B. TECH. PROJECT REPORT

On

Thermal management of electronic components by using phase change composite

BY

Aastha Luthra

DISCIPLINE OF MECHANICAL ENGINEERING INDIAN INSTITUTE OF TECHNOLOGY INDORE

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Thermal management of electronic components by using phase change composite

A PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of the degrees

of

BACHELOR OF TECHNOLOGY in

MECHANICAL ENGINEERING

Submitted by:

Aastha Luthra

Under supervision of:

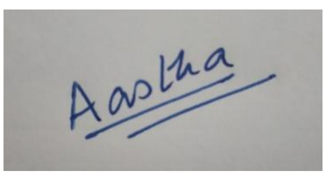
Dr. Santosh Kumar Sahu

INDIAN INSTITUTE OF TECHNOLOGY INDORE May 2021

CANDIDATE'S DECLARATION

I hereby declare that the project entitled **"Thermal management of electronic components by using phase change composite"** submitted in partial fulfilment for the award of the degree of Bachelor of Technology in 'Mechanical Engineering' completed under the supervision of **Dr. Santosh K. Sahu, Professor, IIT Indore** is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.



Aastha Luthra (180003001) **Date:** 30/05/2022

CERTIFICATE by BTP Guide

It is certified that the above statement made by the students is correct to the best of my knowledge.

Signature

Dr. Santosh K. Sahu, Associate Professor, Mechanical Engineering, IIT Indore

Preface

*This report on "***Thermal management of electronic components by using phase change composite***" is prepared under the guidance of Dr. Santosh K. Sahu.*

The performance of HS (Heat Sinks) comprising pin fins, to reach an SPT (Set Point Temperature) has been investigated in this work by integrating TCE (thermal conductivity enhancer) materials into the heat sink. To increase the running time, phase change material (paraffin wax) was utilized in the heat sink. PCM contains nanoparticles (CuO and Al_2O_3). Considering constant Heat Flux value of 2.5kw/m^2, the concentration of nanoparticles has been changed (0, 0.5, and 1 %). The influence of heat sink configuration and nanoparticle concentration has been investigated.

An attempt has been made to provide the methodology, findings, and conclusions of this inquiry in the most thorough and clear manner possible. For added convenience, graphs, charts, and photographs are included.

Aastha Luthra (180003001)

B.Tech. IV Year Discipline of Mechanical Engineering IIT Indore

Acknowledgments

First and foremost, I'd want to express my gratitude to our project supervisor, Dr. Santosh K. Sahu, for guiding us judiciously throughout this project, allowing us to work at our own pace but also providing us with helpful direction when needed. Mr. Vivek Saxena (Ph.D. scholar) and Mr. Pradyumna Dutta (MS scholar) have been extremely helpful and supportive throughout the project. I'd also like to thank the Fluid Mechanics lab and Machinery staff for their unwavering support throughout the process.

I'd like to use this time to express my gratitude to our fellow classmates for serving as excellent sources of inspiration and support throughout this project.

Finally, we want to express our gratitude to everyone else who knowingly or unknowingly supported us in accomplishing this project.

Aastha Luthra (180003001)

B.Tech. IV Year Discipline of Mechanical Engineering IIT Indore

Abstract

The current investigative study is based on the thermal performance of a nano enhanced phase change material (NePCM) based thermal energy storage system for cooling of electronic components.

The cooling technology based on NePCM filled heat sink (HS), is a passive method of cooling which can replace the cooling methods based on machinery example, fans. Copper oxide (CuO) and aluminium oxide (Al_2O_3) are used as nanoparticles, aluminium for HS material and paraffin wax is used as the phase change material (PCM) for the study. A constant volume fraction of 9%is considered for the fin material and different HS designs which are, heat sink without fin (HSNF), heat sink with square pin fins (HSSPF), and heat sink with circular pin fins (HSCPF) have been considered.

For varied nanoparticle concentrations ($\emptyset$=0.5 and 1) and for the same heat flux value (q' =2.5 kW/m^2), thermal performance of different HS designs is investigated.

Up to 80°C, the HSSPF filled with PCM/NePCM performs better than the other two HS configurations considered in terms of thermal performance. Above this temperature, HSNF gives better results. HSSPF attains the highest value of enhancement ratio of 4.1 for SPT as 65℃.

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Chapter 1

Introduction

1.1 Introduction

Electronic components that are being made nowadays are designed to provide enhanced speed and increased compactness. Due to this miniaturization, and higher power density, the heat production in the circuitry is increasing. Higher heat production leads to higher working temperatures, and hence, a higher failure probability [1,2]. Thus, it is required to design a system having higher cooling efficiency to decrease failures and increase the life of these components.

There are a lot of active cooling techniques which have been, and still are adopted in order to maintain the permissible temperature limit of different electronic components [3-5]. Even then, these systems comprising active cooling methods are considered as not very efficient because they have larger volume occupancy, operation is noisy, continuous maintenance is required, and additional power consumption is also there. Although, PCM has very good thermal properties in terms of cooling, like they have high latent heat of fusion, specific heat is high, high density, non-corrosive, non-toxicity, and chemical inertness etc. It also shows very low or negligible sub-cooling effect, but it has a low thermal conductivity and this is a major drawback.

In order to improve the thermal conductivity of PCM, several thermal conductivity enhancers (TCEs) such like fins (plate fins or pin fins), metallic/non-metallic foams, and different nanoparticles are utilized. Rehman et al. [6] reported on metallic foams (Cu and Iron-Nickel) which were coated with PCM and tested under various heating settings. Copper foam-PCM composite was able to achieve a maximum of 17% reduction in the base temperature of the heat sink when compared with empty HS i.e., HS without PCM. The TP (thermal performance) of different PCM-filled HS designs such as HSNF, HS including two plate fins (HSTPF), HSNF comprising of metal foam, and also HS involving two fins (plate) as well as metal foam was reported by Kothari et al. [7]. According to reports, metal foam filled PCM having two fins performs better than the other HS configurations used in the study, considering the enhancement ratio. Furthermore, several research studies have been conducted to examine the heat transfer and thermal properties of PCM-based systems which include various HS designs filled with PCM for the purpose of electronic cooling [8–18]. The TP of plate shaped fins and pin finned heat sinks was worked upon as experimental investigation by Baby and Balaji [8]. According to them, heat sink comprising of pin fins gives better performance when compared to HS which has plate fins. Ali and Arshad [13] conducted an experiment to analyze the influence of pin fin thickness on thermal efficacy and found that HS which has fins of 3 mm thickness gives the best thermal efficiency. Arshad et al. [14] investigated the influence of thickness of pin fins and found out that the HS which had fins of 2 mm thickness offered the highest thermal performance. Using a sink with 9% volume fraction of thermal conductivity enhancers (like plates or fins) arranged in a staggered form and an inline form, Ashraf et al. [16] conducted an experimental inquiry to optimize the HS comprising square or circular fins, and filled with PCM. According to reports, inline design improves thermal performance.

The thermal performance of NePCM-based HSs is influenced by nanoparticle characteristics (concentration, size, and type) [19,20], fin properties (height, number, cross-section, arrangement, and thickness), heat load, and set point temperature [13-18]. For different applications, the heat-load and SPT requirements vary. There are just a few experimental studies on the thermal performance of HSs with various SPT and heat load levels. In addition, there are no investigations in the literature on the thermal performance of heat sinks with circular pin fins (HSCPF) and HSs with square pin fins (HSSPF) filled with NePCM. Furthermore, there have been a few studies that have looked at the CuO nanoparticle in a PCM-based HS thermal energy storage system for cooling electronic components.

Efforts were made in the current experimental study to analyze the TP of different heat sink configurations that are heat sink with no fin (HSNF), heat sink with square pin fins (HSSPF), and heat sink with circular pin fins (HSCPF), with paraffin wax (melting range 53-58^{o}C), and, CuO and Al_2O_3 based NePCM for a two different values of nanoparticle concentration ($\emptyset$= 0.5 and 1.0), and a heat flux value of q"=2.5 kW/m_2 for two different values of SPT (set point temperature) (65^{o}C and 85^{o}C).

1.2 Why PCM in thermal management?

Due to its isothermal phase change property, PCM cooling is considered a very efficient passive cooling technique used for the thermal management of electronic components. During the process, PCM stores large amount of heat during melting, in the form of latent heat of fusion. PCM based passive cooling also does not require any moving machinery and hence does not need continuous maintenance. This mechanism can be re-used. No external power is required for its operation since it stores energy in itself.

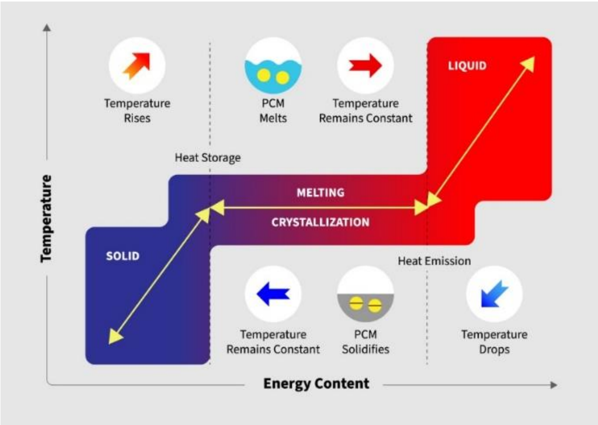


Fig. 1 Ideal heating and cooling curve of PCM for thermal management system

Fig.2 PCM (Paraffin wax)

1.3 Selection Criteria for PCM

If PCM has the required properties, it will operate well. It is required have a melting temperature that is lower than that of electronic equipment to be cooled in order to absorb the heat at a consistent temperature without causing damage to the device. PCM should have a high value of latent heat of fusion, which aids in being able to absorb huge amounts of heat keeping the temperature constant. It should have a high thermal conductivity to allow heat to move swiftly from the bottom to the top. High specific heat storage is also required to provide more storage in form of sensible heat. PCM should be dense and have a modest volume change. It should be harmless, affordable, and easily accessible.

1.4 Difficulty with Phase Change Material

The phase-changing materials have a low value of thermal conductivity, which is a big cause of concern. Heat transmission that takes place from the base of the HS is slower due the low value of thermal conductivity.

As electronic equipment can quickly reach the critical temperature, this results in a higher base te mperature, which could cause malfunctions and permanent damage.

Solution: - We can add thermal conductivity Enhancers (TCEs) to PCM, which include:

There are majorly three different types of thermal conductivity enhancers: -

- Extended surface (fins), which are simple and effective and cheap too.
- Metallic/nonmetallic foams, which are lightweight and effective but costly
- Nanoparticles, which are lightweight but might increase the thermal conductivity.

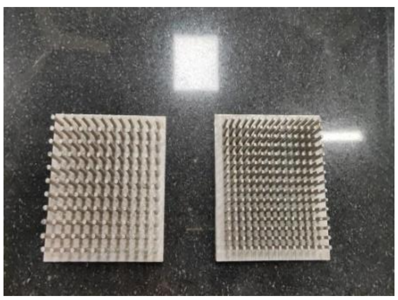


Fig.3(a)

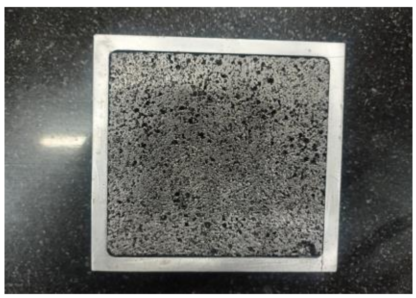


Fig. 3(b)

Fig. 3(c)

Fig.3 Different TCEs (a) fins (b) Foams (c) Nanoparticles

1.5 Literature Review

Source	Methods/ Heat input	HS size (mm^3)	PCM (M.P., °C)/ Nanoparticle (∅)	Observations
Ho et al. [1]	Experimental (40°C)	No fins 25 x 25 x 60	n-octadecane (25.1°C –26.5°C) Al_2O_3 (5.0, 10.0)	The natural convection gets degraded when the nanoparticle is increased in the octadecane
Farzanehnia et al. [2]	Experimental (2kW/m²–6 kW/m²)	Plate fins 73 x 68 x 44.5	Paraffin wax (40.22–46.92) MWCNT (0.2, 2.0)	The Effect of NePCM gets more dominant after the latent phase has finished
Tariq et al. [3]	Experimental (0.86 kW/m²–2.4 kW/m²)	No fins 106 x 106 x 29	RT-44 HC (44°C) RT-64 HC (64°C) Graphene (0.002%, 0.005%, 0.008%)	PCM composite based on graphene better performance in terms of enhancement in operation time as compared to pure PCM
Motahar et al. [4]	Experimental (0.74 kW/m²–1.98 kW/m²)	Triangular plate fins 65 x 65 x 40	RT-42 (42) Carbon nanofibers 0.5%, 2%) TiO_2 (2%, 4%)	Addition of carbon nanofibers and titanium oxide to RT-42 does not help in improvement of the thermal performance
Bayat et al. [5]	Numerical (10 kW/m²–30 kW/m²)	Plate fins 50 x 50 x 40	Paraffin wax (41–45) Al_2O_3 (2, 4, 6) CuO (2, 4, 6)	The PCM is solid, temperature is not much affected by the addition of nanoparticle

Source	**Methods/ Heat input**	**HS size (mm^3)**	**PCM (M.P., °C)/ Nanoparticle (Ø)**	**Observations**
Sharma et al. [6]	Experimental (0.8 W)	Without and with micro-fin 36 x 35 x 35	RT-42 (42°C) CuO (0.5%)	Finned HS containing NePCM did not give promising results
Alimohammadi et al. [7]	Experimental (1 kW/m² to 5 kW/m²)	Four plate fins 75 x 75 x 40	$Mn(NO_3)_2$ (37°C) Fe3O4 (1%)	Considering HSNF, the reduction in temperature of base of the sink is better with PCM as well as NePCM when compared with convection (free and forced both)
Joseph and Sajith [8]	Experimental (2.835 kW/m²–11.338 kW/m²)	Four plate fins 42 x 42 x 32	Paraffin (59.6°C) Graphene (0.05% to 0.5%)	HS filled with PCM-GR composite showed higher energy saving than HS being empty or filled with PCM
Kothari et al. [9]	Experimental (2kW/m²)	With and without two fins (plate type) 100 x 100 x 22	Paraffin wax (58°C –62°C) Al_2O_3 (0%, 0.5%, 4% and 6%)	Melting time of the PCM is decreased when small amount of nanoparticles is added to it

1.6 Objectives of Present Study

This investigation has been done to analyze and compare various heat sink configurations such as

1. Un-finned heat sink filled with pure PCM
2. Pin finned heat sink such as square and circular pin fins filled with pure PCM
3. Un-finned heat sink filled with NePCM
4. Pin finned heat sink such as square and circular pin fins filled with NePCM

Various parameters such as Operation time, Enhancement Ratio, Surface area vs volume have been studied.

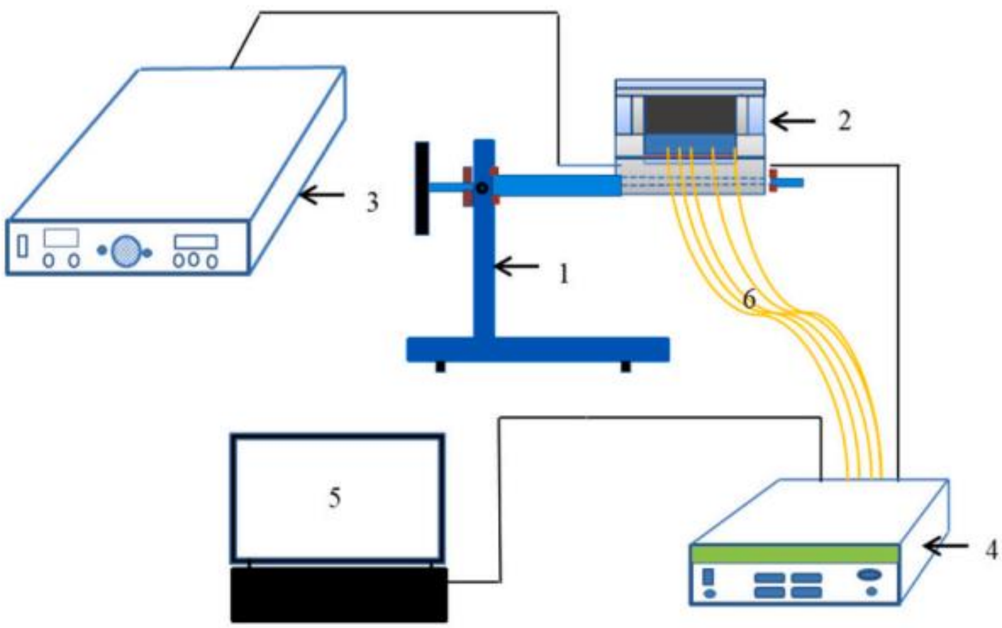
Enhancement ratios have been obtained for different phase change materials/NePCM and for different configuration of heat sinks.

Chapter 2

Experimental Analysis

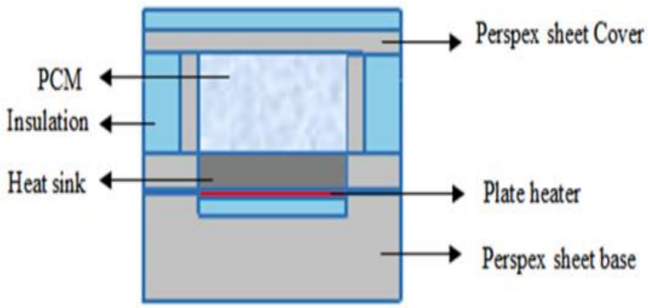
2.1 Experimental Setup

The many modules used in this research project are depicted in Figure 1. During the studies, the heat sink assembly used heat sinks without fins and various heat sinks with fins, built of aluminium, filled with PCM, and insulated from all sides using ceramic glass wool so as to minimize the heat loss happening to the environment, allowing the plate heater to be able to transfer the maximum amount of heat to the assembly. 100x100x20 mm^3 heat sinks were employed. As shown in Fig. 2, the experimental study used three different heat sink configurations: HSNF, HSSPF, and HSCPF. The heat sinks were positioned on top of a plate heater having a dimension of 100x100x4 mm^3. the plate heater was linked to a DC power source to provide a consistent value of heat flux.

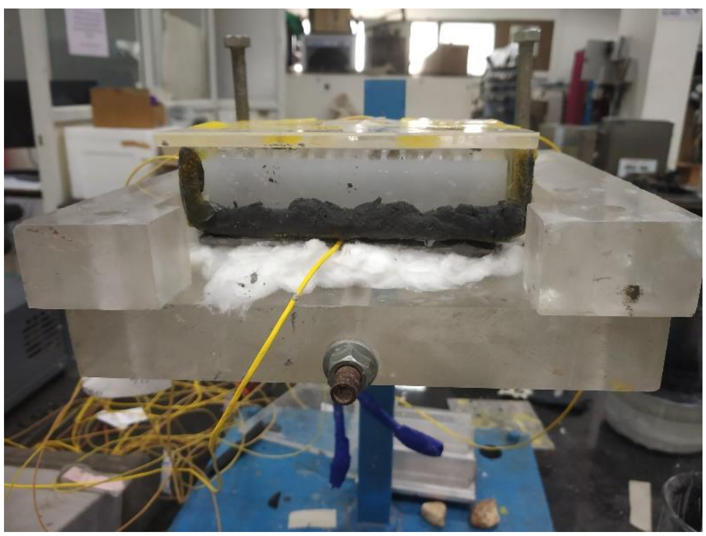


4(a)

1	Support system	4	Data acquisition system
2	HS assembly filled with NePCM	5	Laptop
3	DC power source	6	Thermocouples



4(b)



4(c)

Fig. 4 Experimental Setup (a) Schematic diagram of the experimental setup (b) Detailed view of the heat sink assembly (c) Actual setup

2.2 Heat Sink Configurations

Three different heat sink configurations have been used in this investigation. Each has a unique number and shape of pin fins. Each heat sink's fin configuration is shown in **Figure 5. Table 1** lists the measurements of each of the heat sinks. We know for a fact that the cavity of each heat sink varies, still the volume fraction of the fins in each heat sink remains constant at 9%.

The Base dimensions of all the Heat sinks are of 100x100 mm^2. Height of each cross fin and heat sink is 25 mm. Thickness of base is 2mm. Pin fin thickness and wall thickness varies for each configuration.

5(a) 5(b) 5(c)

Fig. 5 Aluminium pin fins Heat Sink Configurations (a) No fins (b) Square pin fins (c) Circular pin fins

Table 1 Dimensions of Heat Sinks

Materials used	**Dimension (mm)**	**Surface area density of fins**
Plexiglass sheet (side wall)	100×25×5	-
Plexiglass sheet (top surface)	115×115×5	-
Aluminum Heat sink base	100×100×5	-
Aluminum circular pin fins	2.95×20	1.27
Aluminum square pin fins	20×2×20	1.84
Heater	100×100×4	-

2.2.1 Locations of Thermocouples in Heat Sinks

In all of the heat sinks, grooves of 2 mm are made on the base the of heat sinks. Thermocouples are placed in these slots. Fig. 6 shows these slots.

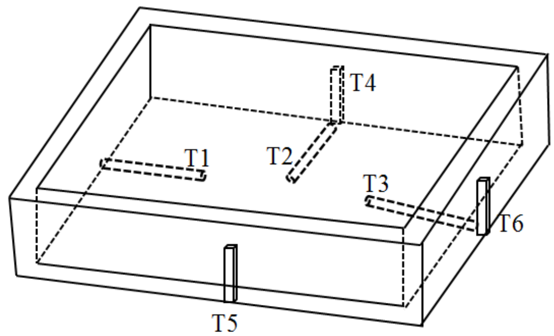
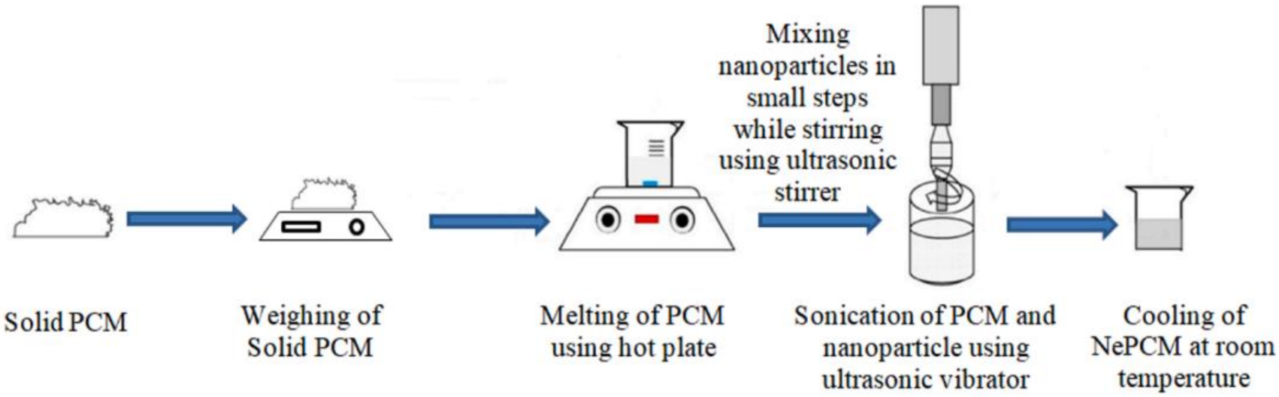


Fig. 6 Grooves in Heat Sinks for placing thermocouples

2.3 NePCM Preparation

CuO and Al_2O_3 are mixed in PCM to make NePCM. The pure PCM is initially weighed using an analytical mass balance equipment. An amout of 140 grams of PCM was used. The PCM is then melted on a heating plate between 90 and 120 ^oC. Pure PCM is melted and placed in an ultrasonic vibrator. The ultrasonic vibrator is filled with water and adjusted at a temperature that is above PCM's melting point. In an ultrasonic vibrator, nanoparticles are mixed with PCM at the appropriate concentration of NePCM (0.5%, 1% wt). To make a suitable mixture, an ultrasonic vibrator is utilized to sonicate the mixture and disperse nanoparticles uniformly. This sonication takes about 2 hours. The sonicated mixture is then stirred for 1 hour at 500 rpm using a magnetic stirrer (REMI, 2MLH, India). The bottom of the magnetic stirrer features a heater, which prevents the fluid from solidifying while it is being stirred. The NePCM is prepared and placed into the heat sink, where it solidifies at room temperature. Experiments using PCM/NePCM on a heat sink are now possible. The complete preparation of NePCM is shown in Figures 7(a) and 7(b).



(a)

Ultrasonic Vibrator | **Sonication of PCM and nanoparticle** | **Magnetic Stirrer**

(b)

Fig. 7 Preparation steps of NePCM (a) Schematic (b) actual

2.4 DSC Analysis

The variation in melting point and the change in the amount of latent heat of fusion of PCM/NePCM with varying CuO and Al_2O_3 mass fractions are determined using Differential Scanning Calorimetry. This DSC analysis is carried out at temperatures ranging from 35^{o}C to 90^{o}C, with a constant heating rate of 10^{o}C/min. The obtained heating curvefrom the analysis for PCM/ NePCM at various CuO and Al_2O_3 mass fractions is shown in Fig. 3.

It's worth noting that adding CuO/Al_2O_3 nanoparticles into pure PCM does not have much effect the melting temperature of the material. The addition of CuO/Al_2O_3 nanoparticles to pure PCM, on the other hand, reduces the latent heat of fusion. It is observed that there is a decrease in the latent heat of fusion and also an increase in thermal conductivity of the material which is caused by the insertion of CuO and Al_2O_3 nanoparticles into pure PCM. The change observed in the latent heat of the NePCM becomes significant when the nanoparticle loading increases. Because nanoparticles reduce the amount of PCM, NePCM absorbs less energy during the phase change process than pure PCM.

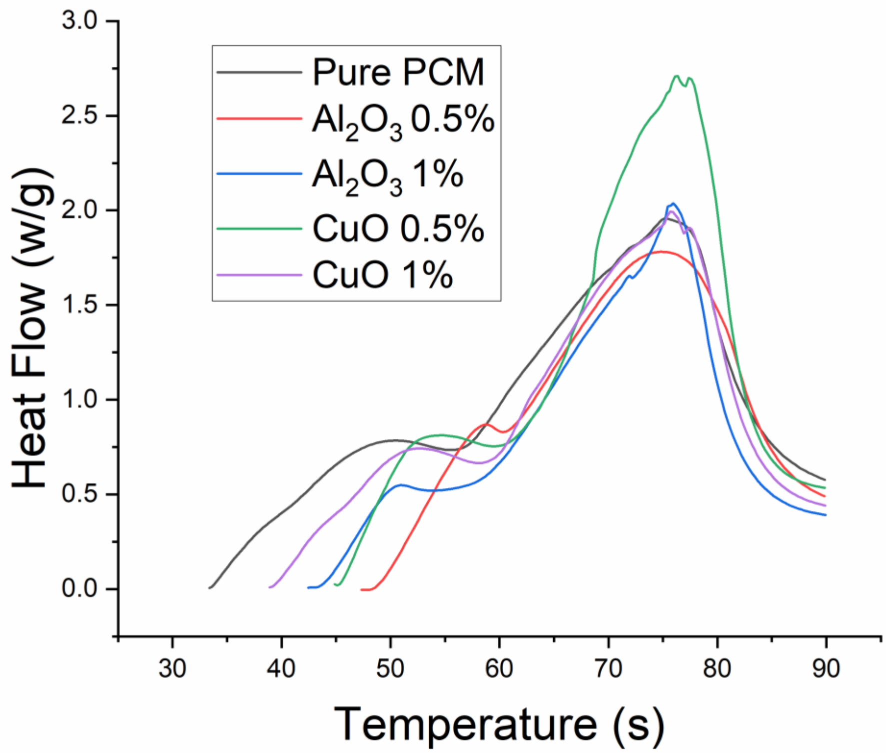


Fig. 8 Heating curve for NePCM

Table 2 Variation of latent heat of fusion with concentration

Material	**Latent heat of Fusion (KJ/Kg)**	**Percentage decrease in latent heat of fusion**
Pure PCM	125.15	--
0.5% Al_2O_3	115.51	7.70

1% Al_2O_3	104.75	16.30
0.5% CuO	118.85	5.03
1% CuO	109.56	12.45

2.5 Thermophysical Properties of NePCM

The standard formulas are used to determine thermophysical parameters like thermal conductivity(k), density (ρ), specific heat (C_P), and viscosity (μ). The nanoparticles must be evenly dispersed throughout the PCM in order to use these calculations.

Nanoparticle weight fraction: The ratio of the mass of nanoparticle to the mass of PCM:

$$\varphi = \frac{m_N}{m_{PCM}} \quad \text{--(1)}$$

Density, thermal conductivity and specific heat capacity of the NePCM as a function of the weight fraction:

$$\rho_{NePCM} = \varphi\rho_N + (1-\varphi)\rho_{PCM} \quad \text{--(2)}$$

$$k_{NePCM} = \varphi k_N + (1-\varphi)k_{PCM} \quad \text{--(3)}$$

$$(\rho c_p)_{NePCM} = \varphi(\rho c_p)_N + (1-\varphi)(\rho c_p)_{PCM} \quad \text{--(4)}$$

Variation of viscosity with the addition of nanoparticles:

$$\mu_{NePCM=0.983e^{12.959\phi}\mu_{NePCM}} \quad \text{--(5)}$$

Where, ϕ represents the volume fraction of nanoparticles which can be obtained by:

$$\emptyset = \frac{\frac{Wt_N}{\rho_N}}{\frac{Wt_N}{\rho_N} + \frac{Wt_{PCM}}{\rho_{PCM}}} \qquad \text{--(6)}$$

Here,

Wt_N – weight of nanoparticles;

ρ_N – Density of nanoparticles;

Wt_{PCM} – Weight of PCM;

ρ_{PCM} – Density of PCM

Table 3 Thermo-physical properties of paraffin wax, thermal conductivity enhancer, and insulator

Properties	Paraffin Wax	Aluminum (TCE)	Plexiglas	Ceramic glass wool	Al_2O_3 nanoparticle	CuO nanoparticle
Melting Temperature (^{0}C)	53-58	660.37	-	-	-	-
Specific Heat (kJ/kg-K)	2.4	0.896	1.470	-	0.765	0.551
Density (kg/m^3)	770 (l) 839 (s)	2719	-	128	3600	6310
Thermal Conductivity (W/m-K)	0.22 (l) 0.22 (s)	218	0.19	0.12	36	33
Latent Heat (kJ/Kg)	237.5	-	-	-	-	-

By utilizing properties in Table 3 and the above mentioned equations we can calculate the thermophysical properties of NePCM.

Table 4 Thermophysical properties of Nano-enhanced Phase Changing Material

Material	Density (kg/m3)	Thermal conductivity (K)(W/m-k)	Percentage change in K	Specific heat(Cp)	Percentage change in Cp	Viscosity (Kg/m-s)	Percentage change in viscosity
Pure PCM	839	0.22	-	2.4	-	0.0235	--
0.5% CuO	866.35	0.38	72.72	2.33	-2.9	0.0243	3.4
1% CuO	893.72	0.5478	149	2.7	12.5	0.0275	17.02
0.5% Al_2O_3	852.80	0.4	81.81	2.31	-0.8	0.0244	3.83
1% Al_2O_3	866.61	0.58	163.63	2.33	-2.9	0.0268	14

The thermal conductivity (K) increases as the nanoparticle concentration rises. The case with 1% Al_2O_3 has the greatest decrease in thermal conductivity (163.63 percent) from Pure PCM. It can be observed that the value of heat conductivity increases as the concentration of nanoparticles increases. When compared to CuO, it is greater in Al_2O_3. In the case of viscosity, a similar pattern can be seen. In comparison to pure PCM, the viscosity increases as the concentration increases. The maximum increment is 1 percent CuO. The improved thermal conductivity has a good impact on NePCM's thermal performance. The longer it takes to reach the SPT, the higher the thermal conductivity. The higher viscosity, on the other hand, has a negative impact on thermal performance. Natural convection is hampered greatly in viscous media. As a result of the lower natural convection in the case of increased viscosity, it takes longer to reach the Set Point Temperature. It demonstrates that combining nanoparticles with pure PCM has two opposing impacts. With increasing nanoparticle concentration, the specific heat drops.

Chapter 3

Results and Discussions

3.1 Validation

A comparison between the current and prior studies [17] was used to validate the experimental setting. The current results for the heat sink with no fins, with and without the inclusion of Paraffin wax are compared to those of Kothari et al. [17] in Figures 4 and 5. A plate heater provided a heat flow of 2.0 kW/m^2 and 2.7 kW/m^2 to the heat sink assembly, and time-temperature measurements were taken. The results of the current analysis show a pattern that is similar to that shown in prior tests on heat sinks with similar dimensions. The variation in ambient conditions, i.e., the initial heating temperature, may have been explained by a minor variance in validation.

The heat sink used in this study is a 100x100x25 mm^3 heat sink contained with paraffin wax having a melting range of 53^{o}C to 58^{o}C. On empty and filled heat sinks with heat flow values of 2.0 kw/m^2 and 2.7 kw/m^2, the current experimental result is compared to earlier data. Figure 9(a) and (b) illustrate the results of the current and prior investigations plotted on graphs for empty and loaded heat sinks, respectively.

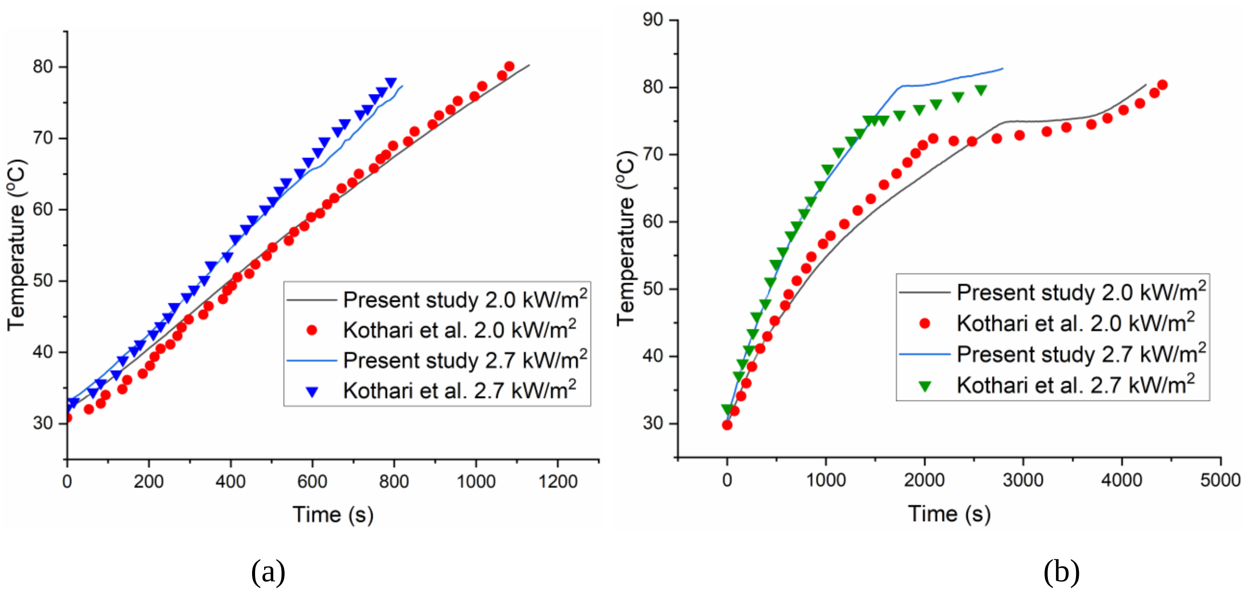
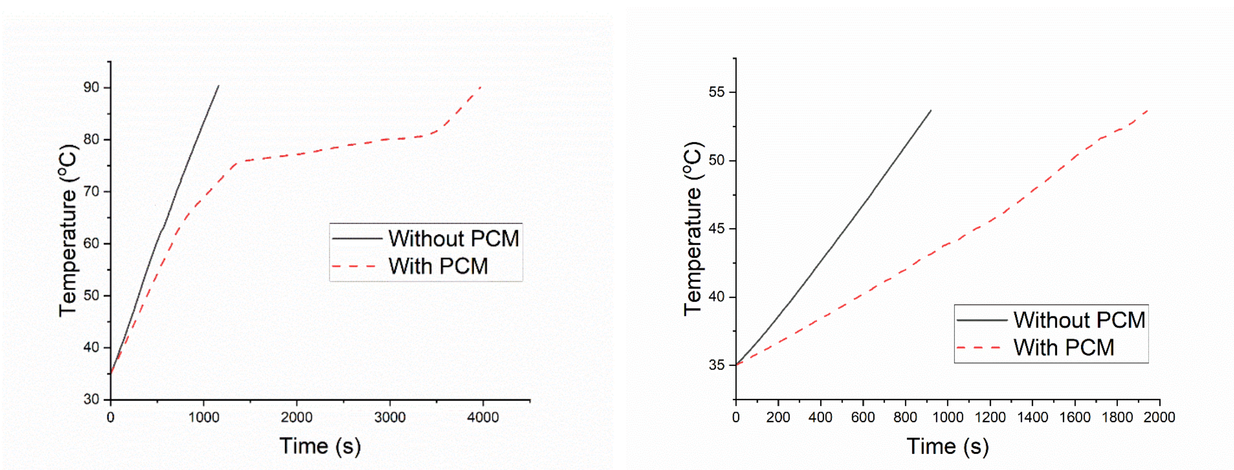


Fig.9 Validation of Experimental setup with (a) HS without PCM (b) HS with PCM

The values of the base temperature in the graph follow the same trend as the previous investigators in both situations, according to the figure. The modest differences in the curves of the current and prior investigations could be attributable to differences in heat sink dimension, PCM type and melting point, ambient temperature, and the initial base temperature and insulation process.

3.2 Effect of PCM on Base and Side wall Temperature

The heat sink was compared with as well as without PCM using paraffin wax as PCM with a melting range of 53 to 58°C and a heat flux of q= 2.5kW/m^2. The unfinned heat sinks were used in the comparison. The base and side temperatures of the heat sink were measured with k type thermocouples at 2 mm distances from the center for the comparison. Every 10 seconds, the average temperature of heat sinks is determined, and a comparison plot of the heat sink containing PCM and also without PCM is displayed below.



(a) **(b)**

Fig. 10 Comparison of variation of (a) base temperature and (b) Side wall temperature of HS with PCM and Without PCM

3.3 Visual Observations

i. Before melting

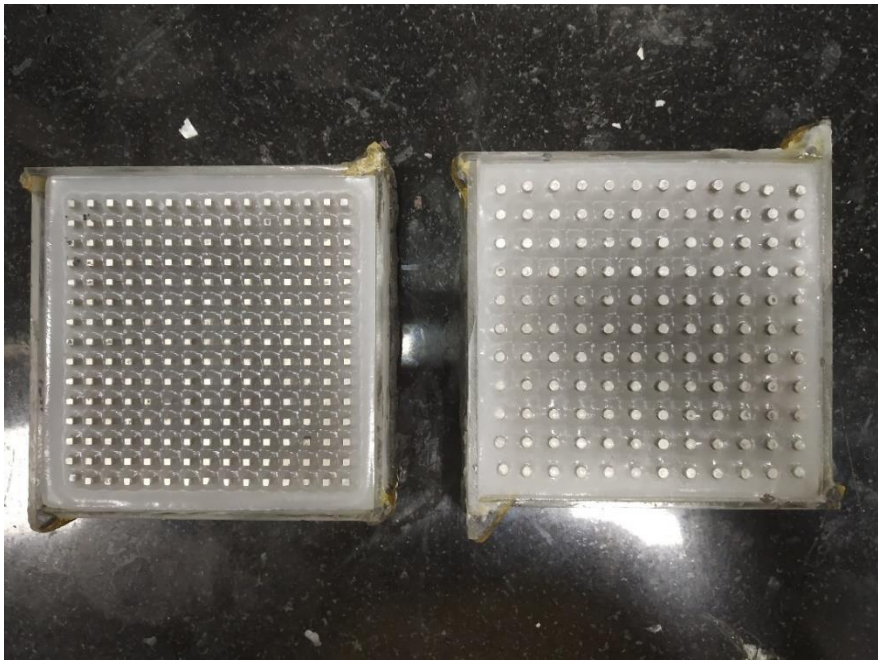


Fig. 11 HS filled with solid PCM

NePCM is first prepared and then poured to fill into the heat sinks. After it gets solidified, it shrinks. A 2 mm gap has been left at the top of the HS to compensate for any expansion of the PCM that takes place during the melting phase.

ii. Mid melting

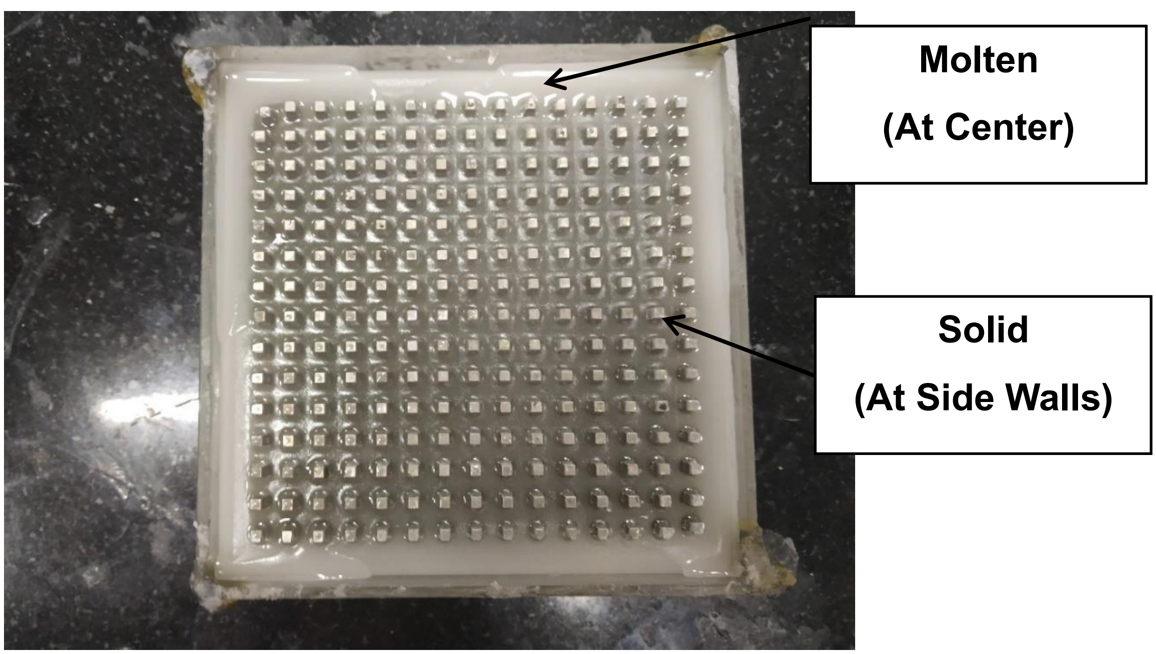


Fig. 12 PCM in latent melting phase

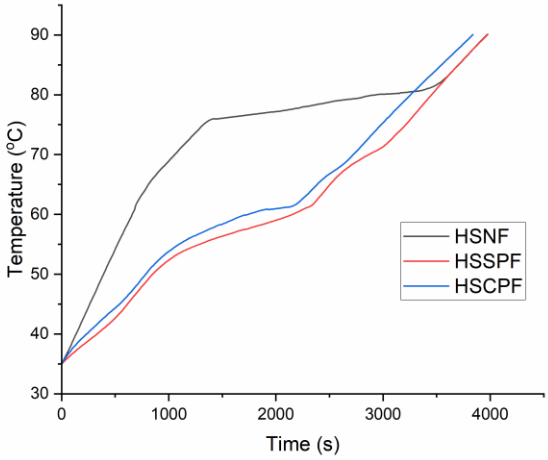
iii. After melting

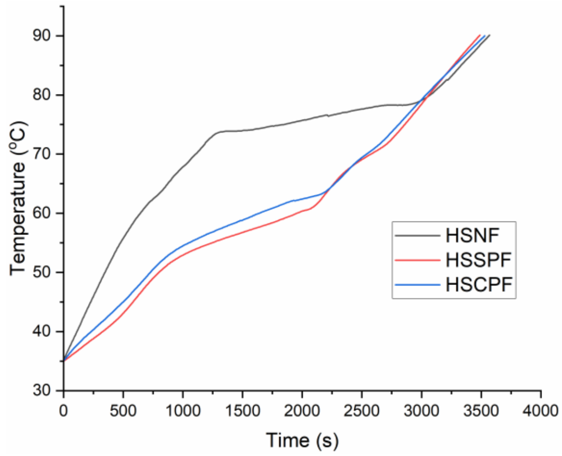
Fig. 13 HS filled with liquid PCM

The heat sink is heated upto 90°C and NePCM is completely molten at this stage. It can be seen that the material is fully liquid with no traces of solid PCM left.

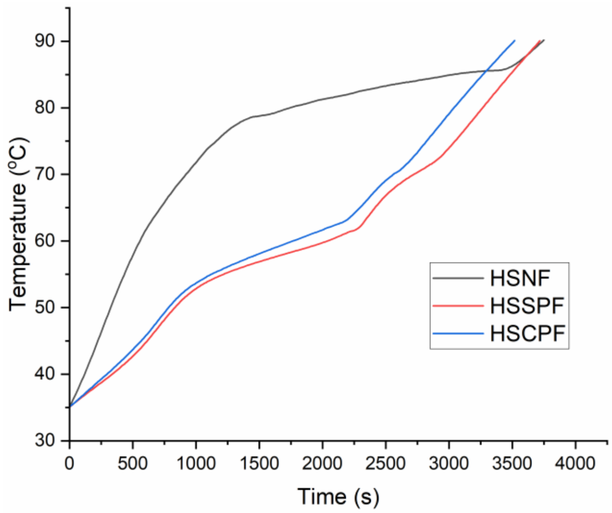
3.4 Effect of configuration of Heat Sink

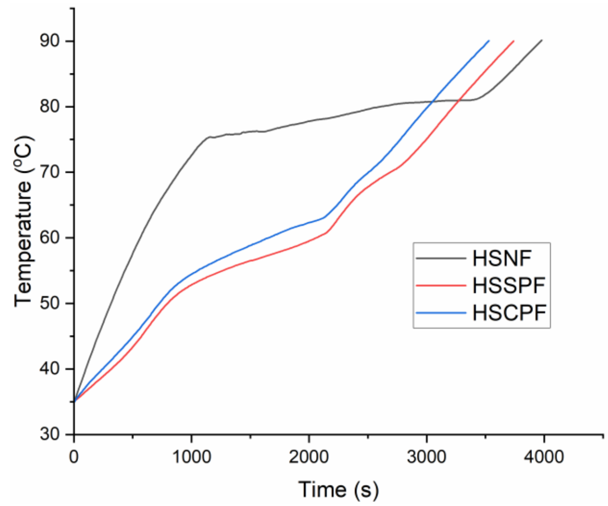
The present investigation was performed with different heat sink configurations that are HS with no fins, heat sink with square pin fins, and heat sink with circular pin fins. The variation of temperature with time for all these heat sink configurations for different materials are shown in Fig. 14. For the various heat sink values given above, the average change in base temperature is taken into account.



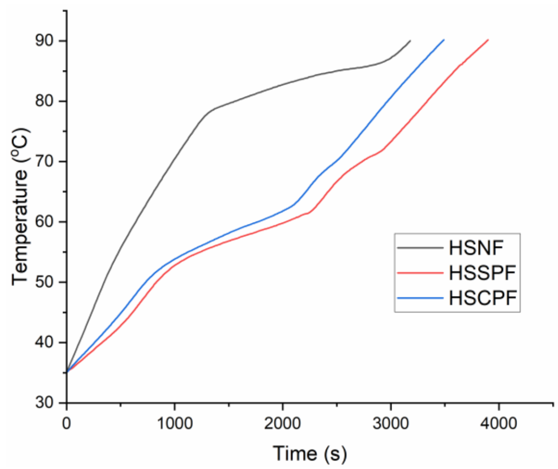


(a) (b)





(c) (d)

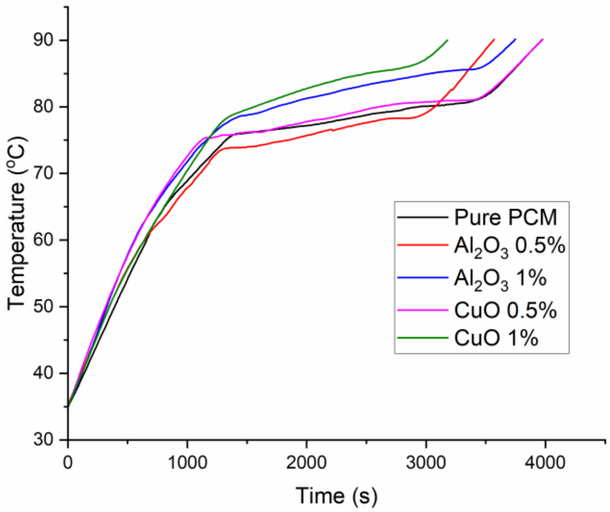


(e)

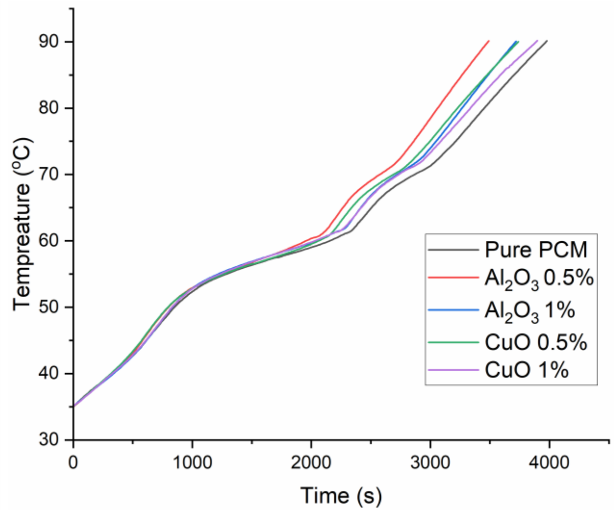
Fig. 14 Variation of base temperature with each concentration of nanoparticles in different HS (a) Pure PCM (b) 0.5% Al2O3 (c) 1% Al2O3 (d) 0.5% CuO (e) 1% CuO

3.5 Effect of concentration of nanoparticles on heat sinks

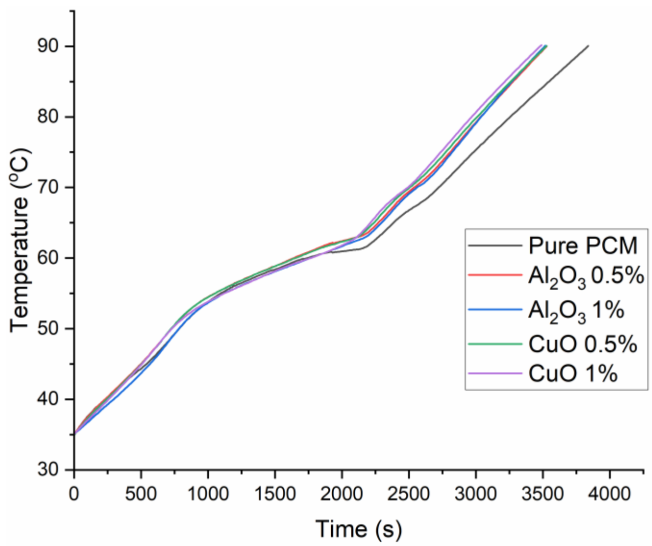
The time-temperature relation of NePCM-based HS topologies for two different mass fractions each of CuO and Al_2O_3 (0.0%, 0.5%, 1.0%) at constant q″=2.5 kW/m^2 is shown in Fig. 15(a-c). In all the three configurations considered (HSNF, HSSPF, and HSCPF), the HS containing pure PCM performs better than HSs containing NePCM, regardless of the concentration of nanoparticles. The thermal conductivity of pure PCM can be increased by adding CuO at higher nanoparticle concentrations. Despite this, NePCM-filled HSs are not able to dissipate more heat than pure PCM-filled HSs.



(a)



(b)



(c)

Fig.15 Variation of base temp. for each HS with (a) HSNF (b) HSSPF (c) HSCPF

This could be due to a number of factors, like there is an increase in thermal contact resistance or due to high viscosity, between the surface of the HS and NePCM due to the combined properties of nanoparticles and PCM [21], a lower rate of heat transfer through convection in NePCM due to a large increment in viscosity, especially for high concentrations [22], and a lower latent heat of fusion as compared to pure PCM.

3.6 Enhancement Ratio

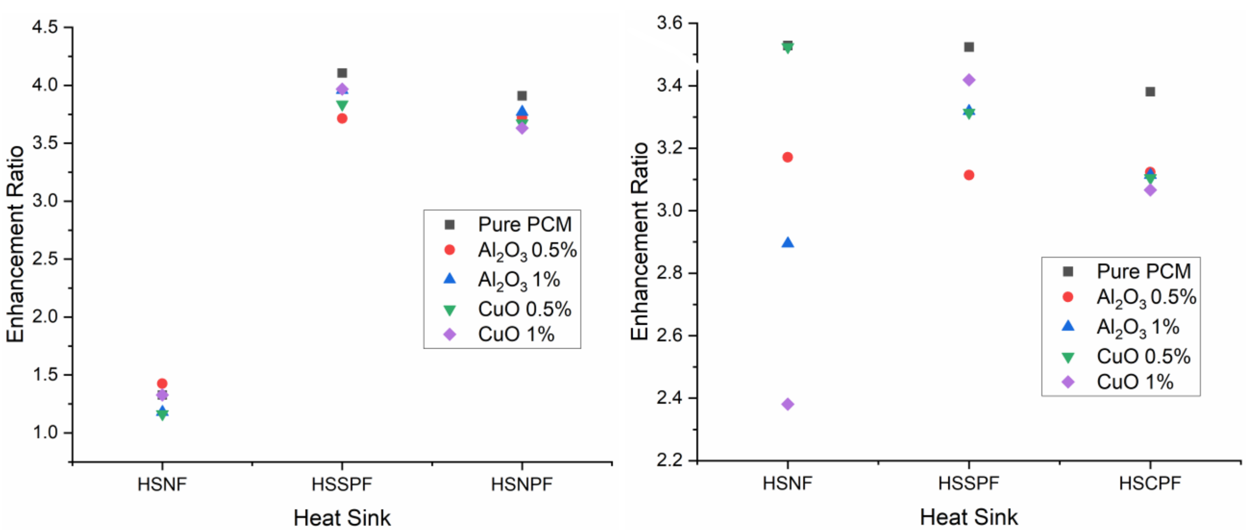
Enhancement ratio (ε) is defined as the ratio of the time taken by the heat sink filled with NePCM to reach the SPT, to the time taken by the heat sink without PCM/NePCM to reach the SPT.

$$\boldsymbol{\varepsilon} = \frac{\textbf{Time taken by heat sink to reach SPT with NePCM and TCE}}{\textbf{TIme taken by heat sink to reach SPT without NePCM and TCE}}$$

Set point temperature (SPT) is defined as the maximum temperature till which electronic device can perform efficiently.

Figure 16 (a, b) shows the increase in operating time required to achieve various values of critical SPTs for various HS configurations combined with various materials. The critical SPT is the maximum working temperature at which electronic equipment's performance and reliability decrease. As critical SPTs, temperatures of 65°C and 85°C have been chosen.

It has been observed that at q''=2.5 kW/m^2, HSSPF shows highest enhancement in time and hence the highest enhancement ratio for the SPT of 65°C when HSSPF is filled with pure PCM (Fig. 8a). For SPT of 65°C, the maximum value of enhancement ratio obtained is 4.1, while in case of SPT of 85°C, the maximum enhancement ratio is obtained as 3.52.



(a) (b)

Fig.16 Comparison of Enhancement ratio for (a) SPT 65°C (b) SPT 85°C

3.7 Surface area vs volume

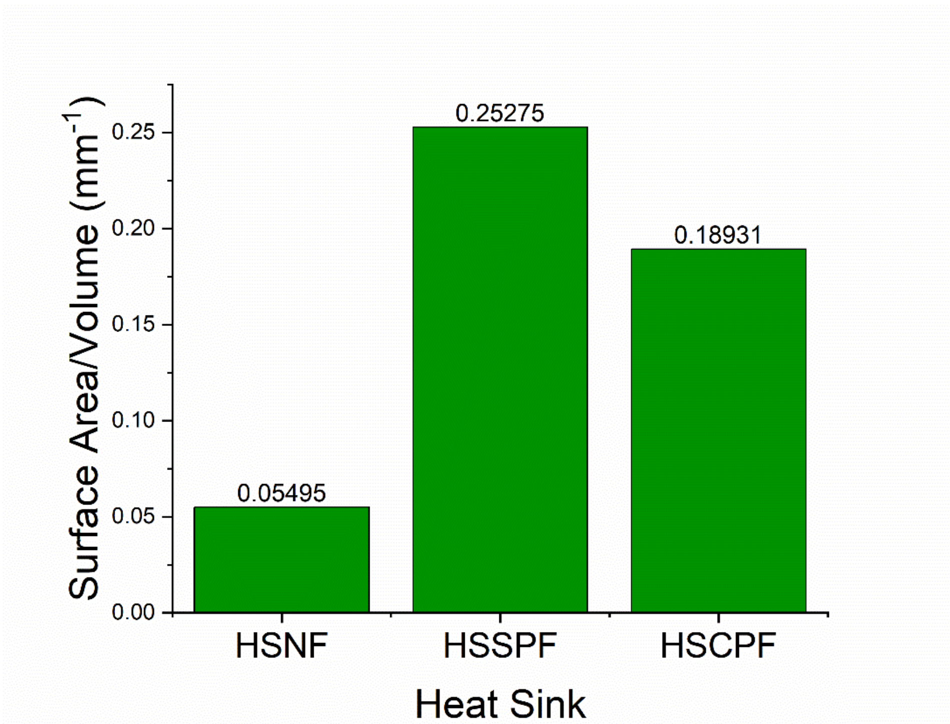


Fig. 17 Surface area per unit volume comparison of HSNF, HSSPF, and HSCPF

It can be seen from the graph that the heat sink with square pin fins has the maximum surface area. We have also observed that HSSPF gives the best performance.

When the surface area of the fins increases, the heat released increases and hence the fin efficiency increases. The same effect can be seen here since the or der of surface area from smallest is HSNF, HSCPF, HSSPF. The order of efficiency obtained is the same.

Chapter 4

Conclusion and Scope For Future Investigation

4.1 Conclusions

An experimental investigation of the thermal performance of PCM (paraffin) based heat sinks of three different configurations (HSNF, HSSPF, and HSCPF) was performed in this work. The conclusions from this study are as follows.

i) Thermal conductivity of the PCM is increased by the addition of nanoparticles.
ii) CuO gives better results than Al_2O_3 in case of square pin fins while in case of circular pin fins, Al_2O_3 gives better results than CuO.
iii) Pure PCM gives the best results in all the three heat sinks considering the time taken to melt completely.
iv) NePCM give better performance as compared to PCM upto 80°C and pure PCM gives better results above this temperature.
v) HSSPF (Heat sink with square pin fins) performs better than the other two sinks, considering pure PCM as well as all NePCM composites. Having the PCM volume as same for all experiments, HSSPF has the highest surface area and thus better results.
vi) The NePCM composite melts at the center first and later at the side walls in case of both the pin finned heat sinks.

4.2 Scope of Future Investigations

- To compare the performance of different concentration of NePCM with other TCEs such as metallic foam,

- To study the effect of CuO and Al_2O_3 on different configurations of heat sinks such as heat sinks with pin fins, plate fins, vertical heat sinks etc.

- To study the effect of Phase change materials other than Paraffin wax with different nanoparticles.

- To study the cooling rate and base temperature variation of different heat sinks with CuO and Al_2O_3.

- To study the thermal performance and enhancement ratio of different size heat sinks with same configurations.

Nomenclatures

ρ – Density

μ – Viscosity

$\emptyset$ - Mass fraction

ε – Enhancement ratio

φ – Volume fraction

k – Thermal conductivity

C_p – Specific heat

t_b – Base thickness of Heat sink

t_w – wall thickness of heat sink

t_f – fin thickness of heat sink

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