$ ρ - air of density

$\quad\quad\quad\quad$ V volume of container

$L = 0.003$ m

$L \rightarrow$ Thickness of MdF sheets

from equation 2

we will get the function

of Temperature depending on time

$f(t) = T(t)$

Now for cooling phase

Energy Balance

$$\dot{Q}_{mdf} = m_{air} C_p \frac{dT}{dt}$$

$$\dot{Q} = \frac{kA\Delta T}{L} \Rightarrow \dot{Q} = \frac{\Delta T}{R_{net}}$$

$m_{air} = \rho V$

$C_p \rightarrow$ air

With PCM

1. Heating phase

$\dot{Q}_{absorbed} = m_{PCM} \times \Delta H$ $\quad$ $\Delta H \rightarrow$ Latent Heat of fusion

$Q_T = m \times c \times \Delta T(t) + \cancel{Q_{absorbed}}$

$$\frac{dQ}{dt} = P$$

$P \rightarrow$ power of Heat source (Bulb)

$$\frac{dT}{dt} = \frac{P}{m \times c} + \frac{Q_{absorbed}}{m \times c}$$

2. Cooling phase

$\hat{Q}_{pcm} = m_{pcm} \times \Delta H$

$\dot{Q}_{pcm} = m \times c \times \Delta T(t) - \dot{Q}_{released \cdot by\ MDF}$

(MDF) $\dfrac{dQ}{dt} = \dfrac{-\Delta T}{R_{net}}$

$$\frac{dT}{dt} = \frac{\Delta T}{m_{air} C R_{net}} + \frac{m_{pcm}\, \Delta H}{m_{air}\, C \cdot \cancel{dt}}$$

EFFICIENCY

$$\eta = \frac{\text{change in temperature with PCM in container}}{\text{change in temperature without PCM in container}} \times 100$$

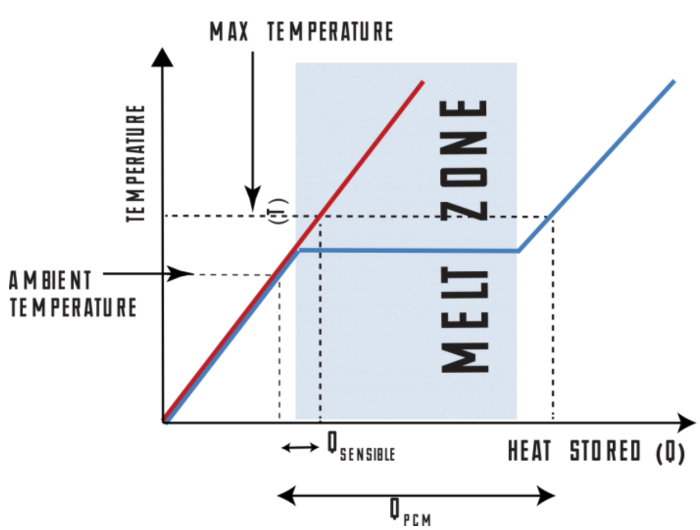
from experiment (for 30 min)

without PCM (°C)	with pcm
$T_{final} = 58.5\ °C$	$T_{final} = 52°C$
$T_{initial} = 27°C$	$T_{initial} = 27°C$

$$\eta = \left(\frac{52° - 27}{58.5 - 27}\right) \times 100\ \%$$

$$\boxed{\eta = 79.365\ \%}$$

Results:



After conducting an experiment and calculations, we determined the efficiency to be 79.365%. Additionally, we analyzed the temperature profiles of two containers: one containing Phase Change Material (PCM) and the other without PCM. Graphs depicting the cooling and heating processes for both containers were plotted. The data revealed distinct trends in temperature change over time, showcasing the effectiveness of PCM in maintaining temperature stability. These findings underscore the potential for utilizing PCM in various applications where precise temperature control is crucial, offering insights for further optimization and innovation in thermal management systems.

Challenges and Solutions:

The first and main challenge was to hold the PCM vertically and horizontally against the walls of the setup. To overcome this problem, we constructed a cage-like structure on the walls.

The second problem was the interaction of the setup with the surroundings. We had to select high-insulation material under the proposed budget. We chose MDF sheets, which helped to minimize interaction with the surroundings.

The third challenge was the common partition for the PCM and non-PCM containers, which caused heat transfer from one container to the other. To overcome this, we created two different containers with the exact dimensions so that there would be no extra heat transfer affecting the observations.

The last challenge was the size of the cage-like structure (skeleton). In the prototype, we had made a 10cm x 10cm square on the walls, which led to leakage and the fall of PCM. This was solved by creating a 4cm x 4cm square on the wall so that the volume and mass of PCM were reduced, and aluminum foil could hold it easily without any strain.

Conclusion:

In conclusion, PCM technology, particularly utilizing paraffin wax, offers promising solutions for temperature regulation in various applications. By understanding the underlying principles, advantages, and challenges associated with PCM systems, we can explore innovative approaches to address the evolving needs of thermal management in diverse industries.

References

[1] Phase transition (2023) Wikipedia. Available at: link (Accessed: 12 February 2024).

[2] *Potential applications of phase change materials for batteries' thermal management systems in electric vehicles*, *Journal of Energy Storage*. Available at: link (Accessed: 12 February

2024).

[3] T.-C. Ling and C.-S. Poon, "Use of phase change materials for thermal energy storage in concrete: An overview," Construction and Building Materials, vol. 46, pp. 55–62, Sep. 2013. [Online]. Available: link