Phase Change Material Based Heat sinks for Thermal Management of Electronic Devices

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degrees
of
BACHELOR OF TECHNOLOGY
in

MECHANICAL ENGINEERING

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CANDIDATE’S DECLARATION

We hereby declare that the project entitled **“Phase Change Material Based Heat sinks for Thermal Management of Electronic Devices”** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in ‘Mechanical Engineering’ completed under the supervision of **Dr. Santosh K. Sahu, Professor and Head of Department of Mechanical Engineering,** IIT Indore is an authentic work.

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

Harshit Ziniwal (180003024) **Date:** 05/30/2022

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CERTIFICATE by BTP Guide(s)

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

Signature

Dr. Santosh Kumar Sahu

Professor

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Preface

This report on "**Phase Change Material Based Heat sinks for Thermal Management of Electronic Devices** " is prepared under the guidance of Dr. Santosh K. Sahu.

Through this report, the performance of Heat Sinks to reach a Set Point Temperature has been studied by adding thermal conductivity enhancer materials inside heat sink. Phase Change material (paraffin wax) has been used in heat sink to enhance the operating time. Nanoparticles (CuO and Al2O3) are added to PCM. The concentration of nanoparticles has been varied (0%, 0.5% and 1%) at constant Heat Flux of 2.5kw/m^2*. The effect of configuration of heat sink and concentration of nanoparticles has been studied.*

We have given our best effort to showcase methodology, results and conclusions of this investigation in most comprehensive and lucid manner. Graphs, tables and photos are also attached for better preference.

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It is their help and support, due to which we became able to complete the experiments and technical report. Without their support this report would not have been possible.

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Abstract

The current research examines the thermal performance of Nano-enhanced Phase Change Material (NePCM) based Heat Sinks for electronic component cooling. CuO and Al_2O_3 are employed as nanoparticles, while Paraffin wax with a melting range of 53 to 58 degrees Celsius is used as a Phase Changing material, with aluminum heat sinks. Tests are carried out with a constant volume fraction of 6.60 percent of fins in each heat sink for various configurations (no fin, 1x1 fin, 2x2 fin, 3x3 fin, 4x4 fin, 5x5 fin, and 6x6 fins). The nanoparticle concentration varies (0, 0.5,1 %wt). The heating plate imitates heat-producing electrical gadget which is linked to the bottom of the heat sink. All tests are carried out at a steady heat flux of 2.5 kW/m2.

The properties of NePCM varies with variation in concentration of nanoparticles. With increase in concentration of nanoparticles, the density and thermal conductivity increases. Moreover, the higher thermal conductivity is found in case of Al_2O_3. The highest thermal conductivity of 0.58W/m-k is in case of 1% Al_2O_3.

It is found that the pure PCM stretches the operating time for electronic devices to reach 75C base temperature by 190% as compared to case of heat sink without PCM. The maximum operating time is found to be 2920s in case of 6x6 with pure PCM and 2820s in case of 4x4 with 1% Al_2O_3. Best enhancement ratio of 4.62 and 4.47 is also found these two cases.

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Chapter 1
Introduction

1.1 Introduction

Life style of human beings is constantly changing and upgrading and to meet its requirements electronic devices are also becoming modern. Electronic devices are becoming more compact and with higher processing speed. This miniaturization and modernization of electronic devices is leading to high heat generation which in result increases the working temperature of electronic devices above a miserable level. It is claimed that when the working temperature rises, the failure rate of electronic components rises drastically (refer references 1,2). As a result, an effective cooling solution is required to prevent malfunctions and ensure the long-term longevity of electrical devices.

Keeping the temperature of electronic devise below critical temperature is called thermal management of electronic devices which can be classified into two different categories 1.) Active thermal management 2) Passive thermal management. Active cooling technique requires energy from external source. They are considered inefficient in cooling electronic devices as they are bulky, produces noise and requires continuous maintenance. Forced liquid cooling, fan based cooling, heat pipes are generally classified under active cooling techniques.

Due to these reasons, efforts have been made to utilize the passive cooling techniques in cooling electronic devices. Passive cooling technique doesn't require energy input from outside. One of the most promising passive methods is using Phase changing material (PCM) in heat sinks. Phase changing materials (PCM) are those materials which changes their phase in a particular range of temperature by absorbing latent heat from different sources.

1.2 Why PCM in thermal management?

PCM are the best in thermal management due to their constant temperature phase change process as shown in fig.1. It absorbs heat from electronic devices in form of latent heat to change its phase which in turn helps in maintaining the temperature of electronic devices below miserable condition. Its latent heat of fusion is high, causing it to absorb high amount of heat from base. Moreover, PCM based passive cooling does not acquire any moving parts and no need of continuous maintenance. PCM based cooling does not require external power to operate.

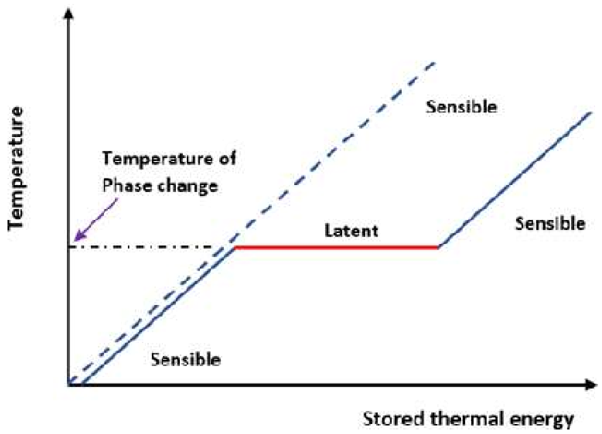


Fig. 1 Ideal heating and cooling curve of PCM based thermal management system

Fig.2 Phase changing Material (PCM)

1.3 Selection Criteria for PCM

PCM will perform beat if the it meets the required characteristics. It should have melting temperature lower than the miserable temperature of electronic devices so that it can absorb heat at constant temperature without damaging the device. The latent heat of fusion of PCM should be high which helps in maintaining absorbing large amount of heat at constant temperature. It should have high thermal conductivity so that heat can be transferred quickly from bottom to top. High specific heat to provide additional sensible heat storage. PCM should have high density and small volume change. It should be nontoxic, cost effective and easily available.

1.4 Difficulty with Phase Change Material

Major difficulty with the phase changing material is that they have very low thermal conductivity. Low thermal conductivity leads to low rate of heat transfer from base of heat sink. This results in higher base temperature which might cause the malfunctioning and permanent damage of electronic devices as electronic devices can reach to the vulnerable temperature quickly.

Solution:- Phase changing material should be added with the thermal conductivity enhancers(TCEs).

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

- Extended surface(fin): It is simple, effective and reliable.
- Metallic/Nonmetallic foams: Light weight, stable properties and more cost
- Nanoparticles: Light weight, agglomeration issues.

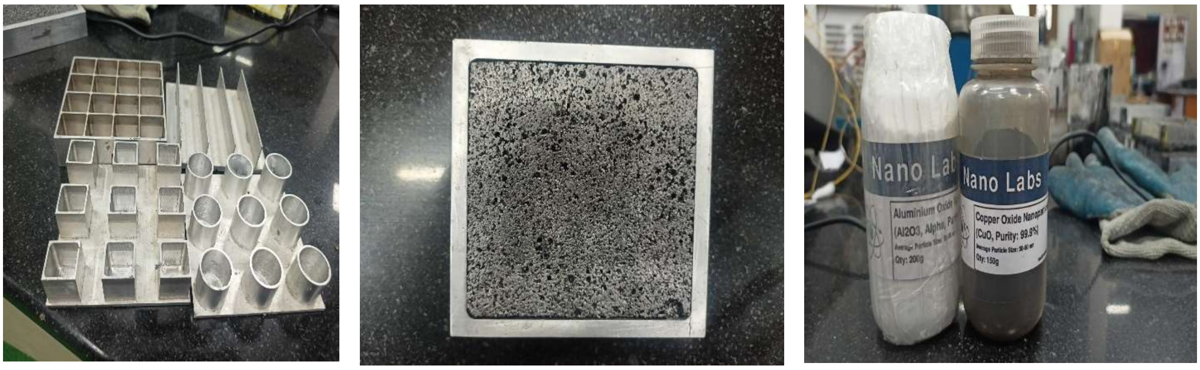


Fig.3(a) **Fig. 3(b)** **Fig. 3(c)**

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

1.5 Literature Review

Various numerical and experimental researches have been done on the application of phase change material for thermal management of electronic devices. Various types of phase change material are used generally most of them are organic or inorganic materials. Hence most of them have poor thermal conductivity, therefore thermal conductivity enhancers are used along the phase change material to increase their thermal conductivity in the solidus form. The most common types of TCEs are extended surfaces, metal foams and nanoparticles.

Anuj Kumar conducted experiments on cross fin-based heat sink with paraffin (58-62℃) as PCM. The experimental result shows that the thermal performance of heat sinks improves as the number of cavity increases. The increase in cross fin improves the thermal performance from the side wall of cross fins. The maximum enhancement ratio was found to be 6.5 for 6x6 cross fin-

based HS. In the study done by Kothari with plate fins and Al_2O_3 as nanoparticle argued that the use of nanoparticle degrades the performance of plate fin-based heat sinks. The improvement in thermal efficiency was found on heat sinks with no fins the performance of heat sinks increases with nanoparticle concentration. The operating time increased by 25% for 2% nanoparticle concentration. While it increased by 28% for one finned 4% nanoparticle concentration.

After that increasing nanoparticle concentration and the fin number, degrade the thermal efficiency of the heat sinks.

The study done by Rehman and Ali analysed the thermal performance of copper foam iron nickel foam and copper foam in PCM. When compared to iron nickel foam, copper foam with 95 percent porosity and.8% volume fraction provides better heat management. In the numerical investigation done by Nakchi orientation of novel stepped fin was analysed using lauric acid as PCM. Constant temperature was fixed at one side of 2d figure. The enthalpy porosity method was used for melting of PCM and Simple algorithm was used with Presto scheme for pressure correction. The result suggested that the downward stepped fin with b/c=4 has the best influence on the thermal management of PCM by increasing it by 65%. Tariq et al. proposed applying PCM to a variety of real-world issues, including heat pipes, thermal management, sun harvesting, food packaging, and battery thermal management. But the right combination of nanoparticle concentration and the other thermal conductivity enhancer is very challenging to obtain. Numerical investigation was done on finned HS embedded with NePCM it was observed that the latent heat of PCM decreases with increase in nanoparticle concentration and also the melting time of the PCM decreases. It was found that the optimum level of addition of nanoparticle is sound out to be the function of fin height.

Various other research paper suggests the method for the preparation of NePCM which includes several processes such as sonification, magnetic stirring and the time required for each process.

Numerical simulation of NePCM series two-layer solidification process in a triple tube with porous fin by Somayeh Davoodabadi Farahani et al., through the numerical investigation it is argued that applying the triple tube geometry over double tube geometry increases the solidification rate by 36%. RT35 and RT50 were used in combination and it was found that the combination in which RT35 was in middle and RT 50 was outside having lower solidification time as compared to other arrangements. Using fins in the middle layer improved the phase change process. Solidification rate increased with the use of nanoparticle and out of the CuO, Al_2O_3 and Fe_3O_4 the performance of Al_2O_3 found out to be best. The solidification rate also decreased with the usage of porous fins.

From the literature review it is observed that numerous methods have been used to enhance the thermal conductivity of PCM. Various experimental and numerical research has been done on metal foam, fins and their orientation in HS. The study and usage of nanoparticle is limited and the study of optimum level of NePCM to be used in a particular heat sink decides the performance of HS. The study of nanoparticles with different HS and other application requires more insight hence the present study suggests the usage of NePCM with cross fins-based heat sinks.

Table 1:

S. No.	Source	Study type /Q(kW/m^3)	PCM (MP in °C)	Nanoparticles	Dimension of HS mm^3/configuration	Observation
1	Mahmoud et al.	Experimental (3-5)	RT (42)	None	50x50x25/plate and cross fin	Cross fin performs better than plate fins.
2	Kumar et al.	Experimental (1.5-2.5)	Paraffin (58-62)	None	100x100x25/ cross fin	Cross fin with max. 36 cavity performs better.
3	Kumar et al.	Numerical (1-2)	Paraffin (58-62)	None	100x100x25/cross fin	Melting rate and heat flow improves by increasing the number of fins.
4	Kothari et al.	Experimental (2)	Paraffin (58-62)	Al_2O_3	100x100x22/plate fins	Increasing nanoparticle concentration decreases efficiency of finned HS.
5	Bondarev et al.	Numerical (47°C)	n-Octadecane (28.5)	Al_2O_3	-	Melting time of nanoparticle increases with slight inclination in the HS.
6	Nakhchi et .al	Numerical 2D (63°C)	Lauric Acid (43.5-48.2)	-	120x50/novel stepped fin ratio (b/c=.66, 1, 1.5, 2.33, 4) upward and downward face	Maximum heat flux is shown by downward stepped fin with b/c = 4. Stepped fins are better than

						conventional fins
7	Farzanehnia et al.	Experimental (2-6)	Paraffin (40.22-46.92)	MWCNT (0.2, 2.0)	73x68x44.5	After the completion of latent heat phase, effect of NePCM is more prominent.
8	Tariq et al.	Experimental (0.86, 1.44 and 2.40)	RT-64HC (63 65) and RT-44HC (41-44)	Graphene	102 × 102 × 25/Unfinned	In 0.008 weight percent of RT-44HC/GNPs at room temperature, the maximum reduction of 23 percent is found.
9	Ren et al.	Numerical /(4.5 to 7.5)	Paraffin (45)	Expanded Graphite	112 × 112 × 27/unfinned and pin fins	The right balance is required in decrease in latent heat and increase in NePCM%. Medium no. and medium height perform best.
10	Present study	Experimental	Paraffin (53-58)	Al_2O_3CuO	100x100x25/ Cross fin	Al_2O_3 - performs better than CuO. Overall NePCM decreases operating time by 3%

Objectives of Present Investigation

Through this present investigation we wish to evaluate the thermal performance of electronic devices at constant heat flux of 2.5kw/m^2 when heat sink is filled with PCM or NePCM.

The specific objectives are defined below: -

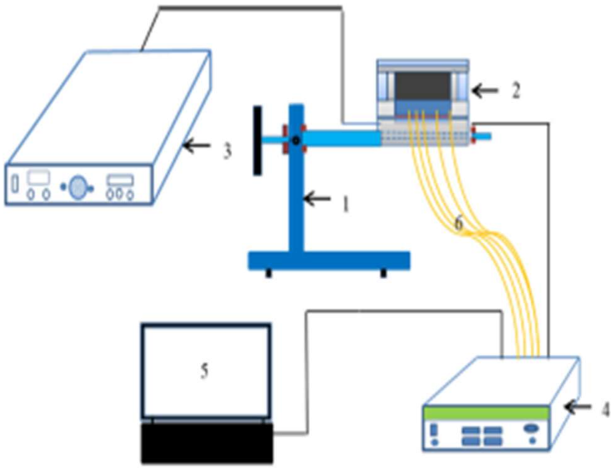
- Create NePCM and investigate its thermophysical properties (latent heat, specific heat, density, thermal conductivity, and viscosity) at various nanoparticle concentrations.
- To study the effect of pure PCM on base temperature of HS as compared to the HS without any PCM.
- To investigate the thermal performance of different cross fin HS designs using pure PCM and NePCM with various nanoparticles such as CuO and Al_2O_3.
- To study the enhancement ratio of different combination of HS and NePCM concentration for two different Set Point Temperature of 65℃ and 75℃.

Chapter 2

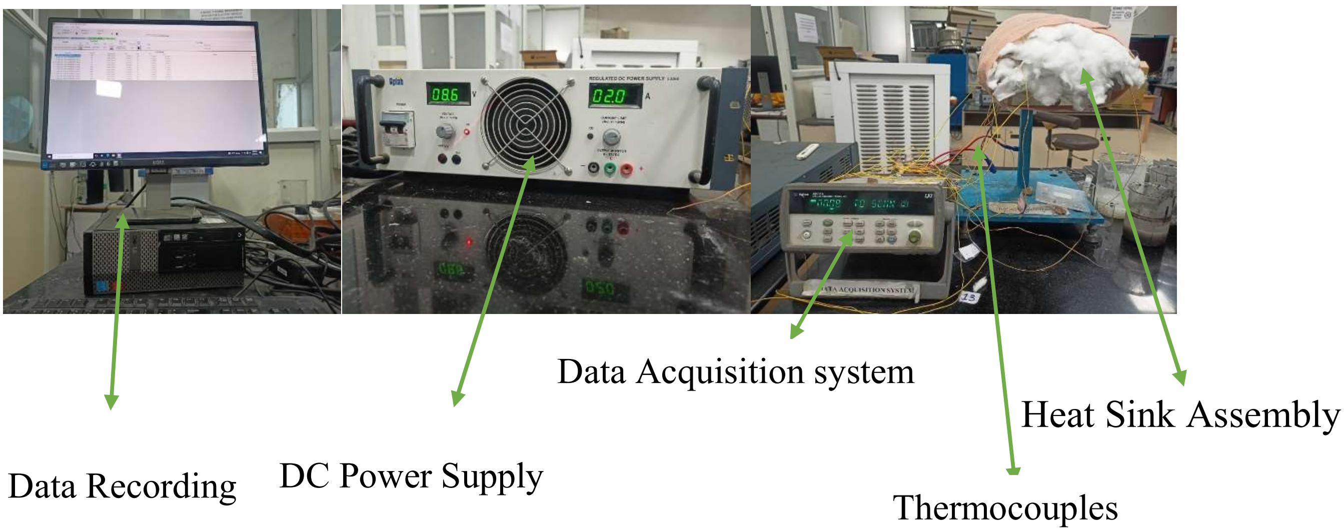
Experimental Analysis

2.1 Experimental Setup

The schematic of experimental setup is shown in fig. 3. Heat sink assembly, data gathering system, k-type thermocouples, DC power supply, and computer system with Agilent software to record temperature are all part of the setup. Heat sink assembly consists of a heating plate which is connected to a DC power supply with 0–32 V and 0–5 A voltage and current ranges, respectively. The heating plate is made of coil type nichrome wire coiled on mica sheet and has a thickness of 4 mm. The combination of both heating plate and DC power supply imitated the heat producing electronic device. K-type Thermocouples are calibrated and fixed to the heat sink and heating plate to and are joined to data acquisition system. Data acquisition system records the temperature and then send to the Agilent software, where it is stored in the memory. The heat sink assembly is covered with the glass wool to prevent heat losses. In present study paraffin wax with melting range of 53-58℃,is used as PCM and CuO & Al_2O_3 are used as nanoparticles having average size of 30-50 nm.



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



4(b)

Fig. 4 Experimental Setup (a) Schematic of experimental setup (b) Actual setup

2.2 Heat Sinks Configurations

In the present study, 6 different configurations of heat sinks are used. Each with different number of cross-fins. **Fig.4** shows the arrangement of fins in each heat sink. The dimensions of each heat sink is mentioned in **Table 1.** Though the dimensions of cavity of each heat sink changes but the volume fraction of fins in each heat sink remains constant and equal to 6.60%.

The Base of each Heat sink is of 100x100 mm2. Height of each cross fin and heat sink is 25 mm. Thickness of base (tb) is 2mm. Cross fin thickness(tf) and wall thickness (tw) varies for each configuration.

Heat Sink	Dimension (L x W x Hmm3)	t_b (mm)	t_w (mm)	t_f (mm)	Cavity Dimensions (d x d x h mm3)
1 cavity (No fin)	100 x 100 x 25	2	3.5	-	93 x 93 x 93
4 cavity (2 x 2)	100 x 100 x 25	2	2	2.00	47 x 47 x 23
9 cavity (3 x 3)	100 x 100 x 25	2	2	1.50	31 x 31 x 23
16 cavity (4 x 4)	100 x 100 x 25	2	2	1.00	23.25 x 23.25 x 23
25 cavity (5 x 5)	100 x 100 x 25	2	2	0.75	18.6 x 18.6 x 18.6
36 cavity (6 x 6)	100 x 100 x 25	2	2	0.60	15.5 x 15.5 x 23

Table 2 Dimensions of Heat Sinks

2.2.1 Locations of Thermocouples in Heat Sinks

In all heat sinks, slots of 2 mm are made on the base as well as the side walls of heat sinks. Thermocouples are attached in these slots. Fig. 5 shows these slots.

Fig. 5 Aluminum cross fin Heat Sink Configurations (a) 2x2 (b) 3x3 (c) 4x4 (d) 5x5 (e) 6x6

2.3 NePCM Preparation

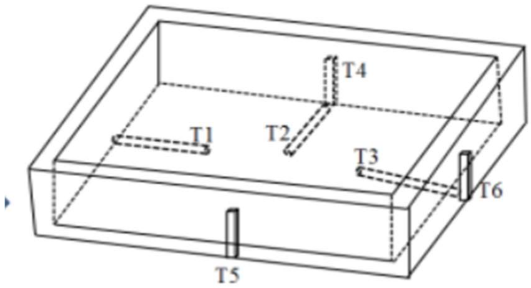
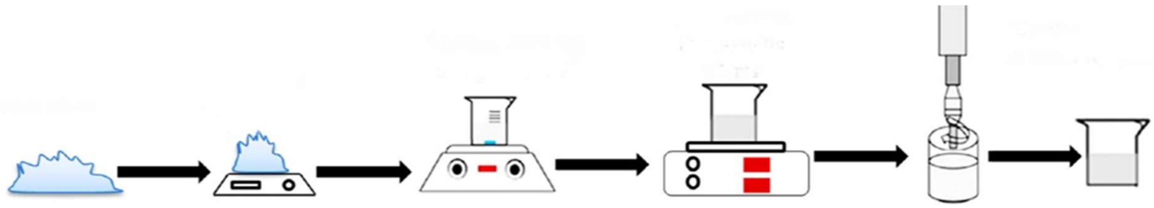
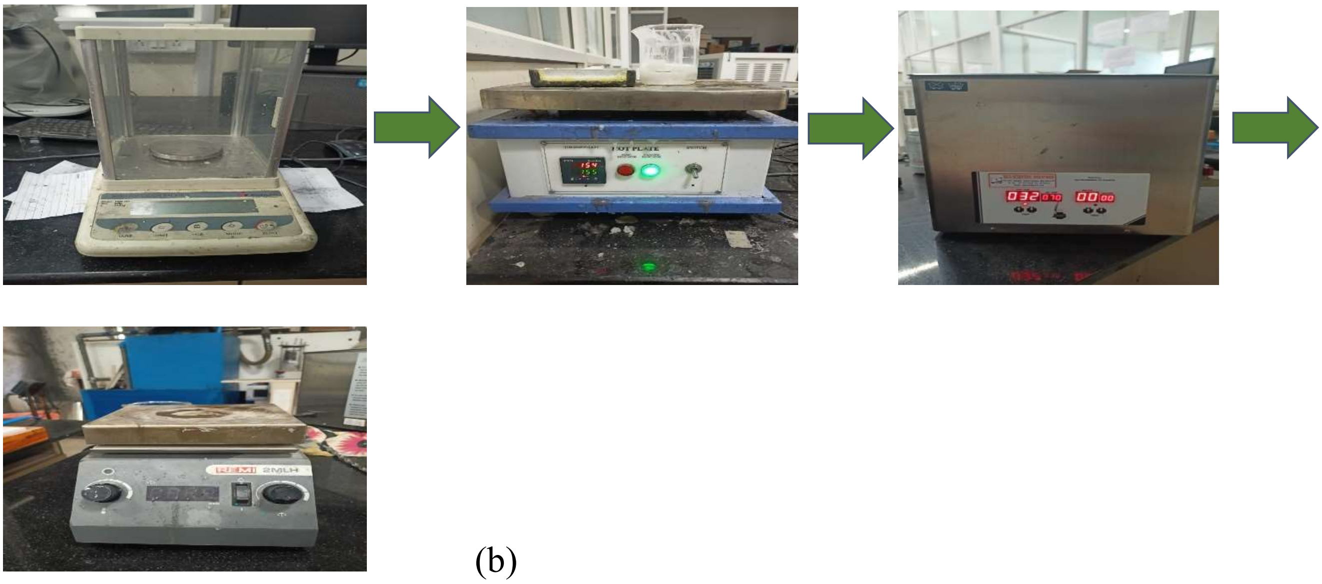


Fig 6

NePCM is prepared by mixing CuO and Al_2O_3in PCM. Initially, the pure PCM is weighted with the help of analytical balance machine (Wensar weighing scale, PGB 301, Chennai India). The total weight of PCM used is 140gms. PCM is then melted on heating plate at temperature range of 90-120C. After melting, pure PCM is put in a sonicator (Rico scientific Industries, USBT-6, India). Ultrasonic vibrator is filled with water and set at temperature above the melting range of PCM. Nanoparticles are mixed with PCM according to the concentration of NePCM required (0.5,1%wt) in ultrasonic vibrator. Ultrasonic vibrator is used to sonicate the mixture and distribute nanoparticles uniformly to make a good mixture. This sonication is done for around 2 hrs. The sonicated mixture is then put on magnetic stirrer (2MLH, REMI, India) for 1 hour at around 500 rpm. The magnetic stirrer has heater at the bottom which doesn't allow the mixture to solidify while it on magnetic stirrer. The NePCM is prepared and placed into the heat sink, where it solidifies at room temperature. The experiments can now be done on heat sink with PCM/NePCM. Fig. 6(a) and 6(b) shows the complete preparation of NePCM.



(a)



(b)

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

2.4 DSC Analysis

Differential Scanning Calorimetry was used to determine the latent heat of fusion for PCM/NePCM with various CuO and Al_2O_3 mass percentages (Perkin-Elmer, DSC 8000, USA). The DSC analysis is performed at temperatures ranging from 25 to 80°C, using a 10°C per minute heating rate.. Figure 7 shows the heating curve for PCM/NePCM at various CuO and Al_2O_3 mass fractions. Table 2 shows how adding nanoparticles to pure PCM reduces the latent heat of fusion. The highest latent heat of fusion is with pure PCM. As compared to Al_2O_3, CuO nanoparticle mixture has higher latent heat of fusion at both concentration (0.5,1%wt). 0.5% Al_2O_3 has 7.70% less latent heat as compared to pure PCM while 1% has 16.3% less latent heat. In case of CuO nanoparticle, 0.5% has 5.03% less latent heat of fusion while 1% CuO has 12.45% lesser as compared to pure PCM. So, Al_2O_3 decreases latent heat of fusion more as compared to the CuO. The higher the concentration of nanoparticles, lower the latent heat of fusion.

Material	Latent heat of Fusion (L)(KJ/Kg)	Percentage decrease in 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

Table 3 Variation of latent heat of fusion with concentration

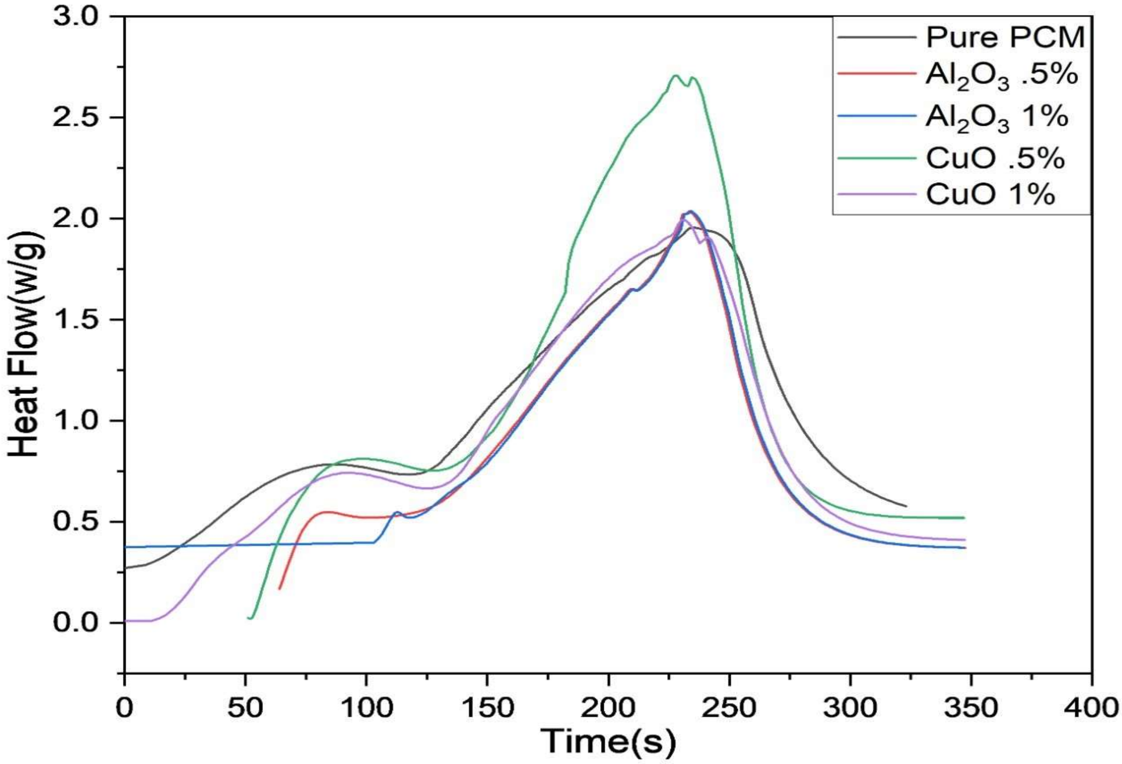


Fig. 8 Heating curve of NePCM

2.5 Thermophysical Properties of NePCM

Thermophysical properties such as thermal conductivity(k), specific heat, density and viscosity are determined by using the standard formulas. For using these formulas, the nanoparticles should be uniformly distributed inside the PCM.

The weight fraction of nanoparticles ($\boldsymbol{\varphi}$) is defined as the ratio of Nano particle mass to PCM mass,

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

As a function of constituent weight fraction, the density, thermal conductivity, and specific heat capacity of NePCM may be calculated as follows:

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

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

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

Below eq. gives the variation in viscosity (μ) with the addition of nanoparticles.

$$\mu_{NePCM=0.983e^{12.959\emptyset}\mu_{NePCM}} \qquad \text{.... (5)}$$

Where Φ is the volume percentage of nanoparticles that can be generated using,

$$\emptyset = \frac{\frac{\boldsymbol{Wt_N}}{\boldsymbol{\rho_N}}}{\frac{\boldsymbol{Wt_N}}{\boldsymbol{\rho_N}} + \frac{\boldsymbol{Wt_{PCM}}}{\boldsymbol{\rho_{PCM}}}}$$

Here,

$\boldsymbol{Wt_N}$ **– weight of nanoparticles;**

$\boldsymbol{\rho_N}$ **– Density of nanoparticles;**

Wt_{PCM} **– Weight of PCM;**

ρ_{PCM} **– Density of PCM**

Substances	Latent Heat (KJ/Kg)	Thermal conductivity (W/m-k)	Melting Point (°C)	Density (Kg/m3)	Specific heat (KJ/Kg)
Al_2O_3	--	36	--	3600	.765
Paraffin wax	127	.22	53-58	839	2.4
CuO	--	33	--	6310	.551
Aluminum	--	218	660.37	2719	.896

Table 4 Thermal properties of Pure materials used in experiment

By utilizing properties in Table 4 and the above mentioned equations we can calculate the thermophysical properties of NePCM.

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

Table 5 Thermophysical properties of Nano-enhanced Phase Changing Material

The thermal conductivity (K) increases as the nanoparticle concentration rises. The highest change in thermal conductivity of 163.63% from Pure PCM is found in the case of 1% Al_2O_3. It can be seen that as the concentration of nanoparticles increases, the value of thermal conductivity increases. It is higher in case of Al_2O_3 as compared to CuO. Similar trend can be observed in the case of viscosity. As the concentration increases, the viscosity increases with respect to pure PCM. Increment in 1% CuO is highest. The increased thermal conductivity has positive impact on the thermal performance of NePCM. Higher the thermal conductivity, higher will be operating time to reach the Set Point Temperature. While the increased viscosity has negative effect on the thermal performance. In viscous medium, the hinderance in natural convection is high. So, natural convection in case of higher viscosity is less due to which it takes more time to reach the Set Point Temperature. It shows that there are two counter effects of mixing nanoparticle with pure PCM. The specific heat decreases with increase in the concentration of nanoparticles.

Chapter 3

Results and Discussions

3.1 Validation

The validation of the experimental setup was done with the help of previous experimental data. The base temperature of the heat sink in the present investigation were recorded every 10 seconds and were compared with the experimental data of Kothari et al. Each heat sinks in the previous test was of 100x100x22 mm^3 with 4 mm base thickness and enclosed within 5 mm Plexiglass sheet. The same setup is used to validate the present investigation. According to the literature review the heat flux value for almost every experiment lies between 1 to 3 kW/m^2. Most of the study used paraffin was as PCM with melting range lying between 47°C to 62°C, while some literature also contained inorganic acids such as stearic acid (68.77 °C) and lauric acid (42 to 44°C). The initial ambient base temperature varied between 20 to 35°C.

The heat sink used in this study is a 100x100x25 mm^3 heat sink filled with paraffin wax (Sigma Aldrich, USA) with a melting range of 58 to 62°C. The comparison of present experimental result and the previous data is done on empty and filled heat sinks with heat flux value of 2.1 kw/m^2 and 2.8kw/m^2. The result of the present investigation and the previous one are plotted on the graphs and are shown in **figure 1 & 2** for empty and filled heat sinks.

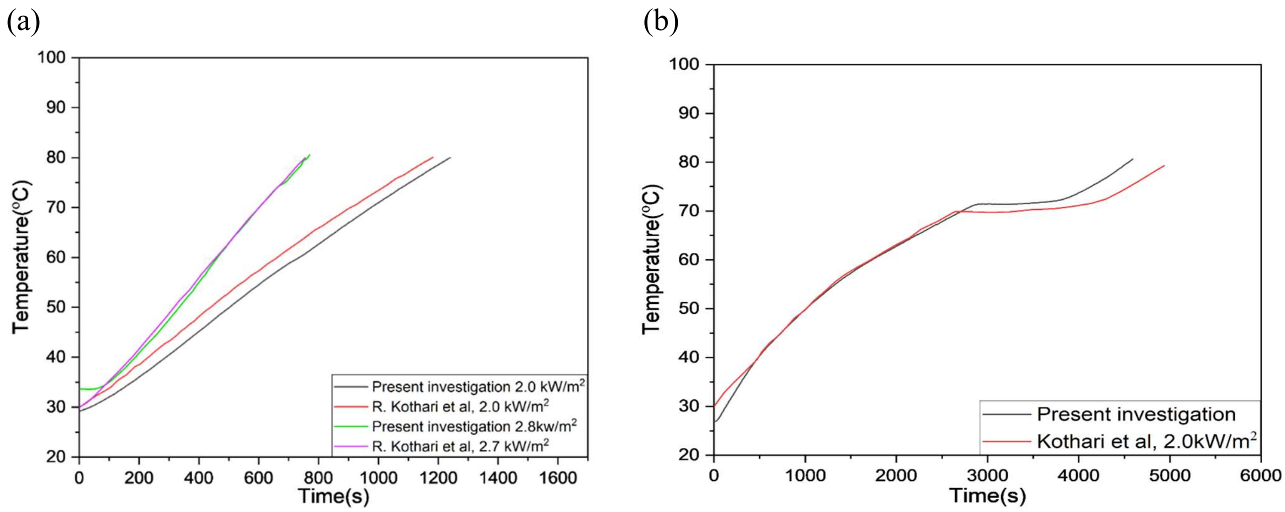


Fig.9 Validation of Experimental setup with (a) Heat Sink without PCM (b) Heat Sink with PCM

The values of the base temperature in the graph follow the same trend as the previous investigators' results in both situations, as shown in fig.9. However, 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 PCM effect on Base Temperature

The comparison of heat sink with and without PCM has been done on paraffin wax as PCM with melting range of 53 to 58°C at the heat flux value of q= 2.5kW/m^2. The comparison has been done using the unfinned heat sinks. For the comparison the base temperature was recorded using k type thermocouples each at the 4 side of the heat sink with 2 mm distance from the center. The value of average temperature of heat sinks is calculated at every 10 seconds and the comparison

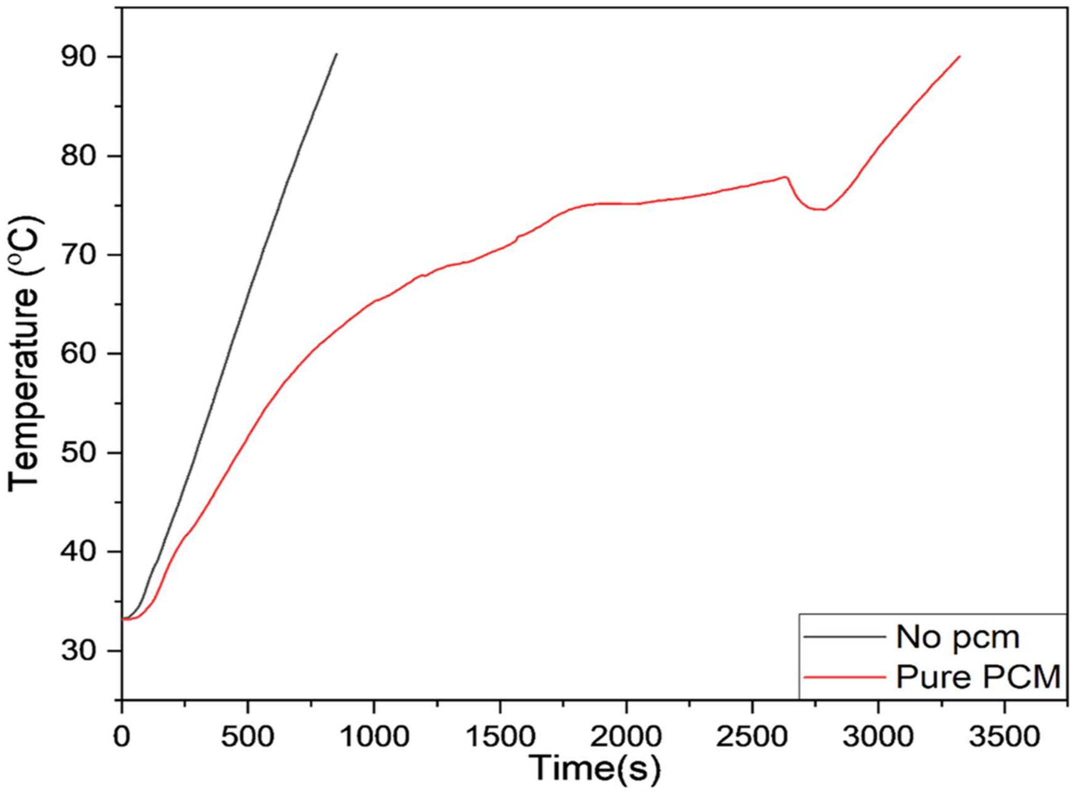


Fig. 10 Base temperature variation comparison of HS with PCM and Without PCM

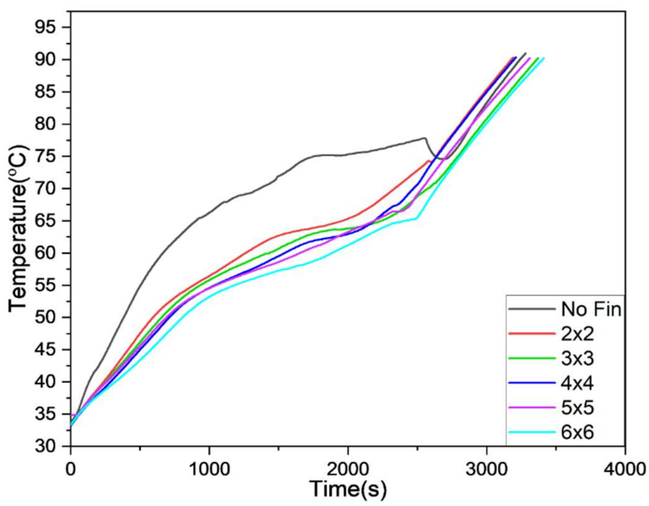
plot of heat sink with PCM and without PCM is shown below.

From the figure obtained it can be concluded that the heat sinks without PCM have a steep constant rise in temperature whereas in the case of a PCM-filled heat sink the rise in temperature is less steep and becomes even less steep in the melting range. The time taken by the base temperature to reach 60°C in the case of heat sink without PCM is 430s and 750s in the heat sink with PCM. In order to reach a even higher SPT of 70°C the time taken by the unfilled heat sink is 560s and 1440s in the case of filled PCM. In the case of heat sink without PCM there is a sudden rise in the side wall temperature which is not desirable in the electronic devices. The overall extension in the operating time of the heat sink to reach a SPT of 60°C & 70°C is 74.71% and 157.14% respectively. It may be noted that the use of PCM significantly increases the operating time which is the motive of the investigation.

3.3 Configuration effect on Heat Sink

There are 6 different heat sinks based on cross fins are compared with same material as PCM. The heat sinks are no fin, 2x2, 3x3, 4x4, 5x5 and 6x6. The comparison of heat sinks has been done with Al_2O_3 and CuO as nano particle. 0%, .5% and 1% has been chosen as nano particle comparison. Thus, total of 36 experiments were performed and the variation of average temperature every ten second is plotted with same material as PCM for different heat sinks. The heat flux was maintained constant at $q=2.5kW/m^2$.

(a).



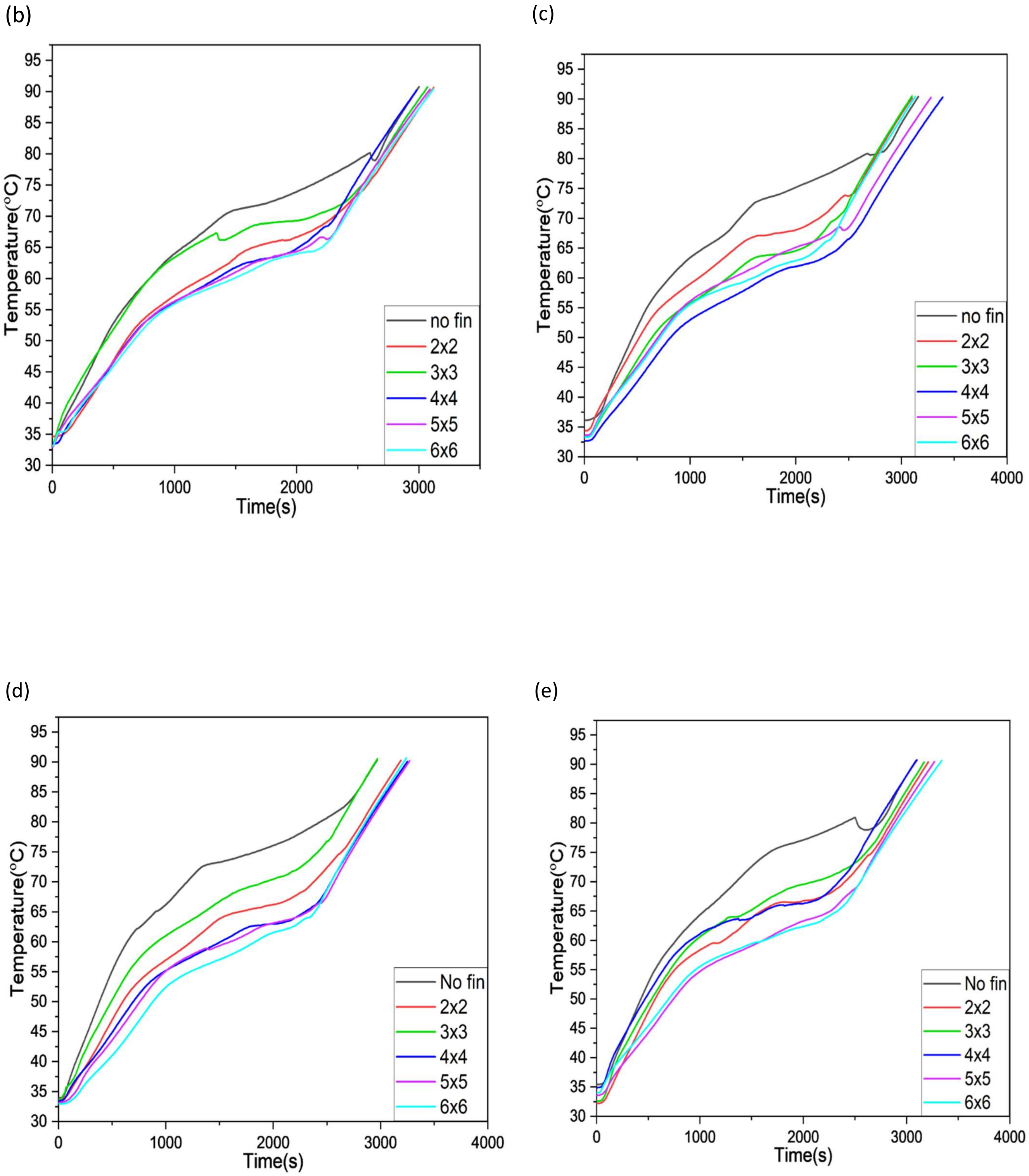
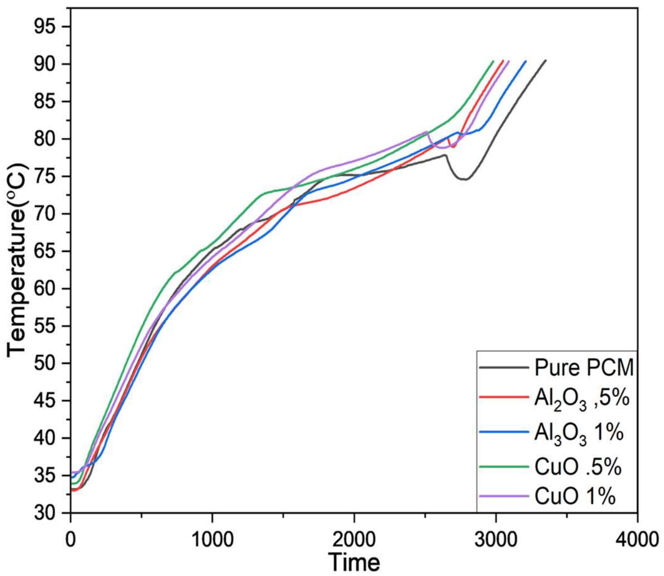


Fig. 11 Variation of base temperature with each concentration of nanoparticles in different HS (a) Pure PCM (b) 0.5% Al_2O_3 (c) 1% Al_2O_3 (d) 0.5% CuO (e) 1% CuO

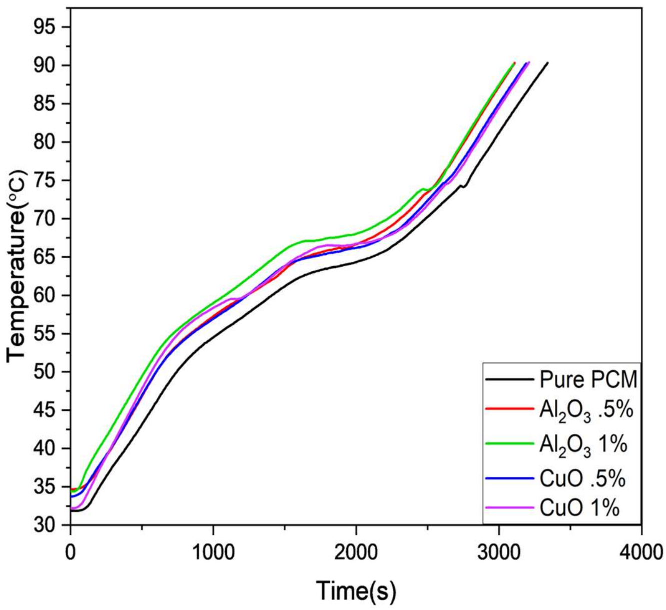
3.4 Effect of Nanoparticle concentration on heat sinks

Fig. 10(a)-(f) shows the variation of base temperature of each heat sink with different nanoparticle's concentration at constant heat flux of 2.5kw/m2. The time taken by each heat sink's base to reach set point temperature (SPT) of 75℃ is recorded. The increased nanoparticle concentration has two effects, first, it increases the thermal conductivity of NePCM which in turn increases the time required to reach the SPT. Second, it increases the viscosity which weakens the effect of natural convection. As concentration increases the effect of viscosity surpasses the effect of increased thermal conductivity. This causes negative effect on the operating time to reach SPT.

(a)



(b)



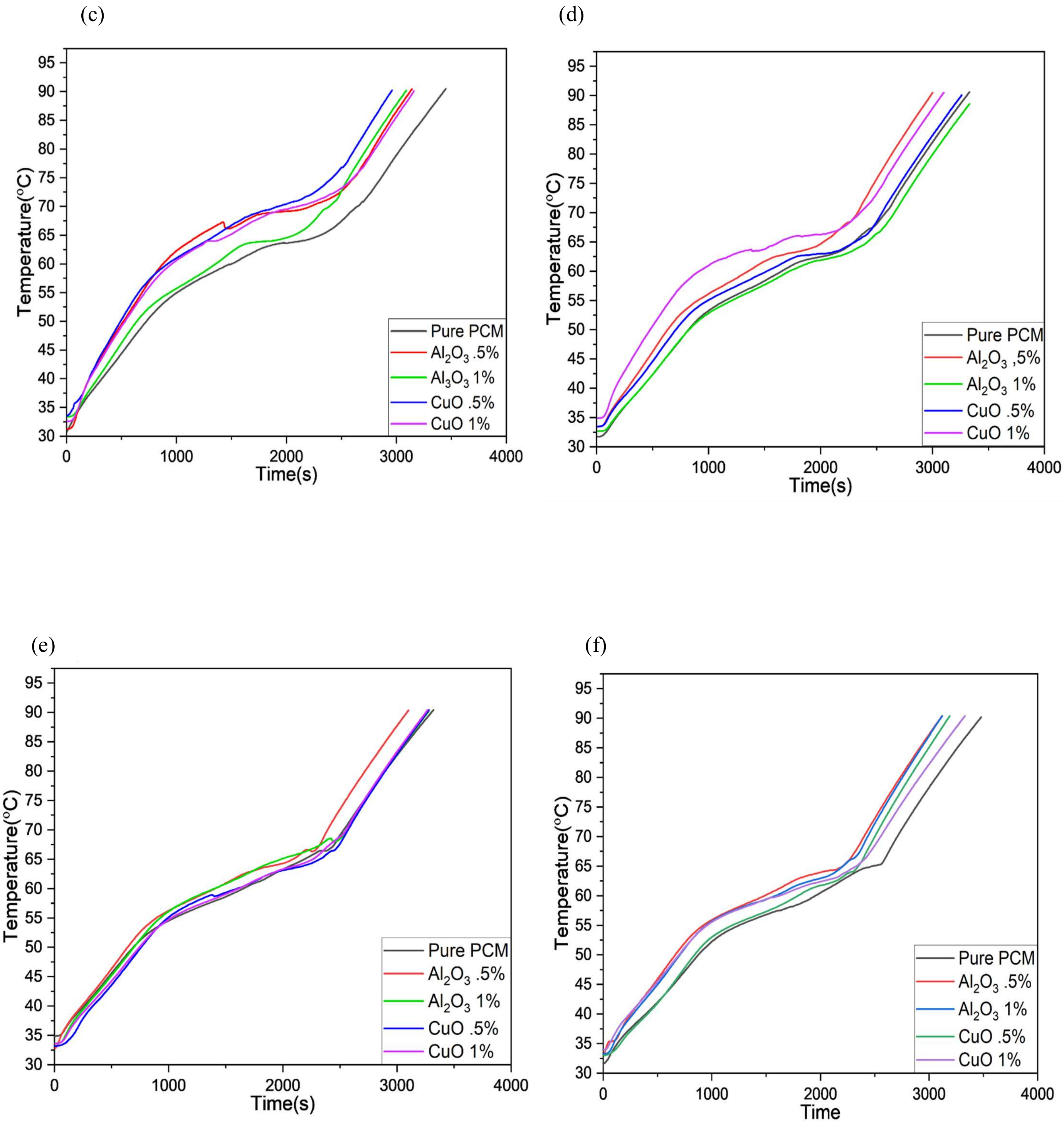


Fig.12 Variation of base temp. for each HS with (a) No fin, (b) 2x2, (c) 3x3, (d) 4x4, (e) 5x5, (f) 6x6

In case of 6x6 HS with pure PCM the operating time is found to be 2920s. Here, increased thermal conductivity due to fin configuration overcomes the increased the viscosity due to nanoparticles. For 5x5 HS, the nanoparticle have negligible effect. Pure PCM performs similar to 1% CuO and 1% Al_2O_3, with operating time of 2710s for SPT 75℃. In 4x4 HS nanoparticles have significant effect. Here, 1% Al_2O_3 has maximum operating time of 2820s. Operating time in 3x3 and 2x2 HS increase with increase in the concentration of both Al_2O_3 and CuO but at low concentrated NePCM, pure PCM performs better. For HS with no fin, 0.5 % Al_2O_3 NePCM and pure PCM gives the best operating time.

So, it can be seen that nanoparticles in case of higher fin numbers have negative effect on the performance of HS. Usage of nanoparticles is effective in case of heat sinks with less number of fins.

3.5 Enhancement Ratio

The enhancement ratio ($\boldsymbol{\varepsilon}$) is the ratio of the time it takes a heat sink with NePCM to reach the set point temperature over the time it takes a heat sink without PCM/NePCM.

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

The set point temperature (SPT) is the highest temperature at which an electrical equipment can function properly.

Fig. 7(a) and (b) shows the variation of enhancement ratio (ε) at critical SPT of 65℃ and 75℃ respectively for each heat sink at different concentration. Heat flux remains constant at 2.5kw/m^2 in each case.

The highest enhancement ratio is found in the case of 6x6 Heat sink with pure PCM which is equal to 5.14 for SPT of 65℃ and 4.62 for SPT of 75℃. For no fin HS, best enhancement ratio comes to be 3.52 with 1% Al2O3 at SPT of 65°C. Similarly, at SPT 75°C 0.5% Al2O3. performs better with enhancement ratio of 2.39. For 2x2 HS, pure PCM has best enhancement ratio of 4.3 and 4.43 for both 65°C and 75°C respectively. In case of 3x3 also pure PCM performs best. The 4x4 heat sink show maximum enhancement ratio for 1% $Al_2O_3$for both the SPT cases. For 5x5 heat sink, at SPT 65°C 0.5% CuO performs best with enhancement ratio of 4.77 while at SPT 75°C, pure PCM, 0.5% and 1% CuO and 1% Al2O3 performs similar with enhancement ratio of 4.33.

In cases of nonzero nanoparticle concentration, 4x4 heat sink with 1% Al_2O_3 has highest enhancement ratio as compared to other cases.

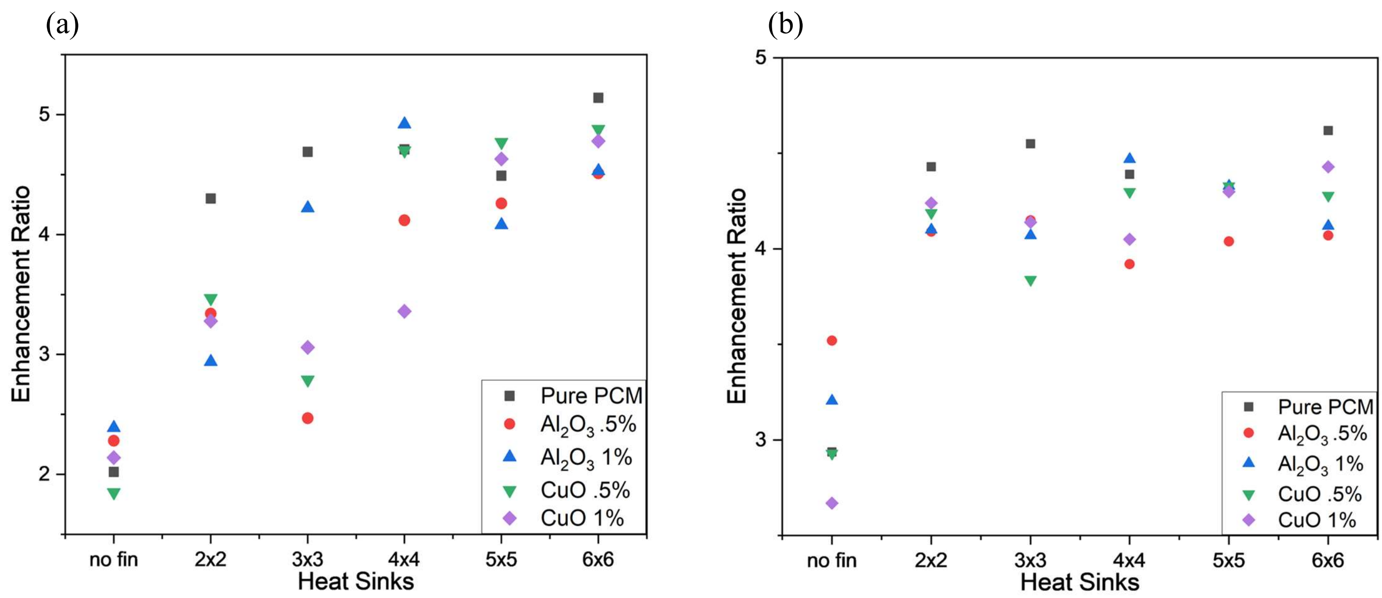


Fig.13 Comparison of Enhancement ratio for (a) SPT 65°C (b) SPT 75°C

Heat sink	SPT	Pure PCM	.5% Al_2O_3	1% Al_2O_3	.5% CuO	1% CuO
No Fin	65°C	910s	1080s	1140s	920s	1050s
	75°C	1840s	2140s	1990s	1840s	1680s
2x2	65°C	1990s	1660s	1440s	1710s	1610s
	75°C	2640s	2580s	2590s	2640s	2770ss
3x3	65°C	2240s	1140s	2080s	1370s	1490s
	75°C	2800s	2540s	2570s	2430s	2610
4x4	65°C	2200s	2030s	2420s	2310s	1640s
	75°C	2650s	2470s	2820s	2710s	2560s
5x5	65°C	2210s	2090s	2000s	2340s	2270s
	75°C	2720s	2540s	2730s	2730s	2720s
6x6	65°C	2450s	2220s	2230s	2400s	2350s
	75°C	2820s	2570s	2600s	2700s	2740s

Table 6 Time taken of different HS to reach SPT

Chapter 4

Conclusion and Scope For Future Investigation

4.1 Conclusions

The combined effect of extended surfaces (fins) and nanoparticles is investigated. In this study on heat sinks with 1,4,9,16,25, and 36 cavities at a constant TCE volume percentage (6.60%). At two distinct concentration levels (0.5 percent and 1%wt), the thermal performance of two different micro particles (CuO and Al_2O_3) is compared, The tests are carried out with a steady heat flow of 2.5kw/m2.

The important conclusions which can be derived from present study are as under:

- With increment in nanoparticle concentration, latent heat decreases whereas thermal conductivity increases. The thermal conductivity also increases with increase in concentration of nanoparticles in pure PCM.
- Operating time with pure PCM increases by 190% as compare to HS without PCM for reaching SPT of 75°C. This implies that thermal performance of heat sinks become better by using the PCM. In comparison to HS without PCM, PCM integrated HS extends the functioning time of electrical gadgets.
- Operating time for 4x4 HS with 1% Al_2O_3 is 2820s which is higher than all other NePCM HS combination cases but less than 6x6 HS with pure PCM which has operating time of 2920s.
- Enhancement ratio of pure PCM with 6x6 HS is superior than rest and in nonzero NePCM concentration cases, 4x4 HS with 1% Al_2O_3 performs better than rest.
- Above both results suggests, Hs with higher number of fins performs better for less nano particle concentration (0% and 0.5%) and HS with less number of fins performs better for higher concentration.
- Based on the operating time and enhancement ratios, 6x6 HS with pure PCM performs best than rest, while 4x4 HS with 1% Al_2O_3 performs superior as compared to other HS

configurations with Nonzero NePCM concentrations. So, 4x4 HS with 1% Al_2O_3 can be used in place where we need low cost of production and faster cooling of heat sinks. While if there is no restriction on cost of manufacturing, 6 x 6 HS with pure PCM can be used.

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 investigate the thermal performance and enhancement ratio of various heat sink sizes with identical designs.

<u>Nomenclatures</u>

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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