EXPERIMENTAL INVESTIGATION ON THERMAL PERFORMANCE OF PLATE FIN HEAT SINKS WITH NANO PCM

by

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In this study, electronic devices are experimentally examined to improve the thermal performance of the plate fin heat sink. It is performed on the basis of the paraffin wax used as a phase change material (PCM) filled in a heat sink plate. The aim of the study is to select the most efficient SiO_2 volume fraction in paraffin wax to be filled in a heat sink with a plate finish. The SiO_2 is considered to be a nanoparticle and 1%, 3%, and 5% of SiO_2 volume is selected for the preparation of nanoPCM. At the base of the plate fin heat sink, a constant heat source is applied. A plate fin heat sink is selected to quantify the effect of nanoPCM as a reference heat sink. The effect of thermal performance of heat sinks was examined using a different volume fraction of nanoPCM. The thermal performance comparison is carried out with and without PCM for the plate heat sink of Reynolds number 4000-16000. In order to find the effect of PCM and variable Reynolds number, the investigation of the plate fin heat sink is examined. The results showed that the inclusion of PCM (paraffin wax and SiO_2-based nanoPCM) in the heat sink plate provides better cooling performance and keeps the desired temperature. The results show that the heat sink based on PCM enriched with nanoparticles provided better thermal performance compared to the heat sink with a simple PCM. The thermal performance of the SiO_2 based nanoPCM 3% volume fraction is better than 1% volume fraction and the heat sinks of the plate finish.

Key words: *plate fin heat sink, SiO_2 based paraffin wax, electronics cooling, Reynolds number*

Introduction

All electronic devices generate excess heat with the rapid development of electronic technology so that the operating temperature of the devices exceeds the desired temperature level. Now one day the electronic device's features increase and size decreases, increasing power density. The reliable operation of electronic devices therefore reduces and leads to early failure. Thermal management is very important in this scenario in order to improve reliability and prevent failure. For heat dissipation, it requires a small external surface area. Cooling techniques such as thermoelectric coolers, heat pipe [1, 2] and jet impingement [3] are available. In addition to improve cooling techniques, the investigation of PCM based heat sinks have been studied in recent times. During the melting process of PCM at a constant temperature, it absorbs an enormous amount of thermal energy which enhances the cooling effect. In addition to improve cooling techniques, the investigation of PCM based heat sinks have been studied in recent

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times. During the melting process of PCM at a constant temperature, it absorbs an enormous amount of thermal energy which enhances the cooling effect. In this literature, three categories of research on air-cooled heat sinks, heat sinks with dimples/protrusion and heat sinks based on PCM are comprehensively available. In this literature, three categories of research on air-cooled heat sinks, heat sinks with dimples/protrusion and heat sinks based on PCM are comprehensively available. Many researchers focused on the new design of the heat sink, the effect of the fine profile, the cross-cut heat sink, different fine parameters and the addition of porous surfaces. Saravana Kumar [4] and Govindasamy *et al.* [5] said that emission reduction can be done by using corn oil and Spirulina algae. Mousa *et al.* [6] researched the air-cooled heat sink with various square modules. Li *et al.* [7] conducted experimental work on heat sinks under cross-flow conditions and studied the effects of Reynolds number, fin width and fin height on thermal resistance and drop in pressure. Wu *et al.* [8] developed an asymptotic model for a variety of Reynolds numbers, including laminar, transition, and turbulent flows to calculate the thermal performance of the plate fin heat sink. Optimum values of base thickness, base width, base length, fin pitch, and fin thickness have also been recommended. Kim *et al.* [11] and Kim and Webb [12] studied experimentally the effects of cross-cutting on heat sink thermal performance. They ranged from 0.5 mm to 10 mm in the cross-cut range and tested conventional parallel plate fin, single cross-cut and multiple cross-cut. The thermal performance of single cross-cut heat sinks was better than multiple cross-cut heat sinks. Mohan *et al.* [13, 14] and Mohan [15] have studied the performance of slot parallel plate fin heat sink, double base plate heat sink, elliptical fin heat sink, pin fin heat sink with various base plate materials and un uniform fin width heat sinks with nanocoating. Also studied was the effect of the base plate on the heat sink thermal performance. The results of the experiment are compared to the results of CFD. The few researchers deal with foam heat sink to enhance the system's thermal performance. Srivatsa *et al.* [16] investigated the thermal performance of PCM-based aluminum foam heat sinks and crossed plate fins in natural and investigated the effect of variable pores per inch of metal foam. Gopalan *et al.* [17] the thermal performance of PCM-based heat sinks was numerically investigated using structured porous media as a thermal conductivity enhancer. The results indicated that the heat sink with porous structured media as TCE had a significantly better performance than heat sink with pure PCM consistently. Furthermore, the heat sink performance is explicitly dependent only on the effective thermal conductivity. Pakrouh *et al.* [18] conducted a numerical investigation into the geometric optimization of PCM-based pin-fin heat sinks and the results show that there is a complex relationship between PCM and TCE percentages and optimal PCM percentages. Gharbi *et al.* [19] made an experimental presentation of the behavior of PCM as the electronic component cooling system. Based on their results, the use of graphite matrix filled PCM in heat sink showed better thermal system performance than the silicon matrix. Kalbasi [20] assessed the design of PCM enclosures used for electronic cooling equipment. They found that it is better to use a wider enclosure than the square and thin enclosure for a rectangular enclosure with a constant area. Levin *et al.* [21] presented a procedure for optimizing the design of PCM-based heat sink with internal fins. The 2-D, three-parametric, finite element simulations were performed, with the number and thickness of the fins being systematically varied and the results showed optimal PCM percentages depending on the number and length of the fins, the interface heat flux and the difference between the PCM critical and liquid temperature. Hosseinizadeh *et al.* [22] studied the performance of PCM-based heat sinks with various internal fine configurations experimentally and numerically. Their results showed that the overall thermal performance was significantly increased by increasing the number of fins and fin height. Kandasamy *et al.*, [23] investigated the use of PCM-based heat sinks in the transient thermal control of electronic quad plastic packages. They found that for higher power levels the increase in thermal performance and melting rate until the PCM, paraffin wax, is fully melted. Baby *et al*. [24] tested the PCM-based finned heat sinks for electronic cooling equipment. They conducted study on heat sinks of un-finned and finned cases where a uniform heat load is applied and the results indicate that the operating performance of portable electronic devices can be significantly improved by using PCM heat sinks with fins. Kumar *et al.* [25] carried out computational analysis and optimization of spiral plate heat exchanger. Qu *et al.* [26] investigated rectangular dimple channel flow and heat transfer characteristics. From the results, they suggested that the dimple and dimple depth increase the heat transfer. Moon *et al.* [27] tested convective heat transfer and pressure drop in a square channel with concave and cylindrical dimple wall for turbulent flow. The results suggested that the configuration of dimple is better than concave dimples of the same size. Similar work on PCM-based SC heat sink with dimples and protrusion is less focused. Lan *et al*. [28] studied the flow characteristics and heat transfer performance of a rectangular micro-channel with dimples and protrusions numerically. The plate fin heat sink is selected in this work and the effects of different volume fractions of SiO_2 nanoparticles in paraffin wax on the thermal performance of the plate fin heat sink are investigated experimentally. Additionally, the performance of the heat sink without PCM is compared with the plate fin heat sink of the PCM. This paper suggested that the heat sinks filled with nanoPCM and PCM provide stable performance, and these studies also contribute to finding the best heat transfer heat sink based on the PCM. Avudaiappan *et al.* [29] analyzed the flow using simulation method. Dhandayuthabani *et al*. [30] Inclusion of graphite to the medium increases stability and thermal conductivity of PCM [31].

Experimental set-up and procedure

To examine the thermal performance of the PCM-based heat sink, an imaginative experimental set-up is established. It is displayed in fig. 1. An experimental set-up is arranged as a heat source for imitating a processor with an electrical heater of 25×25 mm size and supplied by DC power supply. A heater strip was mounted on a circuit board piece that was mounted on an insulation piece in turn. The insulation was machined so that the heater's top surface lies just below the isolation's top surface. To allow power routing and thermocouple wires to minimize free stream interference in the vicinity of the heat sink, the insulation was drilled or milled. The heater is fastened with heat sink using anabond compound with thermal conductivity of 0.437 Wm/K and wake field thermal compound with thermal conductivity of 0.735 Wm/K is applied to the heat sink's contact surface for proper surface contact between heat sink and heater. The heat sink rejects the heat that is enhanced by placing the blower in the air. The area covered by

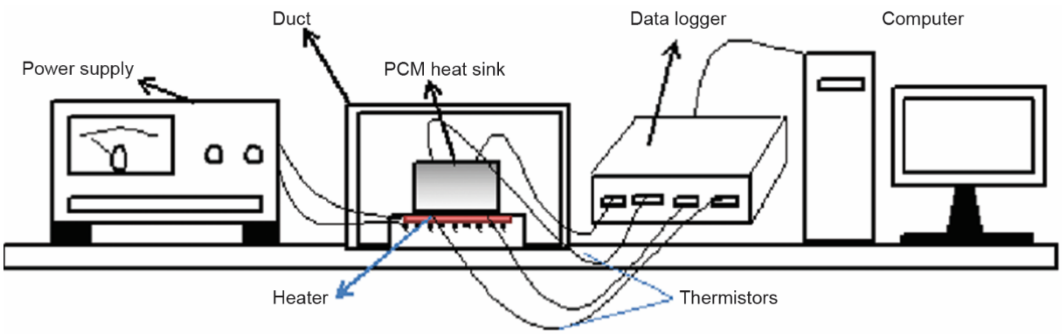

Figure 1. A Schematic diagram of the experimental set-up

the resistance coils (on the heat strip) is less than the heat sink base area, so that the heat sink's bottom surface covers the active heat sink section completely. Using data acquisition unit, the temperature change is measured accurately. In a spreadsheet manner, the temperature values are noted in the computer via a LAN cable. Between consecutive readings, a 10 seconds time interval is set and the total time for a reading set is set at 120 minutes. Ten thermocouples of type K are used to record changes in temperature. These thermocouples are calibrated with a maximum error of ±0.1 ºC [31, 32] reported from previous investigations. The heat sink base temperatures are measured in this experiment, which is used to compare the performance of the heat sink. The four B1 to B4 thermocouples are placed at all sides of the heat sink at a distance of 25 mm in the heat sink base. Four other thermocouples are located to measure temperatures outside of all sides of the wall. To interpret results, the mean value of both of these values is used.

Heat sink configuration

The PCM filled heat sink configuration schematic diagram is shown in fig. 2. In this work, aluminum materials are selected and finished with 80×40×15 mm thick base heat sink. In this geometry, 8 mm fin pitch, 55 mm fin height and 8 3 mm thick aluminum fins are built over the sink to form seven cavities. Inside the cavities, the solid PCM is filled. The PCM are filled up to a depth of 40 mm in heat sink. The heat sink's tops are closed.

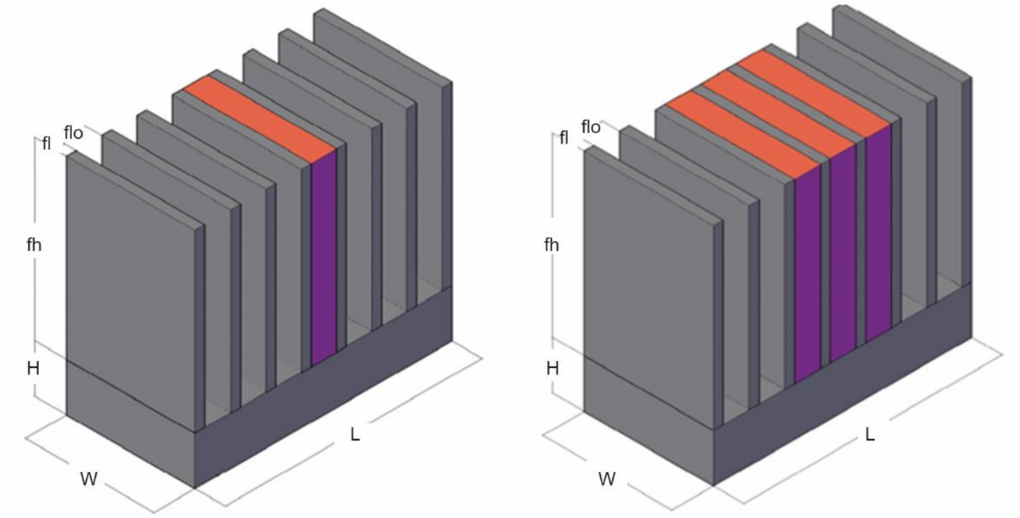

Figure 2. The schematic diagram of the heat sink configuration

Figure 3 shows the set-up made from a 300×100×100 mm glass box. It was separated by two metallic plates as three sections. It has three sections like section of the hot bath, section of the PCM and section of the cold bath. This set-up also includes two electrical systems to keep temperature and temperature measurement in the PCM section of the hot bath section. The materials used as PCM in this experiment: paraffin wax; nanomaterials – SiO_2; and medium for heating and cooling – water. Initially, the PCM was melted using a heater in a glass jar, then they are poured into the middle section of the glass box and allowed to cool for the ambient temperature that would take about a day. Then, a heater with a temperature cut-offer was introduced for the hot bath section, which maintains the temperature at 80 ºC. The thermal samples were inserted into the PCM during the liquid state. The temperature readings were collected using an Arduino board and added every 2 seconds to the excel sheet – on PLX-DAQ.

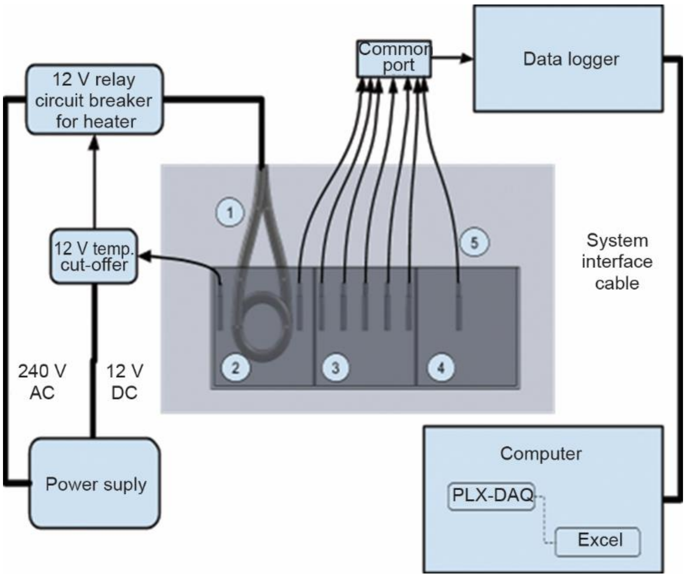

Figure 3. Thermal conductivity experimental set-up arrangement

Thermal conductivity set-up design and test on nanoenhanced PCM

The experiment was conducted four times with 0%, 1%, 2%, 3%, 4%, and 5% concentration of nanomaterials. At successive intervals, five temperature sensors were placed on the PCM. Using EXCEL sheet, the individual thermal conductivity was taken at different concentrations. The 1% concentration of nanomaterials was found to increase the thermal conductivity but it was found that the increasing concentration decreased the thermal conductivity of PCM. It is displayed in fig. 4.

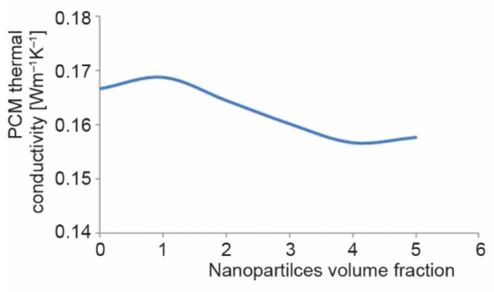

Figure 4. Thermal conductivity of PCM to volume fraction of nanoparticles

Results and discussion

Base temperature comparison

The temperature gain at the heat sink base is important in this study as it imitates the surface of the IC. While the base temperature is low, the heat transfer rate is increased, implying that any electronic device performs well. To select the best heat sink configuration, the experimental analysis is conducted to compare the performance of heat sink with and without PCM. The variation in base temperature with time for the plate fin heat sink and PCM filled SCHS, TCHS and FCSH is illustrated in figs. 5-8. These figures clearly show that the plate fin heat sink's base temperature is higher than the heat sinks filled with PCM. The base temperature of heat sink is decreased for PCM filled heat sinks due to PCM melting it absorbs more amount of heat energy as a latent heat. Although the PCM has low thermal conductivity, the plate fin material is balanced to enhance the heat transfer performance. The figure shows that with and without PCM and SiO_2 based PCM, the variation of base temperature with time for plate fin heat sinks. It can be observed for all cases that, with time, the base heat sink temperature increased and then reached a stable state in between 150 minutes and 180 minutes. The power supply is therefore stopped at 180 minutes. It can be noted that the temperature of PCM filled heat sinks is lower than that of plate fine heat sinks due to PCM absorbing more heat energy from the heat sink base. The PCM filled heat sink therefore clearly shows a lower temperature value. Figures 5-8 shows the higher base heat sink temperature without PCM compared to heat sinks from SCHS, TCHS, and FCSH. The PCM stored more heat energy, including the heat sink in the cooling, to release it back into the environment. So heat sinks based on PCM slowly release the heat energy and heat up at a slower rate as well.

From fig. 5 showing the comparison of the base temperature for SCHS, TCHS, and FCHS based on PCM for Re = 4000 in the heat sink of the plate fin. PCM-based heat sink is easily predicted to be significantly cooler during the heating phase than without PCM in fig. 5.

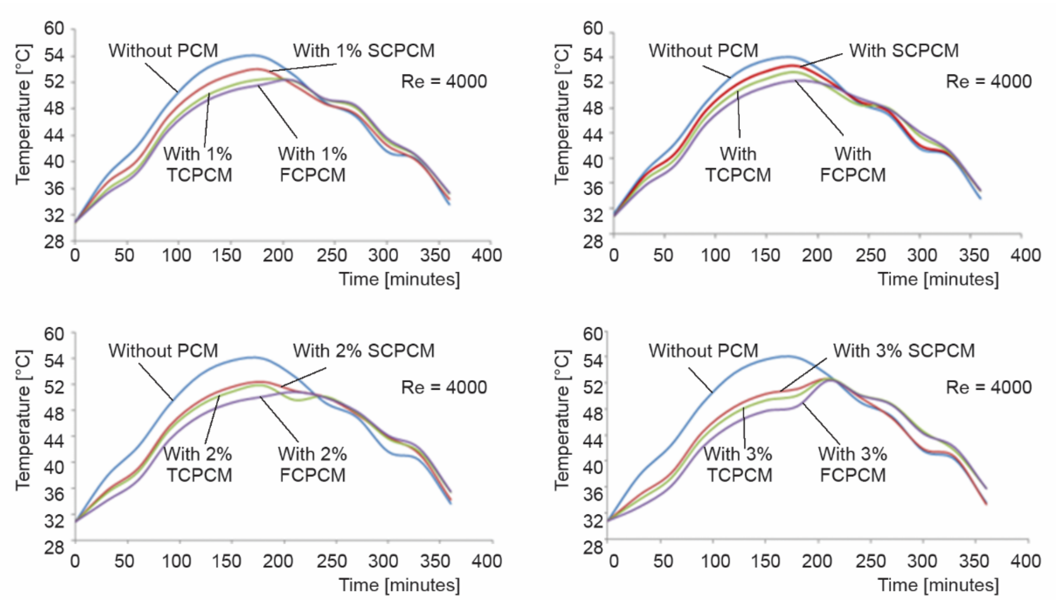

Figure 5. The variation of base temperature with time for the plate fin heat sink and PCM filled HS at Re = 4000

It can therefore be noted that PCM heat capacity is increased by increasing single cavity PCM to 5 cavity PCM sink heat. The heat source was removed at 180 minutes, however, the PCM heat sink cooled down at a lower rate than that without PCM. It is observed that, compared to the heat sink of the plate fin, the base temperature is significantly reduced in PCM-based FCHS. The temperature of the TCHS and SCHS is also relatively low. The base temperature of the PCM-based FCHS is higher than the plate fin heat sink during the cooling process. The base temperature of TCHS and SCHS is slightly the same as the heat sink of the plate fin expects a cooling time of between 270 and 330 minutes. Thus, during this time unpredictable variations in temperature can be observed. Figure 5 shows that for Re = 4000, the plate fin heat sink base temperature comparison with 1% SiO2 based PCM heat sink mass fraction. In the case of 1% FCPCM heat sink, the lower base temperature is achieved. For 1% TCPCM and

FCPCM heat sinks, the base temperatures are comparatively the same. It is evident during the solidification process that the TCPCM base temperature and the plate fin heat sinks are identical. From fig. 5 it is found that some fluctuation of base temperature in SiO2-based PCM heat sinks due to small cavity in PCM that occurs from mass transfer in two different concentrations at the beginning of the cooling stage and SiO2 trying to settle down at the bottom of the sink.

Figure 5 shows the prediction of variation of base temperature in plate fin heat sink with a mass fraction of 2% SiO_2 based PCM heat sink for Re = 4000. It is clearly identified that the 2% SiO_2 based PCM FCHS base temperature is lowered compared to all cases. Significant closure to SCHS is the base temperature of 2% based PCM TCHS. The base temperature of 2% SiO_2 based PCM FCHS higher than PFHS and other cases during the cooling process. It is because more latent heat energy is contained in SiO_2 -based PCM. Figure 5 implies that plate fin heat sink base temperature is compared to 3% SiO_2 based PCM heat sink mass fraction for Re = 4000. The 3% SiO_2 based PCM FCHS base temperature is very low in all cases. It is observed that for 3% PCM SCHS, and TCHS based on SiO_2 it has less base temperature deviation. The base temperature of 3% SiO_2 based PCM FCHS as compared to PFHS and other cases during the solidification process. In cases, there is no significant variation in TCHS and SCHS base temperature.

Compared to PCM based SCHS, TCHS, and FCHS for Re = 8000, the base temperature of the plate fin heat sink is shown in fig. 6. Obviously, PCM-based FCHS has a lower base temperature in all cases. By increasing Reynolds number, the base temperature of PCM based SCHS, and TCHS is comparatively the same during cooling with a plat fin heat sink. Therefore, the base temperature of the PCM based FCHS is slightly higher than the heat sink of the plate fin.

Figure 6 shows that influences of 1% , 2%, and 3% SiO_2 based PCM heat sinks on the base temperature at Re = 8000 compared with plate fin heat sink. In all cases, it is observed that 1%, 2%, and 3% SiO_2-based PCM FCHS base temperature is low. There is considerable deviation for 1% of SiO_2-based PCM, SCHS, and TCHS at Re = 8000. However, the figure shows

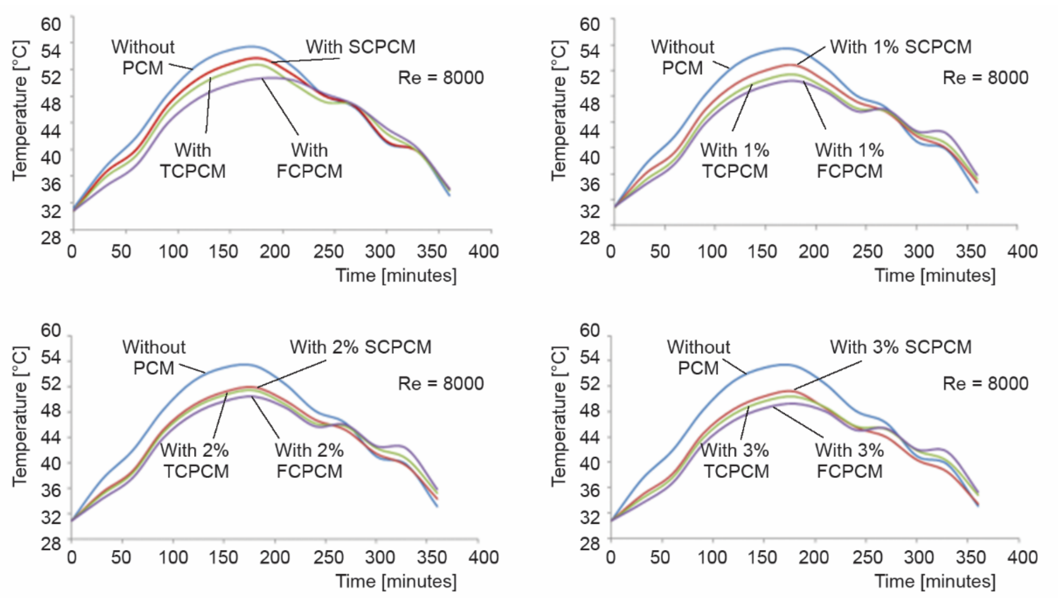

Figure 6. The variation of base temperature with time for the plate fin heat sink and PCM filled HS at Re = 8000

that 2%, and 3% of SiO_2-based PCM, SCHS, and TCHS at Re = 8000 are irrelevant at base temperature. It is also clearly revealed during cooling that the base temperature of PCM FCHS based on SiO_2 is higher than in all other cases.

Figures 7 and 8 discuss the base temperature of paraffin wax heat sinks and 1%, 2%, and 3% SiO_2-based paraffin wax filled with SCHS, TCHS, and FCSH at Re = 12000 and

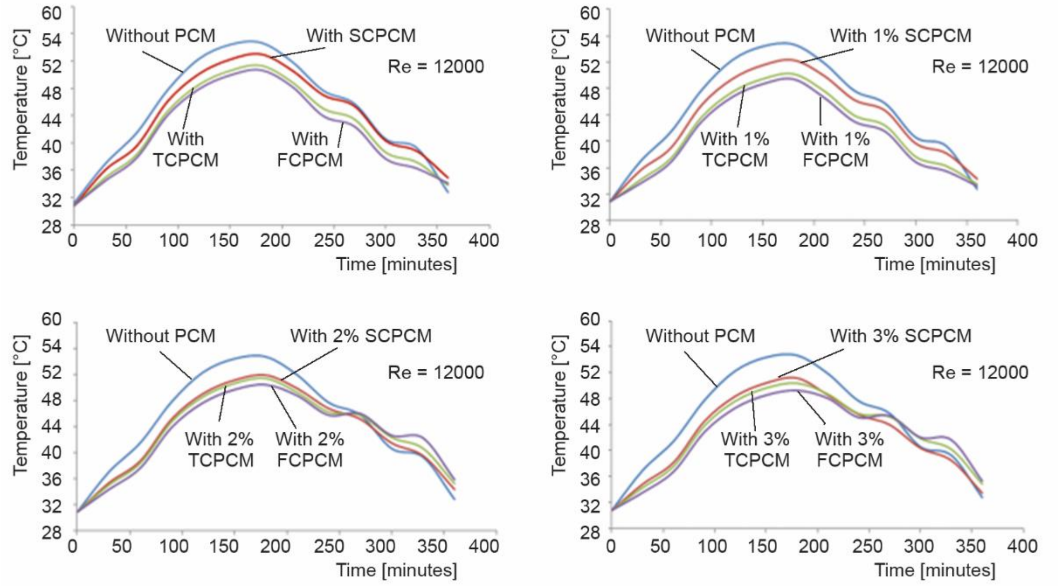

Figure 7. The variation of base temperature with time for the plate fin heat sink and PCM filled HS at Re = 12000

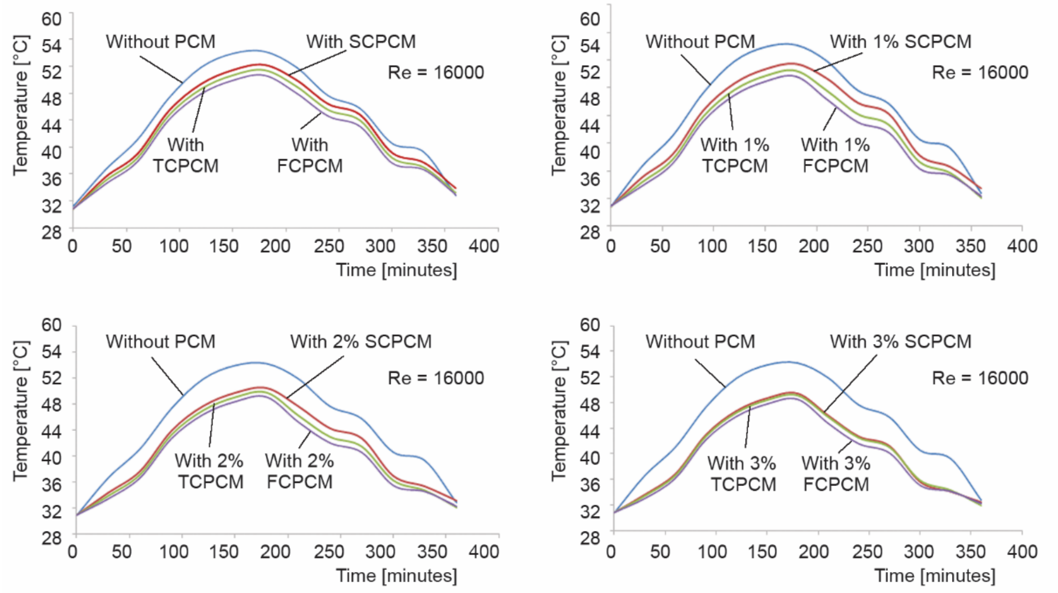

Figure 8. The variation of base temperature with time for the plate fin heat sink and PCM filled HS at Re = 16000

Re = 16000. The PCM-based FCHS is observed to have lower base temperature in all cases. In the case of PCM and 1% SiO_2 PCM filled TCHS and FCHS at Re = 12000, the basic temperatures are comparable. However, the base temperatures are the same for 2% and 3% of SiO_2 PCM filled SCHS, and TCHS at Re = 12000. After 180 minutes, the cooling process is shown in figure. It reveals that the PCM and SiO_2 based PCM filled FCHS base temperature is lower than any other case. The more heat transfer is achieved as the number of Reynolds increases. During the cooling process, 3% of SiO_2 PCM filled TCHS and FCHS released the heat slowly compared to 1% of SiO_2 PCM filled SCHS and without the heat sink of PCM.

Conclusion

The experiments were conducted in this study to evaluate the effect of adding SiO_2 nanoparticles to the paraffin wax in a heat sink with a plate fin. The experimental device is made without PCM and SiO_2 based PCM with a constant input power of 70 W of plate fin heat sink configuration. Plate fin heat sink thermal performance with paraffin wax remained dominant over the PCM-free. Plate fin heat sink thermal performance with PCM has significantly improved and the PCM absorbs more heat energy to lower the base heat sink temperature. The addition of SiO_2 nanoparticles in paraffin wax has resulted in a greater impact on the temperature of the heat sink, according to the results. The results show that 2% of SiO_2 nanoparticles have an effect on paraffin wax in a plate fin heat sink. Increasing Reynolds number enhances the thermal performance of SiO_2 -based PCM heat sink. The heat sink thermal performance at Re = 8000 is comparable to Re = 12000 for all cases. In this analysis, it concluded that 3% thermal performance for all Reynolds number based on SiO_2 PCM TCHS and FCHS is better.

Nomenclature

PCM – phase change material
SCHS – single cavity heat sink
TCHS – three cavity heat sink
FCHS – five cavity heat sink
PFHS – plate fin heat sink
SCPCM – single cavity phase change material
TCPCM – three cavity phase change material
FCPCM – five cavity phase change material

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