Contents lists available at http://qu.edu.iq

Al-Qadisiyah Journal for Engineering Sciences

Experimental investigation of mini-channel heat sink with nano-enhanced phase change materials

Mushtaq I. Hasan [a]*, *Dhuha Rasheed Saber* [a]

[a] *Departmnt of Mechanical engineering, University of Thi-Qar, Thi-Qar,Iraq.*

ARTICLE INFO

ABSTRACT

An experimental investigation is conducted to study the potential of enhancement cooling performance for mini channel heat sink by using different cooling mediums which are air, pure paraffin wax, and nano-enhanced phase change material (NEPCM). Paraffin wax used as phase change material (PCM) and mixed with three types of nanoparticles of alumina (Al_2O_3) and titanium dioxide (TiO_2) to improve the thermal conductivity of PCM. Volume fraction values for each type of nanoparticles are (0.1, 0.2, 0.3, 0.4, and 0.5)% which dispersed through PCM. A constant heat flux had been applied to the heat sink base with values (449, 963, 1839, and 4946)W/m^2. The results showed enhancement in cooling performance when dispersion the nanoparticles through the PCM which mean reducing the temperature of heat sink base as compared with air and pure paraffin wax. The experimental results also indicated that the cooling performance enhancement of NEPCM and reduction the time of melting process continue with increasing the concentrations of nanoparticles for all material types but any surplus addition may cause negative effect due to sedimentation. Optimum cooling performance of mini heat sink is achieved with Al_2O_3 –PCM then TiO_2-PCM as compared with air with percentage of temperature reduction of 23.306 and 22.069% respectively as compared to air.

1. Introduction

   Cooling of electronic devices had been formed a great challenge for many researchers because of the rising temperature of the central processor unit(CPU) which is the most direct reason to reduce the reliability of electronic devices. The high temperature of CPU formed approximately 55% from reasons of device failure , 20% due to vibration, 19% due to humidity, and 5% due to dust according to Ojha [1]. There are many types of researches that performed experimentally and numerically to find out methods for enhancing heat transfer by using heat sink which absorbs the undesirable heat from CPU by conduction and then dissipated it to the ambient. Phase change materials (PCM) can be considered as a promising material for cooling techniques due to having high specific heat, low volume changing during phase change, and high melting heat which allow it to absorb large amount from heat during phase change and then belong

to the solid phase when dissipated this heat to the ambient. Nanoparticles dispersion into the PCM to enhance the low thermal conductivity of it. Nanoparticles have been contributed to uniform heat distribution within PCM which leads to reduce melting time and boundary layer thickness that meaning decreasing the heat sink thermal resistance and enhancement coefficient of heat transfer thus, increasing heat transfer rate. Tuckerman and Pease [2] Found out and performed the concept of the micro-channel and studied the enhancement of heat transfer rate for this channel by forced fluid through it. They explored that the heat transfer rate increased by using micro-channel comparing with conventional channel. They also indicated that the heat transfer coefficient increased when a hydraulic diameter of micro-channel decrease.

---

* Corresponding author.
  E-mail address: Mushtaq76h@gmail.com (Mushtaq I. Hasan)

Nomenclature

A_b	Heat sink base area (m^2)		q	Heat flux (W/m^2)
C	Volume fraction%		TC	Thermocouple
C_p	Specific heat (J/kg.K)		TR	Temperature Reduction%
C_{wt}	Mass fraction		V	Voltage (Volt)
D_{np}	Diameter of nanoparticle (nm)		W	Heat sink Width (mm)
H	Heat Sink Height (mm)		W_{ch}	Channel Width (mm)
H_{ch}	Channel Height (mm)			*Greek symbols*
I	Electrical current (Amp.)		µ	Dynamic viscosity (Pa.s)
K	Thermal conductivity (W/m. K)		λ	Latent heat of fusion (kJ/kg)
L	Heat Sink Length (mm)		ρ	Density (kg/m^3)
MR	Melting Range (°C)			

Peles *et al*.[3] Experimentally studied the thermal resistance of pin-fin micro-channel heat sink. Discussed parameters that affected the total thermal resistance such as geometry and thermo-hydraulic parameter. The results indicated that thermal resistance of pin fin micro-channel heat sinks was lower than the micro-channel heat sink. They concluded that the heat transfer rate can be enhanced by using microscale pin fin heat sink. Forced convection is a very effective heat transfer mode over micro pin fin heat sink. For microscale pins, the coefficient of heat transfer was very large and this lead to decrease fins efficiency. Pin fins should be short to increase its efficiencies. Tang *et al.* [4] Experimentally studied the characteristic of flow for helium and nitrogen in stainless steel microtubes, fused silica microtubes, and fused silica square micro-channels. The findings indicated that friction factors showed a reasonable agreement with theoretical predictions of fused silica microtubes with diameters from 50 to 201µm and fused silica square channels with a hydraulic diameter ranging from 52 to 100µm. Stainless steel tubes with a diameter (D=119-300µm) showed higher friction factor than theoretical results for tubes with conventional size. This difference between experimental and theoretical results occurred due to large relative surface roughness for stainless steel tubes. From the literature and this study, the gaseous flow is suggested to be laminar in the micro-channel with surface roughness below 1%. Because of the compressibility effect, appositive friction factor deviation is observed from the conventional theory. The drawback in friction factor is observed due to the rarefaction and the obtained results explained that the smaller friction factor in fused silica micro-channel. Kuravi [5] Numerically investigated characteristics of the flow and heat transfer for phase change material slurry that flow into the micro-channels with applied constant heat power at the base of micro-channels. This study conducted by changing the type of base fluid, channel dimensions, nanoparticle concentrations, particle size, heat flux which applied on heat sink base, inlet temperature, and melting range for PCM. This study investigated the impact of particle distribution within PCM on micro-channel thermal performance. Micro-channel dimensions which used in this study were 533µm height and101µm width with water as conventional fluid and n-Octadecane as PCM. The focus of the study was on specifically manifold micro-channels. Because the flow in micro-channels is not fully develop in this case, the thermal performance of micro-channels was not obtained as in conventional channels due to the large length of channels as compared with the length of micro-channels. The effect of particle distribution can be ignored in a numerical model for some cases. Thermal performance of slurry depending on the inlet temperature of fluid, PCM purity, the heat power, the thermal conductivity of the base fluid. The results revealed that the heat transfer coefficient of water is larger than the water-based slurry at channel width is 100µm. For the same channel with a pure poly alpha olefin (PAO) which has thermal conductivity equal to the PCM, the slurry heat transfer coefficient was higher than pure PAO and with increased mass concentration, the heat transfer coefficient increased. Ho *et al.* [6] Experimentally investigated the heat transfer rate of the hybrid water suspension of alumina Al_2O_3 nanoparticles and the microencapsulated of n-eicosane as phase change material (MEPCM) and thermophysical properties of this slurry such as density, heat capacitance, thermal conductivity, and dynamic viscosity. The results revealed that increasing the fraction of Al_2O_3 lead to improving the thermal conductivity and enhanced thermal performance. Hasan *et al.* [7] Numerically investigated the performance of micro-channel heat exchanger of counter flow type using nanofluid of (Al_2O_3- water and Cu-water) as a coolant. The volume fraction values of nanofluids (1, 2, 3, 4, and 5)%. The obtained results showed that enhancement thermal performance of counter flow micro-channel heat exchanger (CFMCHE) with nanofluid as a coolant with acceptable increasing in pressure drop because of using proper volume fraction of nanoparticles and ultrafine nanoparticles. At low flow rate, the findings also revealed that thermal performance of (CFMCHE) with nanofluid (Cu-water and Al_2O_3-water)is better than that with conventional fluid due to high value of thermal conductivity of nanofluid while for high volume flow rate, the cooling performance controlled by the volume flow rate and there was no effect of nanoparticles for absorbing an extra amount of heat. The results indicated that thermal performance of (CFMCHE) had been enhanced significantly by increasing thermal conductivity of nanofluid. Amirtham *et al.* [8] Implemented a numerical study to investigate the effect of addition alumina nanoparticles (Al_2O_3) through paraffin wax that used as (PCM) with a pipe system of heat storage. Both melting and freezing rate of paraffin wax have been enhanced by adding the nanoparticle. The freezing rates of nano-PCM was fastened by (28.1, 29.8, and 33.3)% for paraffin wax with (2, 5, and 10)% Al_2O_3 nanoparticles respectively whereas melting rate was maximum enhanced 3.5% for paraffin wax with 2% Al_2O_3, as compared to the pure paraffin wax case. Interestingly, this result indicates that the volume fraction of nanoparticles is an important parameter that required considered to improve the performance of PCM in a system of thermal energy storage. Hasan *et al.* [9] Numerically studied the thermal performance for a micro pin-fin heat sink with three fin shapes (circular, triangular, and square) and micro-channel un finned heat sink. Heat transfer and flow had been studied with pure water as base fluid and nanofluids (Al_2O_3-water and Diamond-water) as coolants with volume fractions of (1, 2, 3, and 4)%. Comparison of thermal and hydrodynamic characteristics for different cooling mediums and fin shapes (circular, triangular, and square) and micro-channel un finned heat sink. Heat transfer and flow had been studied with pure water as base fluid and nanofluids (Al_2O_3-water and Diamond-water) as coolants with volume fractions of (1, 2, 3, and 4)%. Comparison of thermal and heat hydrodynamic characteristics for different cooling mediums and fin shapes

had been studied for the same value of Reynold number which ranging from 100 to 900 to keep the flow in the laminar flow zone. The obtained results indicated that the cooling performance of nanofluid (Diamond-water) is better comparing with nanofluid (Al$_2$O$_3$-water). For all nanofluid types and fins geometries, the findings show enhancement heat transfer performance for heat sink with nanofluid compared with base fluid due to increasing thermal conductivity for base fluid by dispersion nanoparticles which increasing heat dissipation but this causing high pressure drop. The results also revealed that cooling performance of heat sink with circular pin-fin is best from other fin shapes and square pin-fin causing the highest pressure drop. Altohamy *et al*. [10] Experimentally studied the effect of dispersion nanoparticles of alumina(Al$_2$O$_3$) through water on cooling storage performance. The experiments were conducted by using spherical capsules containing pure water firstly, then nanoparticles suspension through water (50 nm Al$_2$O$_3$) as NEPCM with concentration (0.5, 1, 1.5, and 2)% during the charging process. The obtained results revealed that dispersion of nanoparticle with all concentrations has been a significant effect on the thermal performance of phase change material (PCM) which leads to reducing charging time of all volumetric flow rates and the inlet temperature for heat transfer fluid (HTF). The completing charging time reduced with the percentage of (32, 28, 18, and 12)% for HTF inlet temperature -12°C and volume flow rates of 12, 10, 8, 6 lpm respectively. The results indicated also, the total time to complete the charging process at different HTF volume flow rates will decrease with increasing the nanofluid concentration and volume flow rate. Hasan [11] Compared the cooling performance of micro-channel heat sink with gradually and suddenly expanded micro-channels at different expansion lengths and expansion ratios and heat sink with straight micro-channels. Micro pin-fins for different shapes (triangular and square) had been studied to improve the heat sink cooling performance. Effects of using nanofluids (Diamond-water, Cu-water, and Al$_2$O$_3$-water) with volume fraction values (1, 2, 3, 4, and 5)% as cooling fluids on overall heat sink performance by comparing with pure water as base fluid. FVM used to solve governing equations of continuity, momentum, and energy. The results showed enhancement for the overall performance of the micro-channel heat sink (MHS) with decreasing the expansion length and increasing expansion ratio. Diverging micro-channels gives lower modification as compared with the suddenly expanded micro-channel at the same expansion ratio. Improving micro-channel heat sink cooling performance with nanofluid compared with base fluid and nanofluid (Cu-water) gives the best performance of heat transfer compared with the other two types of nanofluids studied. Micro pin-fin enhanced overall performance of micro-channel heat sink for different shapes studied but square fins are the better than triangular. The result also revealed that the enhancement of heat transfer by using micro pin- fins heat sink or expanded micro-channel heat sink is higher than the same heat sink with nanofluids. Manikandan and Rajan [12] Experimentally investigated the reduction in specific heat which occurs as a result of dispersing of nanoparticle in the base fluid such as a mixture of water- propylene glycol. This reduction could be removed by a co-addition surfactant encapsulated paraffin wax, to form hybrid nanofluid. A hybrid nanofluid contained paraffin wax which encapsulated by pluronic P-123(70-120nm diameter, with the concentration of (1-5wt.%) and 1% of sand nanoparticles volume fraction in propylene glycol-water mixture. The findings indicated that efficiency of encapsulated PCM was 84.4% as a comparison with conventional paraffin wax and with the increasing volume fraction of paraffin wax, the specific heat for hybrid nanofluid will enhance with percentage 9.1% for 5wt.% concentration of paraffin wax in hybrid nanofluid when compared with the mixture of propylene glycol-water.

They concluded that the paraffin wax concentration (1wt.%) shows optimum thermophysical properties for the hybrid nanofluid such as viscosity, thermal conductivity, and heat capacitance. Prabhu *et al*. [13] Compared experimentally between thermal storage capacity for pure paraffin wax as base PCM and paraffin wax with nanoparticles which used with a shell and tube heat exchanger. The findings indicated that using of nanoparticle enhanced the thermal energy storage due to the impact of dispersion alumina (Al$_2$O$_3$) nanoparticles through the phase change material (PCM) as compared with the pure paraffin wax. They also examined the effect of 0.833% concentration by volume of nanoparticle on solidification and melting process by comparing pure paraffin wax with nano-enhanced paraffin wax. They found that the time of melting and solidification will reduce 50% by using nanoparticles suspended into the paraffin wax. They found that the discharge efficiency enhancing 4% and the charging efficiency enhancing 6% when using nanoparticle of alumina (Al$_2$O$_3$) with paraffin wax as compared with pure paraffin wax**.** Arshad *et al*. [14] Experimentally studied the effect of round pin-fin diameter of heat sinks on the electronic devices thermal management. Input heat flux ranging from 1.6kW/m^2 to 3.2 kW/m^2 with step 0.4kW/m^2. Around pin-fin made from aluminium which considers as thermal conductivity enhancers (TCEs) and chosen with a diameter of 2mm, 3mm, and 4mm. Paraffin used as PCM with a volume fraction of (0, 0.5, and1)% that poured into the heat sinks with various configurations of pin fin. Un finned heat sink used to compare the cooling performance of PCM and (TCEs). The study analysed the cooling performance of heat sink filling with PCM to illustrate the influence of heat densities, pin-fin diameter, and volume fraction of PCM on heat capacity, thermal conductance, operation time enhancement, and latent heat phase. The experimental results revealed that a heat sink of 3mm pin fin diameter shows the best thermal performance. They concluded that the base temperature of heat sink decreased due to an increase in volume fraction and the operation time has maximum enhancement at the case with 3mm pin diameter to reach 60 °C or 70 °C at each input heat flux. Maximum thermal conductance and heat capacity of o.57W/K and 3.1 kJ/K respectively for around pin fin heat sink filling with PCM with 3mm pin diameter. For electronic devices, the passive cooling being more efficient at low input heat flux because of phase change of PCM occur during a prolonged time. The effects of working fluid inlet temperature, Reynolds number, and mixture ratio of nanoparticles of Al$_2$O$_3$-MWCNT/water hybrid nanofluid on enhancement of heat transfer coefficient are studied experimentally for mini channel heat sink by Kumar and Sarkar [15]. Volume ratios of nanoparticles are (5:0, 4:1, 3:2, 2:3, 1:4, and 0:5). Nusselt number, friction factor, pressure drop, and convective heat transfer coefficient increase by increasing fraction of MWCNT in working fluid. A maximum enhancement for convective heat transfer coefficient has been observed with MWCNT (5:0) hybrid nanofluid is 44.02% compared with water. But maximum pressure drop increased by 51.2% for MWCNT hybrid nano fluid over base fluid at mixing ratio of (5:0) MWCNT and inlet temperature of 20 °C. They concluded that nanofluid with different concentrations has better performance as compared with base fluid (DI water) and optimum mixing ratio of Al$_2$O$_3$ and MWCNT is 3:2.They also observed that inlet temperature of fluid has positive effect on heat transfer and negative effect on the pressure drop. In this paper, cooling performance of mini channel heat sink with various cooling mediums at different heat flux values has been investigated experimentally.

2. Experimental set up

Apparatus had been used for this study is shown in figure 1 which consists of a heat sink, heater, power supply, wool glass, thermocouples, a piece of copper, and data logger. A heat sink made from aluminium with dimensions (92×48×33) mm that involving sixteen channels, each channel with width W_{ch}= 2.375mm and height H_{ch}= 23mm as shown in figure 2. All sidewalls of the heat sink have been insulated by the glass wool and exposed to mixed free convection and radiation from the top only. The power supply provided the heat flux values which applied on the heat sink base. A copper piece has been used to mimic the electronic chip which adhesive with the heat sink base by using thermal paste from zinc oxide to get uniform heat flux. For all experiments the heat flux had been calculated from the following relationship:

$$q = \frac{I \times V}{A_b} \tag{1}$$

Where I: Electrical current (Ampere).

V: Voltage (Volt), A_b: Area of the heat sink base.

q: Heat flux (W/m^2).

And the temperature reduction has been calculated as

$$TR = \frac{T_{air} - T_{pcm}}{T_{air}} \times 100\% \tag{2}$$

Where TR: temperature reduction, T_{air}: heat sink base temperature with air, and T_{pcm}: heat sink base temperature with paraffin wax.

Nine thermocouples of K-type with accuracy <400 °C (0.75% ± 2.5°C), 0.26 mm wire diameter and stainless steel probe had been distributed inside heat sink. Five thermocouples located on the heat sink base for measuring the heat sink base temperature, three thermocouples located at a height from the base for measuring the fluid temperature and one thermocouple located outside the rig which measuring the ambient temperature as shown in (table 1). All these thermocouples linked to the data logger to record its temperature. Calibration of thermocouples had been conducted with thermometer by measuring the temperature of water to ensure the accuracy of thermocouple and the results show a 1% error. All experiments considered the ambient temperature approximately 20°C. Data Logger with 12 channels had been used to provide the time-temperature parameter (Model: BTM-4208SD) with accuracy (±0.4%+1°C), range (-50 to +999.9°C). It contained an SD card which recorded the temperatures at every 10 minutes as an excel sheet that displays on the laptop.

Table 1 Locations of thermocouples in mm inside heat sink with (x, y, z) Coordinates

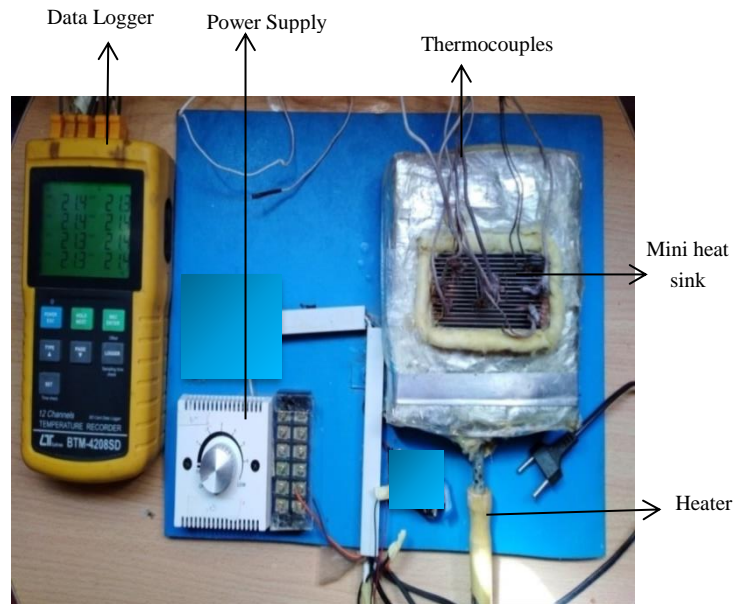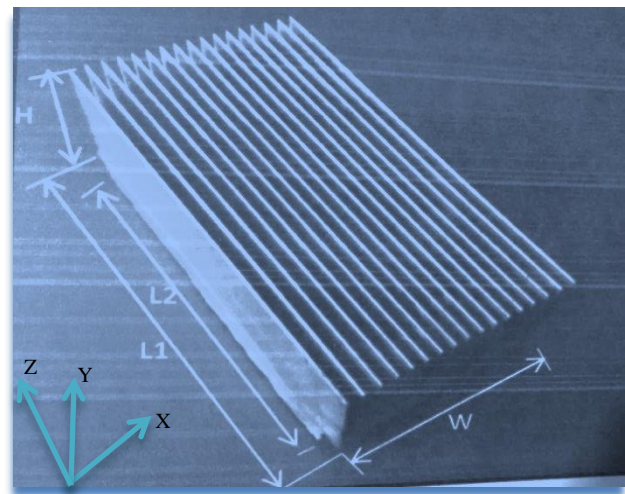| TC1	TC2	TC3
(12,0,23)	(12,0,69)	(36,0,23)
TC4	TC5	TC6
(36,0,69)	(24,0,46)	(24,13,23)
TC7	TC8	TC9
(24,13,46)	(24,13,69)	Ambient

Figure 1 Experimental set up.

Figure 2 Mini Heat Sink.

Figure 3 Electrical mixer.

3. Preparation of nanoparticles-enhanced phase change material (NEPCM) procedure

In this study, the preparation of NEPCM had been conducted by heating the required amount of paraffin wax with thermophysical properties as mentioned in table 2 until completed melting. The amount required of nanoparticle had been calculated from the following relationship which used to convert the volume fraction to mass fraction Dhaidan *et al.* [16].

$$C = \frac{C_{wt}\,\rho_{pcm}}{C_{wt}\,\rho_{pcm} + (1 - C_{wt})\rho_n} \qquad (3)$$

Where C, C_{wt} , ρ_{pcm} , and ρ_n are volume fraction, mass fraction, density of paraffin wax (kg/m^3), and density of nanoparticle (kg/m^3)respectively. Then dispersion a suitable amount of nanoparticles through the paraffin wax with continue heating and moving the mixture until reach to the temperature (30°C) above the PCM melting temperature which has melting range (MR) (50-57°C) and latent heat (λ) (179.6 kJ/kg). When the mixture temperature becomes 87°C Dhaidan *et al*. [16], the mixture is mixed by using the electrical blender as shown in figure 3 for 30 minutes until getting emulsion to retard any possible sedimentation and agglomeration.

Table 2   Thermophysical properties of materials in this study [10, 17, 18].

Material type	ρ (kg/m^3)	Cp (J/kg.K)	k (W/m.K)	μ (Pa. s)	D$_n$ (nm)
Air	1.2	1006	0.0242	1.789e^{-5}	-
Paraffin wax	773	2300	0.215	0.00063	-
Alumina (Al$_2$O$_3$)	3600	773	36	-	80
Titanium dioxide (TiO$_2$)	4156	692	8.4	-	25

4. Experimental procedure

4.1 Experiments of air

Experiments of air as coolant can be summarized by applying the heat load on the heat sink base from heater along the experiment period for all heat flux studied values.

4.2 Experiments of pure PCM

Experiments of pure PCM have been conducted by melting a suitable amount of PCM that filling heat sink. Then pouring melting PCM in the heat sink which heating to reach a temperature above the melting range of PCM.

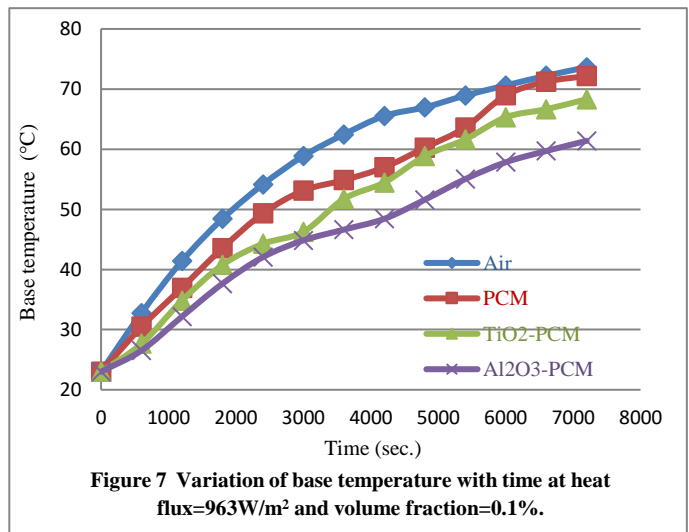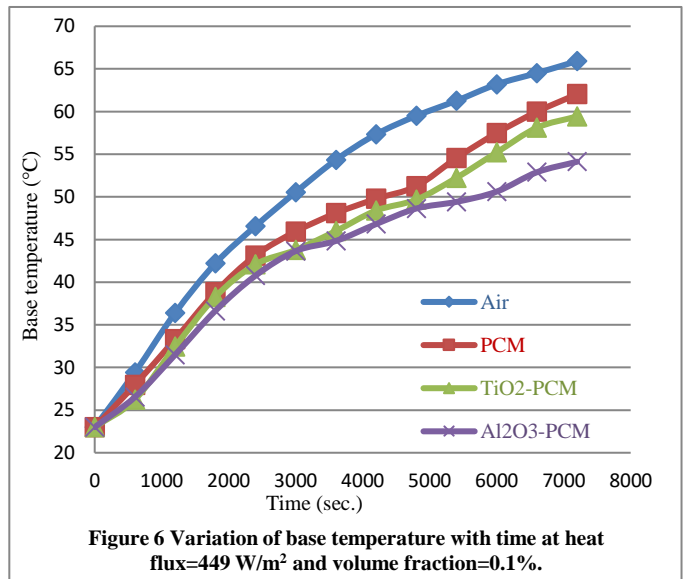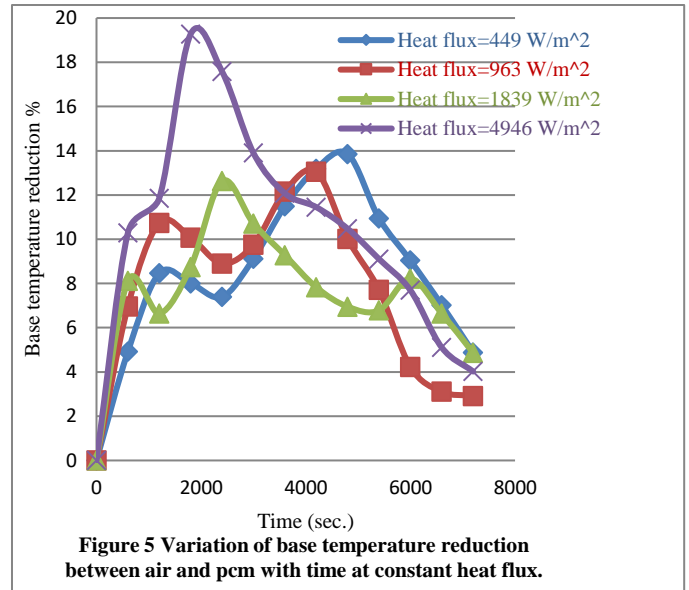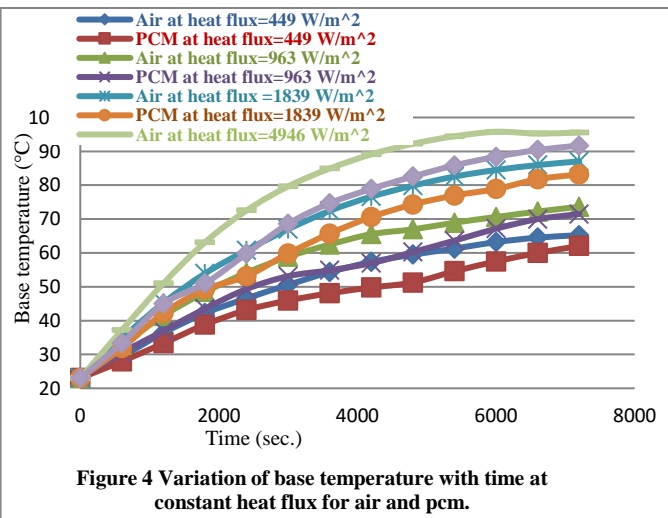### 4.3 Experiments of NEPCM

During the process of preparing NEPCM, the heater must be operated to heat the heat sink base at a temperature above that the temperature for NEPCM to prevent the formation of bubbles or voids within the NEPCM and then pouring the required amount of PCM and NEPCM inside the heat sink. Both the pure PCM and NEPCM had been remained in the heat sink until they reach ambient temperature to start an experiment. For all types of coolants, measuring the heat sink base temperature by using thermocouples linked to the data logger to record the temperature on the SD card every 600 sec for 7200 sec. These thermocouples distributed on the base and at a given height to measure the temperature of the coolants.

For every value of volume fraction of NEPCM and heat flux, these steps have been repeated.

5. Results and discussion

All experimental investigations had been carried out with air as base cooling medium, pure paraffin wax, nanoparticles-enhanced phase change material (NEPCM) with Al$_2$O$_3$, and TiO$_2$ nanoparticles at various volume fractions of (0.1%, 0.2%, 0.3%, 0.4%, 0.5%) and different heat flux values (449W/m^2, 963 W/m^2, 1839 W/m^2, 4946 W/m^2). The ambient temperature was approximately maintained at 20°C at all experiments. The experiments had been conducted on the heat sink to find the best material which showed the best efficiency for cooling electronic devices. Variation of the base temperature of a heat sink versus time for PCM and air for all values of heat flux mentioned in this study is elucidated in Figure 4. This figure explained that the base temperature increased with time for all values of heat flux and with increased heat flux due to increase the amount of generated heat at the heat sink base. At all values of heat flux, there is a reduction in temperature by using paraffin wax as a cooling medium compared with that for air as a result of absorbing an extra amount of heat by paraffin wax during melting process as latent heat. Figure 5 presents the variation of temperature reduction for the case of paraffin wax compared with air versus time at different values for heat flux. From this figure, it can be observed that there is a considerable reduction in the base temperature with paraffin wax as compared with air because of absorbing an extra amount of heat as latent heat during phase change process as explained before. Also, it can be noted that the peak values of temperature reduction happened at different times for different values of heat flux because the melting process occurred at a certain melting temperature range and increasing the value of heat flux cause increasing in paraffin wax temperature which makes the melting process started earlier. The maximum value of temperature reduction occurred at maximum heat flux which reaches 19.27 %. Variation of heat sink base temperature versus time at same volume fraction 0.1% and all heat flux values heat of (449, 963, 1839, and 4946 W/m$^{2)}$ for all cooling medium types used in this study illustrated in figures (6, 7, 8, and 9). These figures illustrated that the heat sink base temperature for all types of nanoparticles-enhanced PCM is lowest than air and pure PCM due to a higher value of thermal conductivity and density of nanoparticle-enhanced PCM. The heat sink base temperature with Al$_2$O$_3$-PCM is lower than TiO$_2$-PCM due to the Al$_2$O$_3$-PCM has a higher value of thermal conductivity and specific heat compared with TiO$_2$-PCM. Heat sink cooling performance with NEPCM for all types of nano-enhanced PCM (Al$_2$O$_3$-PCM and TiO$_2$-PCM) is most efficient from the air and pure PCM because of rising thermal conductivity of PCM when dispersing the nanoparticles through it. These nanoparticles have been contributed to a uniform distribution of the temperature through PCM which causing reduction thickness of the boundary layer hence, reducing thermal resistance of heat sink which leads to enhancement heat transfer coefficient thus, increasing heat transfer rate. Figure 10 indicates the base temperature variation with volume concentration for TiO$_2$ at different values of heat flux. This figure shows obviously that the heat sink base temperature reduced by increasing the concentration of TiO$_2$ at heat flux values (449W/m^2 and 963 W/m^2) and start with rising at higher values of heat flux (1839 W/m^2 and 4946 W/m^2) and increasing the concentration of TiO$_2$ which may causing sedimentation that forming additional thermal resistance. The variation of the heat sink base temperature with concentrations of Al$_2$O$_3$ at various values for heat flux is elucidated in figure11. At all heat flux value which applied to the heat sink base, there was a reduction in a heat sink base temperature until

concentration (0.2%) then begin to rise with increasing concentration and heat flux value which may occur because of the large size of Al_2O_3 nanoparticle as compared with the size of TiO_2 which used in this study. This large size of the nanoparticle may cause early sedimentation. Variation of heat sink base temperature with volume fraction for all nanoparticles materials and the same value of heat flux is illustrated in figure12. This figure revealed that the heat sink base temperature with TiO_2-PCM was the higher than Al_2O_3-PCM respectively until 0.2% volume fraction because of the theromphysical properties of Al_2O_3-PCM is more efficient than TiO_2-PCM. Heat sink base temperature with Al_2O_3-PCM begin to rise for all remain concentrations because of large size of nanoparticles which cause earlier sedimentation. Figure 13 shows variation of heat sink base temperature for all values of concentration and all types of nano-pcm at constant heat power. This figure indicated that the cooling performance of heat sink with Al_2O_3-PCM is better than TiO_2-PCM but by increasing volume fraction of Al_2O_3-PCM, the base temperature begins to rise due to occur sedimentation as mentioned previously. Figure 14 illustrates the impact of increasing concentration of all nano-enhanced PCM on the heat sink base temperature at the same heat flux. This figure explained that the heat sink base temperature with Al_2O_3-PCM is lower than TiO_2-PCM at 1839 W/m^2 and concentration of 0.2%. At this same heat flux value and increasing volume fraction to 0.3%, the heat sink base temperature with Al_2O_3-PCM will rise due to the effect of large size of Al_2O_3 nanoparticles. While the heat sink base temperature with TiO_2-PCM will begin to rise at o.4% due to difference in nanoparticles size between them. The variation of the heat sink base temperature with all values of concentrations for different types of nano-enhanced PCM at the highest value of heat flux elucidated in figure 15. This figure indicated that the heat sink base temperature reduced with increased concentration until reach a certain value for each type of nano-pcm and then begin to rise due to sedimentation which occurring because of increasing the value of concentration and heat flux which forming additional thermal resistance on the base of the heat sink which leads to reduced heat transfer rate. The heat sink base temperature with Al_2O_3-PCM showed minimum heat sink base temperature as compared with TiO_2-PCM due it has better thermophysical properties than TiO_2-PCM.

Figure 5 Variation of base temperature reduction between air and pcm with time at constant heat flux.

Figure 6 Variation of base temperature with time at heat flux=449 W/m^2 and volume fraction=0.1%.

Figure 4 Variation of base temperature with time at constant heat flux for air and pcm.

Figure 7 Variation of base temperature with time at heat flux=963W/m^2 and volume fraction=0.1%.
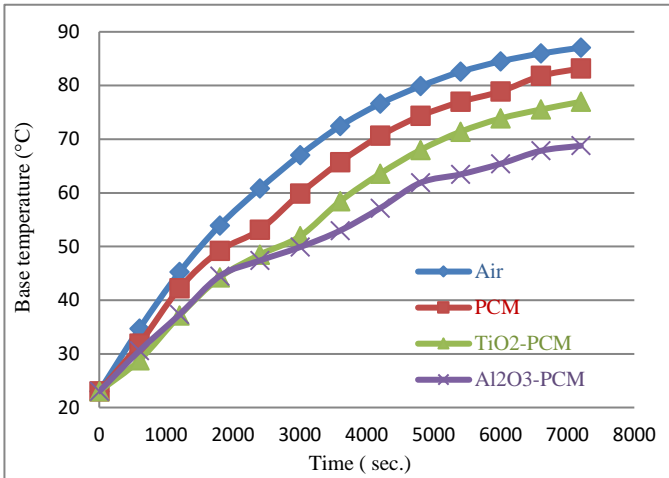
Figure 8 Variation of base tmperature with time at heat flux=1839 W/m² and volume fraction=0.1%.
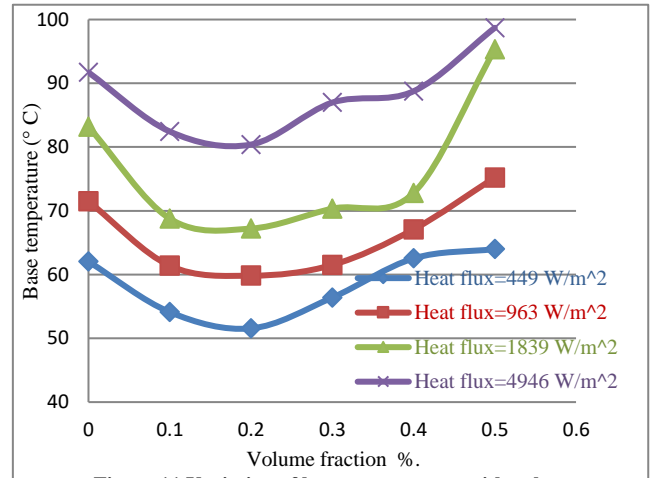

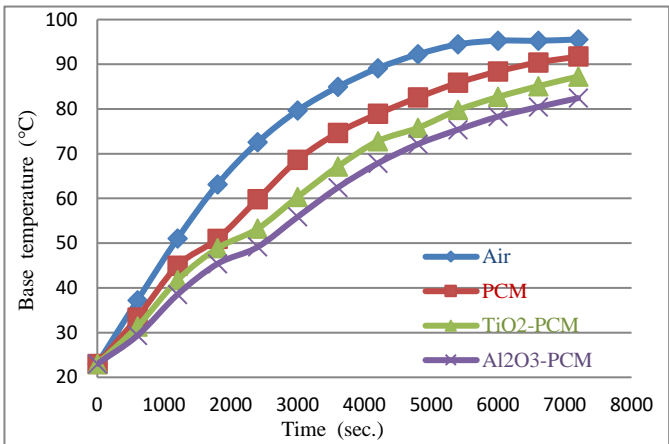**Figure 11 Variation of base temperature with volume fraction of Alumina (Al₂O₃) at constant heat flux.**

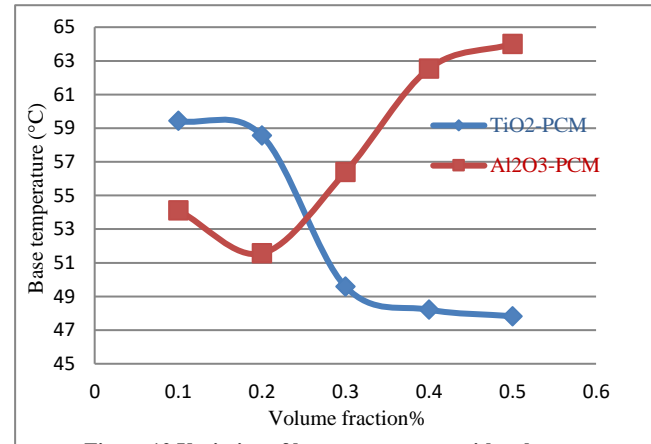**Figure 9 Variation of base temperature with time at heat flux=4946W/m² and volume fraction=0.1%.**

Figure 12 Variation of base temperature with volume fraction at heat flux=449 W/m².
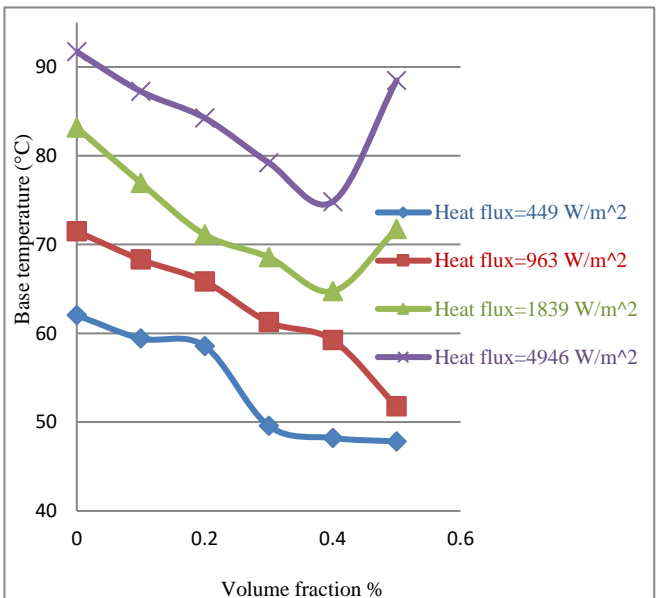

Figure 10 Variation of base temperature with volume fraction of Titanium dioxide (TiO₂) at constant heat flux.
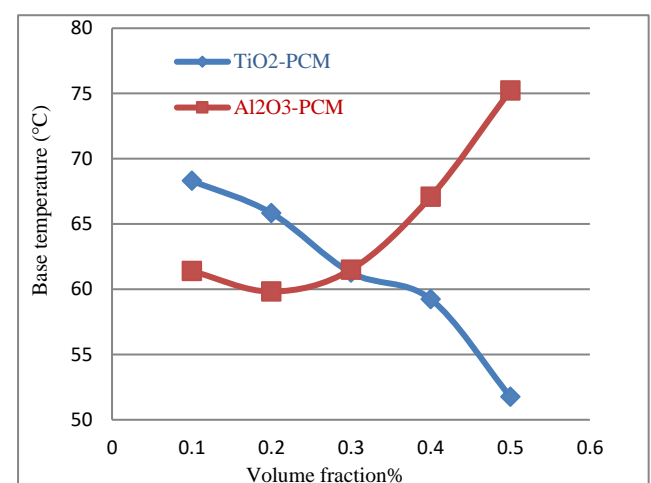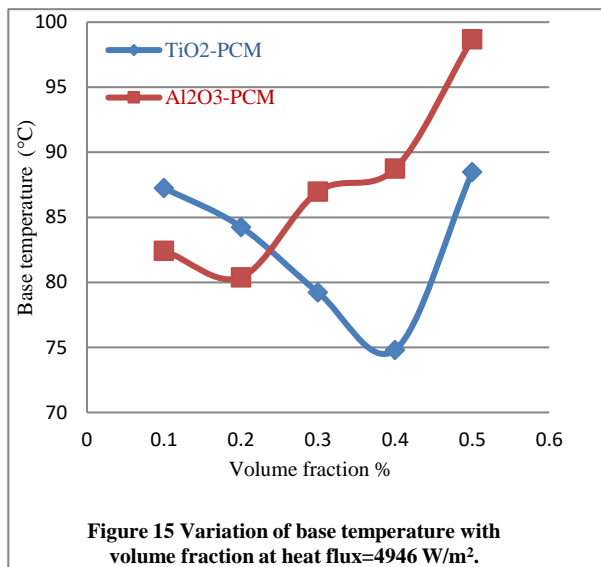

Figure 13 Variation of base temperature with volume fraction at heat flux=963 W/m².

Figure 14 Variation of base temperature with volume fraction at heat flux=1839 W/m².
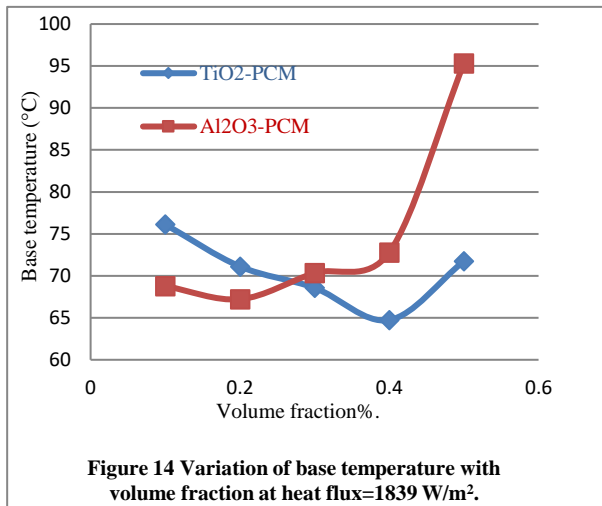

Figure 15 Variation of base temperature with volume fraction at heat flux=4946 W/m².

6. Conclusions

The present experimental study investigated the heat sink cooling performance with different cooling mediums such as air, pure paraffin wax, and nanoparticles enhanced phase change materials for electronics cooling. The impact of different volume fractions (0.1%, 0.2%, 0.3%, 0.4%, and 0.5)% of nanoparticles (Al_2O_3 and TiO_2) and heat flux values(449, 963, 1839 and 4946) W/m² on cooling performance is studied. Air had been considered as base fluid to compare the performance of other cooling mediums with it. The main conclusions presented as following:

1. Cooling performance of heat sink with PCM is more efficient than air at all heat flux values and a reduction of the heat sink base temperature is approximately 19.276% for maximum value of heat flux.

2. At all heat flux values and for all nanoparticle types, the heat sink cooling performance with NEPCM shows a great enhancement as compared with air and pure paraffin wax.

3. The results revealed that the cooling performance of mini heat sink with alumina (Al_2O_3) nanoparticles-PCM is better comparing with

titanium dioxide (TiO_2)-PCM that represented with a percentage of temperature reduction of 23.306 and 22.069% respectively as compared to air.

4. The findings indicated that the melting and solidification time will decrease with increasing the amount of heat power and the concentration by volume of all materials which contribute to distribute temperature distribute temperature uniformly.

5. The experimental results elucidated that by increasing dispersion of volume fraction of all nanoparticle material types, the cooling performance enhancement is increased at all values of heat flux but the excess addition of nanoparticles will lead to increase viscosity that decreased heat transfer rate and giving negative effect.

6. The experimental results of the present study indicated that dispersing a suitable volume fraction of nanoparticles in pure PCM showed a high potential for enhancing the heat transfer characteristics of cooling mediums.

REFERENCES

[1] Shakuntala Ojha, "CFD analysis on forced convection cooling of electronic chips" , National Institute of Technology. Rourkela 2009, A thesis for the degree of master of technology (research) in mechanical engineering.

[2] D.P Tuckerman and R.F.W Pease, "High-Performance of Heat Sinking for VLSI", *IEEE Electron Device Letters,*Vol. 2, No. 5, pp. 126-129,1981.

[3] Yoav Peles, Ali kosar, Chandan Mishra, Chih-Jung Kuo, and Brandon Schneider, "Forced convective heat transfer across a pin fin micro heat sink". International Journal of Heat and Mass Transfer, Vol. 48, pp.3615-3627, 2005.

[4] G.H. Tang, zhuo Li, Y. L. He, and W.Q. Tao, "Experimental study of compressibility, roughness and rarefaction influences on micro channel flow", International Journal of Heat and Mass Transfer,Vol. 50, pp. 2282-2295, 2007.

[5] Sarada Kuravi. "Numerical Study of Encapsulated Phase Change Material (EPCM) Slurry Flow in Microchannels", University of Central Florida Orlando 2009 Dissertation for the degree of Doctor of Philosophy in Mechanical Engineering.

[6] C. J. Ho, J. B. Huang ,P.S. Tsai, and Y. M. Yang, "Preparation and Properties of hybrid water-based suspension of Al_2O_3 nanoparticles as functional forced convection fluid".,International Journal of Heat and Mass Transfer, Vol. 37 PP. 490-494, 2010.

[7] Mushtaq I. Hasan, Abdul Muhsin A. Rageb, and Mahmmod Yaghoubi, "Investigation of a Counter Flow Microchannel Heat Exchanger Performance with Using Nanofluid as a Coolant", Journal of Electronics Cooling and Thermal control, Vol. 2, pp. 35-43, 2012.

[8] Valan Arasu Amirtham, Sasmito Agus P., and. Mujumdar Arun S., "Numerical performance study of paraffin wax dispersed with alumina in a concentric pipe latent heat storage system", Thermal science, Vol. 17, No. 2, pp.419-430, 2013.

[9] Mushtaq Ismael Hasan, "Investigation of flow and heat transfer characteristics in micro pin-fin heat sink with nanofluid", Applied Thermal Engineering, Vol. 63, pp. 598-607, 2014.

[10] Ahmed A. Altohamy, M. F. Abd Rabbo, R.Y. Sakr, and Ahmed A.A. Attia, "Effect of water based Al_2O_3 nanoparticle PCM on cool storage performance", Applied Thermal Engineering, Vol. 84, pp. 331-338, 2015.

[11] Mushtaq Ismael Hasan, "Study of Microchannel Heat Sink Performance with Expanded Microchannel and Nanofluids", Al-Qadisiyah Journal For Engineering Sciences, Vol. 9, No. 4, 2016.

[12] S. Manikandan and K.S.Rajan, "New hybrid nanofluid containing encapsulated paraffin wax and sand nanoparticles in propylene glycol- water mixture: Potential heat transfer fluid for energy management"., Energy Conversion and Management Vol.

137, pp. 74-85, 2017

[13] Selva Prabhu ,Vijay, Chermakani, Gopalasubramanian, Herc, and Beniyel. "Nano Enhanced Phase Change Material for Thermal Energy Storage Application". International Research Journal of Engineering and Technology (IRJET), Vol. 5, pp. 2395-0056-0072, 2018.

[14] Adeel Arshad, Hafiz Muhammad Ali, Shahab Khushnood, and Mark Jabbal, "Experimental investigation of PCM based round pin-fin heat sinks for thermal management of electronics: Effect of pin-fin diameter", International Journal of Heat and Mass Transfer, Vol. 117, pp. 861-872, 2018.

[15] Vivek Kumar and Jahar Sarkar, "Particle ratio optimization of Al_2O_3 MWCNT hybrid nanofluid in minichannel heat sink for best hydrothermal performance", Journal of Applied Thermal Engineering, Vol. 165, 25 January, 114546,2020.

[16] Nabeel S. Dhaidan , J. M. Khodadadi, Tahseen A. Al-Hattab, Saad M. Al-Mashat, "Experimental and numerical investigation of melting phase change material /nanoparticle suspensions in a square container subjected to a constant heat flux", International Journal of Heat and Mass Transfer ,Vol. 66, pp. 672-683,2013.

[17] Ali Akbar Ranjbar, Sina Kashani, Sayed Farid Hosseinizadeh, and Morteza Ghanbarpour, "Numerical Heat Transfer Studies of A latent Heat Storage System Containing Nano-enhanced phase change material", Thermal Science, Vol. 15, No. 1, pp. 169-181, 2011.

[18] C. Kaviarasu, and D. Prakash. "Review on Phase Change Materials with Nanoparticle in Engineering Applications. ", Journal of Engineering Science and Technology Review, Vol. 9, No.4 , pp. 26-386, 2016.