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Investigation Thermal Performance of Heat Sink by Using Metal Foam Partially Immersed in PCM

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A B S T R A C T

This research includes a practical investigation on the impacts of adding phase change materials (PCMs) into metal foam made from copper in heat sinks, as well as using metal foam alone during heating and cooling. This study used RT55 paraffin as a phase change material. Five cases were used in the experiments. Each one contained a varied quantity of PCM and copper metal foam, in addition to the centrifugal fan-forced airflow inside the device duct and electrical heating of a plate made of copper under the thermal dissipator. This study looked at the impact of thermal energy and intake air velocity coefficients on five heat sink cases Throughout the process of heating and process of cooling. The findings indicate that in the situation of copper foam (case 3), The copper plate has a lower temperature relative to the other instances. During the heating procedure, cases 5 (Paraffin partly filled copper foam) and 3 (2-piece foams made of copper) showed percentage temperature reductions of 57.46% and 66.4% respectively, when compared to case 1 (Absent paraffin or copper foam). During the process of cooling, the high conductivity for copper foam results in case 3 having temperatures that are 43.5% lower than that of case 5, which is 34.7%. furthermore, raising the input air velocity includes less of an impact on heating reduction in scenarios involving phase change materials (PCMs).

1. Introduction

The earlier research investigations provide the reader with a summary of heat sinks. In today's digital era, electronics that are becoming more integrated and smaller in size guarantee that devices will work efficiently and last longer. The performance times of some electrical equipment have deteriorated because of inadequate thermal management (TM). The study states that to increase the cooling effectiveness of electronic equipment, the heat created in electrical circuits must be dissipated promptly [1], [2], [3], [4], [5], [6], [7], [8], [9]. Kandasamy et al. [10] conducted combined numerical analyses and experimental. Experimental research was done on the heat transfer properties of a PCM-based heat sink mounted on a quad flat package (QFP) electronic device. The results were compared to those of a pure heat sink without PCMs included. Both the die junction temperature and the designated local temperature within PCMs were monitored. In addition, the problem was simulated using A 3-dimensional fluid dynamics computational simulation that showed good agreement with experimental results. The findings suggest that PCM-based heat sinks might be employed in devices with sporadic use. Feng et al. [11] studied the effect of heat sink height on heat transmission and pressure reductions in finned metal foam (FMF) heat sinks. The two were compared in a performance comparison of FMF heat sinks and MF heat sinks at certain rates of flow and power pump parameters. A computational model for FMF heat exchangers FMF heat sinks was created using the extended laminar Darcy model to analyze the flow of fluid in porosity foam. This model tests Jet Reynolds numbers ranging from 3000 to 12000, also had been further employed to investigate used to explore in depth the effects of the intake thermal boundary connecting substance between plate fins and metal foams. Comparative numerical data and experimental results indicate that a laminar Darcy's expanded model effectively predicts each pressure loss and heat transfer in MF and FMF heat sinks. At elevated Reynolds numbers, provided that the foam specifications are accurately specified. Hayat et al. [12] examined RT-35HC in which the melted temperature is between 34 and 36°C, chosen as PCM for electrical devices that generate less heat. This point of meltdown will prevent a quick during its phase transition, the temperature rises to its melting point over a considerable amount of time because of the high value of heat that is latent. Various layouts of heat sinks are studied. The experimental study makes use of gravity-assisted thermal pipes, both without and with the incorporation of cooling fans, copper foam as well as "RT-35HC" PCM. When the thermal flux is 2, 2.5, and 3 kW/m², the findings show that The maximal temperature decrease associated with hybrid cooling (Foam-PCM-HP) with a fan is 47%, 51%, and 54%, respectively, after 6000 s, when charging ceases. Similarly, for all thermal fluxes, discharging hybrid cooling with a fan demonstrated outstanding cooling outcomes. Marri et al. [14] analyzed the thermal efficacy of a combined metallic foam phase change material heat sink with various arrangements, including both regular and irregular porosity (porosity range) while maintaining a fixed PPI density of the metal foams. This study numerically investigates the kinetics of melting of phase change materials through three-dimensional conjugate heat transport models during both charging and discharging cycles, employing an enthalpy porosity form and a non-thermal state of equilibrium model. This study investigates the heating effectiveness of a mixture of metal foam phase change material heat sink, emphasizing both consistent and incon-sistent pore per inch (PPI) density while maintaining a constant porosity with computational simulations. Heat sink thermal efficiency designs are analyzed and quantified across various power levels during both charging and discharging cycles. When comparing the charging cycle time to reach a set point temperature, the thermal dissipator configurations are not uniform, the decrease in porosity from the bottom to the top, along with the increase in non-uniform PPI density in the same direction, results in performance improvements of up to 28% and 45%, respectively, when porosity remains constant. The configurations of thermal sinks exhibit a uniform porosity and PPI density.

The numerical simulations show that convection velocity cells are drastically affected by the PCM melt percentage, influencing PCM dynamics of melting. For additional numerical simulations on PCM heat sinks, three-layer metal foams with non-uniform porosity (decreasing from bottom to top) and non-uniform PPI density (increasing from bottom to top) gradients were employed. An enhancement ratio of 4 and 4.4 times, respectively, above the baseline scenario (Without metal foams, the PCM heat sink), the tri-layer metal foams (variations in PPI density and irregular po-rosity) in the PCM heat sink perform almost as well as a bi-layer metal foam. The porosity and PPI gradients do not affect the efficiency of heat transfer. of the thermal dissipator during the discharging cycle. Arshad et al. [13] investigated the impact of four distinct heat-absorbing mediums PCM, NCPCM, MF+PCM, and MF+NCPCM utilized within a heat sink for the passive thermal cooling of electronic devices. The RT-35HC functions as a phase change material (PCM), into which copper (Cu) nano-particles of different volume fractions are incorporated.

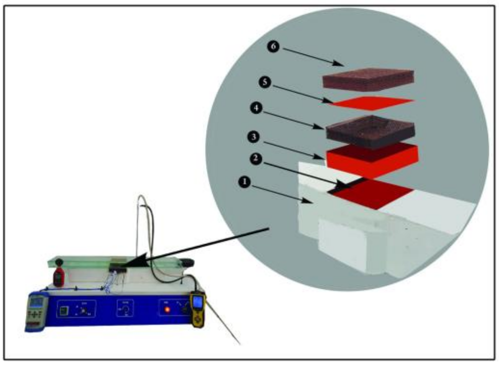
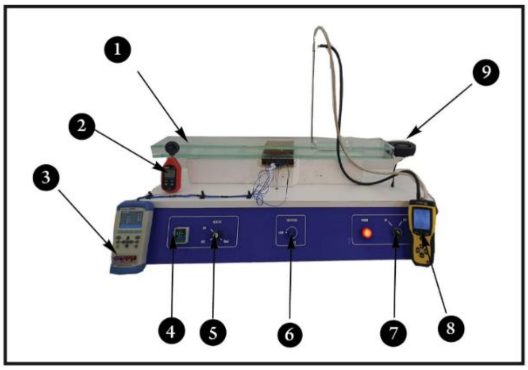


Fig. 1. Explains parts of heat sink (1) Insulation (2) Stainless steel heater (3) Copper plate with thickness 5 mm (4) Copper metal foam immersed with PCM (5) copper plate with a thickness of 1 mm (6) Copper metal foam.

Three distinct metal foams composed of copper (Cu), aluminum (Al), and nickel (Ni) have been studied to identify the most effective heat-conductive metal foam integrated with (PCM). Three porosities, five pore densities, and four input power levels of 5, 6, 7, and 8 W were examined. Initially, the MF with constant porosity is incorporated into the nanocomposite phase change material NCPCM at various volume fractions. Subsequently, the NCPCM with a constant volume fraction is adjusted to different porosities of MF to investigate the influence of the two heat-conductive mediums. This study examines the melting phenomenon and temperature distribution in heat sinks composed of pure PCM, NCPCM, MF+PCM, and NCPCM+MF. Additionally, thermal cooling performance was evaluated through four distinct parameters: heat storage capacity, heat storage density, rate of heat transfer, and rate of heat transfer density, alongside the total melting time. This will ultimately yield a clearer understanding of selecting the optimal heat storage medium within a heat sink, facilitating an efficient approach to passive thermal cooling of electronic devices. The results indicated that the incorporation of Cu nanoparticles and MF enhanced the heat transfer rate and decreased the melting time. The composite of MF+NCPCM exhibited a lower heat sink temperature and a higher liquid fraction. The duration of the latent heating phase decreased as the volume fraction of Cu nanoparticles increased.

Hu et al.[14] used both experimental and computational techniques to assess the thermal management performance of PCM-based heat sinks with fins and Structured porous material (SPM). A numerical model at the pore scale has been developed to examine the heat transfer mechanisms of PCM-based heat sinks, facilitating the identification of optimal parameters for existing configurations. The experiment aims to investigate



the thermal response of the heat sink and validate the precision of the numerical model.

Fig. 2. Explains parts of experiment device (1) Plexiglas duct (2) Anemometer device (3) Thermocouples device (4) Wattmeter device (5) Voltage change (6) Speed change (7) Button ON-OFF (8) Thermocouple device (9) Centrifugal fan.

Two types of Phases change material (PCM)-based heat sinks were designed: one with PCM infiltrated in SPM and the other with PCM filled in the fin. The study also examined the influence of heating power level and heat transfer coefficient on the thermal performance of different PCM-based heat sinks. The results showed that using SPM in a heat sink greatly enhances its ability to manage heat compared to using fins with a similar thermal conductivity enhancers (TCEs) amount. The heating power and convective heat transfer coefficient significantly influence thermal performance. They demonstrated the effectiveness of a novel heat sink that incorporates SPM for cooling electronic devices, providing both experimental and numerical data to guide the optimal design and future applications of PCM-based heat sinks. Wang et al. [15] utilized the apparent heat capacity method to model three-dimensional intermittent processes. Utilizing the BBD and NSGA-II methodologies, the PCM-based heat sink optimized with TPMS was developed to enhance thermal performance by minimizing entrance and maximizing heat storage rate. The numerical simulation examined the thermal performance, including base temperature, liquid fraction, and Grashof number, of the optimized PCM-based heat sink throughout the charging and discharging cycles. Platforms for visualization and temperature testing have been developed to measure the heat sink's internal temperature distribution and liquid fraction distribution. The experimental results were employed to validate the simulation outcomes. Experimental research investigated the impact of heating power on the intermittent process of the optimized PCM-based heat sink. The findings indicated that the base temperature, liquid fraction, and Grashof number exhibit a stable periodic variation throughout the intermittent process. At a heating power of 30 W or lower, the base temperature of the heat sink shows a consistent periodic variation.

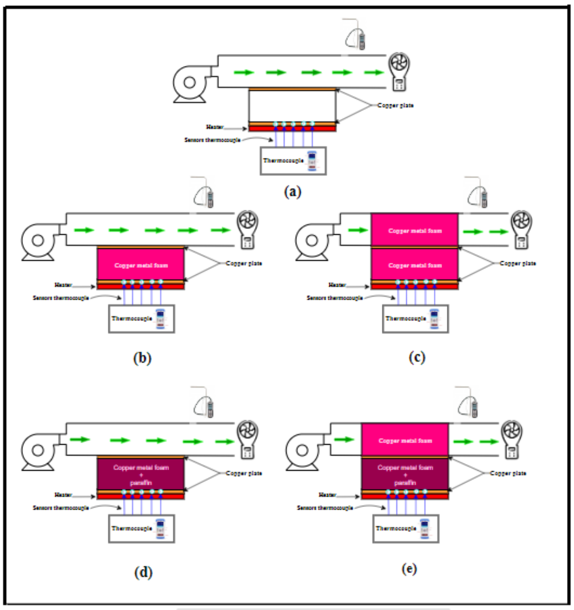


Fig. 3. Explains the experimental cases (a) No copper foam and paraffin (b) A single copper foam (c) Two copper foams (d) A single copper foam with PCM (e) Two copper foams immersed partially PCM.

At a heating power of 40 W, the maximum base temperature of the heat sink surpasses 370 K. Arqam et al. [16] provide guidance on choosing the optimal fin shape for effective electronic cooling. Facilitates decision-making in the design and development of heat sinks for efficient thermal dissipation from high-power electronics. The results demonstrate that power input, convective heat transfer coefficient, and base thickness exert a more substantial impact on performance than fin thickness and height. Reduction of base temperature through enhanced heat transmission. These discoveries enhance the design and development of effective heat sinks for high-power contemporary electronics. Lu [17] conducted a study on the viability of utilizing phase change cooling for high-power electronic packages, particularly to alleviate the rise in junction temperature caused by thermal transient effects. The one-dimensional thermal model comprises a finite slab abruptly chilled by convective air at the lower surface and subjected to a homogeneous heat flux at the upper surface. The phase shift problem has been divided into sub problems and addressed successively. Before the melting of the slab, both precise and approximate solutions for the temperature distribution within the slab can be expressed as functions of time and the Biot number, Bi. The importance of dividing the time domain into two intervals, delineated by the time t_0 required for the thermal front to traverse the whole slab, was highlighted. As the slab melts, quasi-steady-state solutions for the melt depth and surface temperature development can be calculated as functions of time and the Biot number, provided that $t_m > t_0$, where t_m represents the time required for melting to commence at the slab's upper surface.

Li et al. [18] developed a numerical simulation model of the metal foam and pin fin hybrid (MFPFH) heat sink to analyze the intricate flow and conjugate heat transfer properties, methodically comparing its performance with two other heat sink kinds. The study also examined the decline in heat transfer efficiency of the MFPFH heat sink attributable to thermal contact resistance. The findings indicated that the utilization of the MFPFH heat sink significantly enhances heat transmission. This enhancement was attributable to the improved heat conduction and convection resulting from the synergistic action of the MF and PFs. The heat transfer properties of MFPFH heat sinks exhibited greater sensitivity to foam porosity and the pressure drop relative to pore size. The MFPFH heat sink has a thermal performance ratio 1.6 times greater than that of the conventional PF heat sink when considering both augmented flow resistance and enhanced heat transfer simultaneously. When thermal contact resistance is 10-3 $m^2 \cdot K/W$, the average Nusselt number experiences a decrease of around 36%.

Uglah et al. [19] conducted a numerical analysis of natural convection in metal foam heat sinks with two types of fin edges: fillet and sharp edges. Aluminum metal foam with different pore densities was used in the experiment, which was carried out utilizing the control volume approach. Furthermore, a local thermal non-equilibrium (LTNE) model, in which the temperature of the fluid and the solid matrix are calculated independently, serves as the foundation for the energy equations. The air functioned as a working fluid. The findings indicated that the basal temperature of the heat sink was reduced for the revised edge design. The suggested heat sink technology has considerable potential to improve thermal performance and facilitate the development of more advanced cooling devices and procedures. The peak improvement in the heat transfer coefficient with a fillet profile was 5.6% over fins with sharp edges.

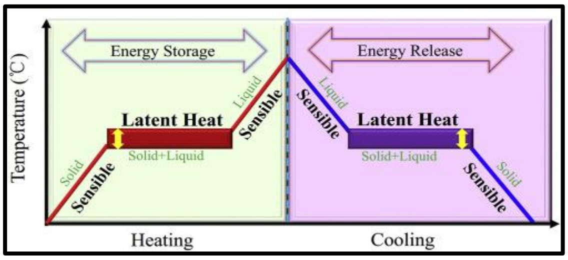


Fig. 4. The operational mechanism of Solid-Liquid phase change materials [24].

A thorough review of the available literature indicates that the problem of heat dissipation has not received enough attention.

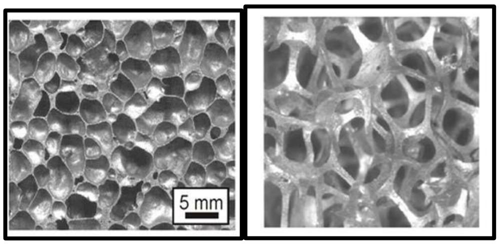
Thus, this study aims to investigate the potential applications of metal foam partially immersed in phase change material (PCM) for analyzing pore structure changes and the potential enhancement of heat conductivity, heat flux supply and different velocities. Subsequently, this was used to analyze the thermal dispersion and efficacy for the standard scenario.

2. Experimental Setup

2.1. Designing experiment

This work describes the components of the experimental setup developed to investigate heat transfer enhancement using a copper foam equipped heat sink. The setup consists of two copper plates of identical dimensions (10 × 10) cm2, in length and width but different thicknesses (1 and 5) mm. The setup includes two pieces of copper metal foam 95% porosity, each measuring (10 × 10 × 2) cm^3, in length, width, and height respectively. Heat is transferred from the heater to the lower metal foam piece via the thicker plate and to the upper metal foam piece through the thinner plate. With a melting point of 57, a specific quantity of paraffin RT55 is used as a phase-change substance. °C. A stainless-steel heater, with dimensions of 10 cm × 10 cm × 1.6 mm and a power range of 0–300 watts, provides the heat source. To minimize heat loss and maximize heat transfer to the copper plate, thermostone insulation is used. Regarding the heater and heat sink configuration, a Plexiglas duct measuring 80 cm in length, 10.2 cm in width, and 2.2 cm in height, with a thickness of 1 cm, is included. Fluid flow within the duct is generated by an electric motor connected to a centrifugal fan at one end. A dimmer controls airflow velocity by adjusting voltage fluctuations. This setup, illustrated in Figure 1, ensures efficient heat transfer and controlled air-flow conditions for the experiment.

Figure 2 displays the anemometer (Rocky Mars, RA30) was used to measure the fan's speed. To read the powers, use a wattmeter. The temperature-measuring thermocouples are placed in five-millimeter-deep holes on this copper plate.



(a) (b)

Fig. 1. Types of Metal Foams: (a) Closed-Cell Foam (b) Open-Cell Foam [26].

Each of these locations is thought to be around the same distance from the one following it, the temperature was measured using thermocouples (AT4208). A Petit tube (TA400) was used to monitor the pressure differential. And requirements to perform the experiments that are the focus of this inquiry, a slit that is less than one centimeter in diameter and 18 cm long has been built at the beginning of the channel and the end opening side. Five laboratory cases, sometimes known as cases, were created for this experiment, and each one used copper foam differently.

For conducting the tests examined in the present study, There were five lab cases made. referred to as instances 1 through 5, which varied in their utilization of paraffin plus copper foam in this study.

Case 1: No copper foam was used. With this case, no copper foam is present. The thermal flow is directly transferred to the copper plate by the channel's circulation. (Figure 3.a).

Case 2: Making use of a single copper foam. In this instance, a single metal foam is positioned in the bottom region of the chamber. The impacts of the copper foam alone were studied. In this case (Figure 3.b).

Case 3: There are two foams of copper are used. With this instance, the copper plate is positioned within the chamber between two metal foams stacked on top. The impacts of the copper foam were examined. (Figure 3. c).

Furthermore, Case 2 and Case 3 replicate towns for 90% and 95% metal foam, respectively.

Case 4: A single copper foam was immersed in the PCM. In this scenario, at the bottom of the chamber is a single piece of metal foam that is submerged in PCM. Only an effects of copper foam with PCM in one piece have been examined in this case (Figure 3.d).

Case 5: Concurrent use of copper foam and composite phase change material (copper foam/paraffin RT55). The copper foam infused with paraffin is positioned in the lower section of the chamber, while the copper foam is situated in the upper section. Airflow crosses the foam inside the tube. The copper plate situated between two foams conducts heat from the lower foam and paraffin to the higher foam (Figure 3. e).

Table 1. Thermophysical Characteristics of foam made of copper and paraffin RT55 [6][29].

Property	copper foam	RT55 Paraffin
Melting point (◦C)	1057	51 ◦C–57 ◦C
Thermal conductivity (W/m-K)	388	0.2 W/m-K
Apparent density (kg/m3)	276	At (15 ◦C solid) →880 Kg/m3 At (80 ◦C liquid) →770 Kg/m3
Specific Heat capacity(kJ/kg.K)	0.383	2 kJ/kg.K
Heat storage capacity ± 7.5 %(kJ/kg)	_	170 kJ/kg
Porosity (%)	90-95	-
Pore density (PPI)	40	-
Congealing area	-	(56-57) ◦C Main. Peak 55◦C
Flash point	-	200 ◦C
Max. operation temperature	-	90 ◦C
Volume expansion	-	14 %
Integration of latent and perceptible heat throughout a temperature range from 48 °C to 63 °C	-	48 Wh/kg

2.2. Material

Phase Change Materials (PCMs). Heat storage solutions rely on superior phase change materials (PCMs) that exhibit exceptional thermal conductivity and substantial heat storage capacity. Four major phase transitions are solid-solid, solid-liquid, liquid–gas, and solid–gas. The considerable phase change enthalpy and little volume alteration render solid-liquid phase change materials optimal for latent heat storage [20]. The solid-liquid phase change material (PCM) absorbs heat (charging) and functions as a sensible heat storage medium, increasing temperature. Nonetheless, after the PCM reaches its melting temperature, it absorbs a significant quantity of the heat at captures a considerable amount of heat while maintaining an almost uniform temperature, which represents the latent heat associated with the phase change of the material. This energy storage capacity is (5-14) times greater than that of sensible storage materials [21]. This is nearly invariably. temperature is maintained by the PCM's absorption of heat until it is liquefied to the liquid state. The temperature of the liquid phase transition material upon complete melting once more begins to rise above the value, as shown in Figure 5 below.

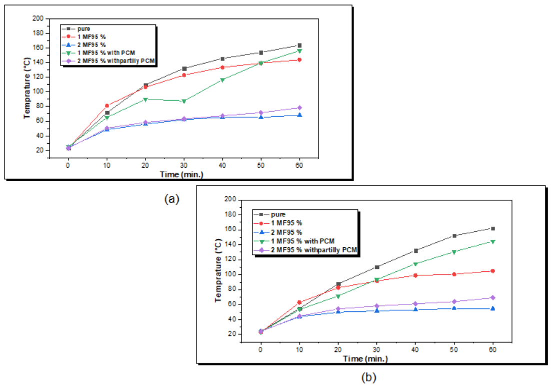


Fig. 6. Explains effect change velocity (a) 1.6 m/s (b) 2 m/s.

The temperature at which a substance melts serves is a site of sensible heat storage and continues to increase with the heating temperature. The process is similarly repeated during the cooling (discharging) phase, where heat is released, resulting in the complete conversion of the PCM liquid into a solid [22]. Paraffin RT55 contains an optimal latent heat capacity and density, resulting in a reduction of the volume of the heat-storing device. For the temperature range that was looked at in this research, the melting point of paraffin RT55 makes sense. Moreover, paraffin exhibits chemical stability, is not poisonous, corrosive, or reactive, with metal containers, and is both cost-effective and easily accessible [23].

Metal foams. Metal foams are cell formations with a substantial proportion of fluid-filled pores and a solid metal matrix. According to [25]. The pores can be sealed (closed-cell metal foam) or made up of ligaments that create an interconnected network (open-cell metal foam). Figure 8 displays a sample of both closed- and open-cell metal foam.

The open-cell metal foams' porosity, relative density, pore density, and pore size are crucial properties that affect how well the porous structure transfers heat. Among the factors that define the foam structure are [27]. The main factor influencing foam strength, stiffness, thermal conductivity, and electrical conductivity is porosity, ranging from 85% to 97%. Relative density has a direct impact on the pore diameter, cell wall thickness, and cell size, which in turn affects the mechanical and thermal properties of the foam [28]. As porosity decreases, the ligament's diameters get bigger and stronger, and as a result, the strength of the foam structure increases, the porousness of the foam sample rises as pore size grows because fluid flow resistance falls and fluid penetration through the sample increases. In the case of natural convection, the foam's permeability and fluid flow resistance are crucial factors in the heat transmission properties of metal foams.

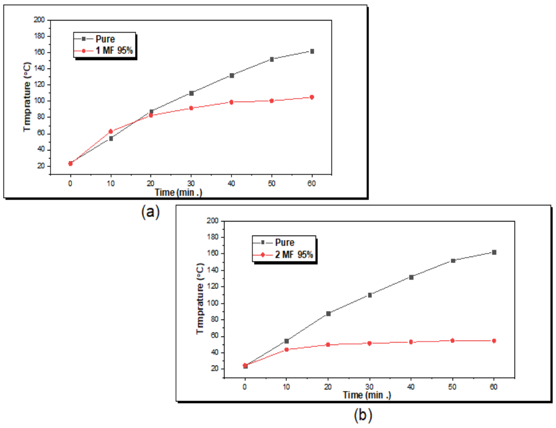


Fig. 7. Explains effect add metal foam (a) 2 m/s with 1 piece of metal foam (b) 2 m/s with 2 pieces of metal foam.

Higher fluid velocities through the foam cause the heat transfer coefficient to increase with permeability as well Foams have a very twisting and convoluted flow route, a low-pressure drop, and a high heat conductivity. In compressed metal foams, the specific surface area ranges from 500 to over 10,000 m²/m³ [26]. The 400 W/m.K. conductivity of copper foam facilitates the efficient enhancement of heat transmission inside the fluid. Two sections of open-cell copper foam with a pore density of 40 PPI and porosities for 95%. Table 1 below present the thermal properties of the materials utilized in the current study.

2.3. Experiment procedure

Five distinct test cases were created to examine temperature variations and the heat in copper foam that is mixed with paraffin RT55 for heating and cooling operations. The input heat flux of (68) w/m2 and the intake air velocity of 1.6 and 2 m/s were used to analyze and compare these cases. The test begins with the surrounding temperature at around 23 °C. By turning on the fan and heater at same time, the inlet airflow velocity is then changed by adjusting the voltage. equipped with an electrical regulator connected to the blower motor. An anemometer measures temperature and velocity of the airflow at the heat sink channel's output. A pitot tube was also used to monitor the air pressure decrease in the channel experiment had a 60-minute duration. In the course of the experiments.

3. Insistently

The level of accuracy of measurements, the particulars of the testing rig's design, and human error all affect how accurately experimental findings are obtained. The accuracy discrepancies were caused by

1. The fixing thermocouples' alignment. accuracy of thermocouples.
2. The heat sink loses heat.

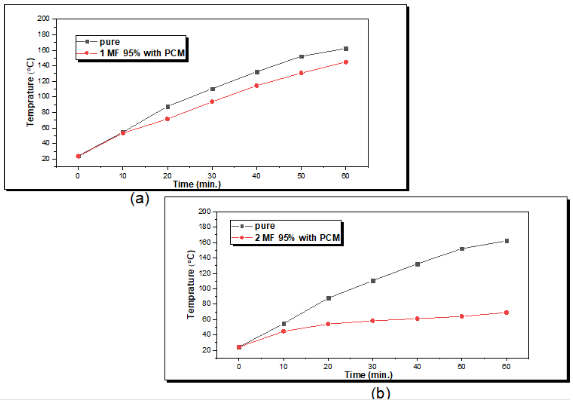


Fig. 2. Explains effect add PCM (a) 2 m/s with 1 piece of metal foam (b) 2 m/s with 2- pieces of metal foam.

3. Human mistake.

Without a doubt, the largest percentage of calculation mistakes is linked mostly to the measured quantity inaccuracies. Therefore, the method described by Holman (2012) was applied in this field to determine the inaccuracy of the data that were obtained [30]:

$$\frac{wR}{R} = \left[\left(\frac{\partial R}{\partial V1} \frac{W1}{R} \right)^2 + \left(\frac{\partial R}{\partial V2} \frac{W2}{R} \right)^2 + \cdots + \left(\frac{\partial R}{\partial vn} \frac{Wn}{R} \right)^2 \right] \quad (1)$$

4. Result and Discussion

4.1. Heating process

Effect changes of velocity. The impact of varying velocity from 1.6 m/s to 2 m/s within heat flux 68 W/m² for five cases during 60 minutes, Figure 6. a and Figure 6.b illustrate the impact of varying velocity at 68 W/m², this represents a significant enhancement rate. The initial case (without metal foam or PCM) demonstrates a 1% increase in velocity variation. The third and fifth cases are 20% and 11.87%, respectively.

Increasing velocity improves convective heat transfer by diminishing the thermal boundary layer thickness, thus increasing the heat transfer coefficient. This effect is most evident in forced convection situations, where increased velocity enhances energy transfer between the solid surface and the fluid. As velocity rises, the rate of energy dissipation from the hot surface increases. In this scenario, increasing velocity continues the enhancement of heat dissipation by further optimizing convective heat transfer.

Effect added metal foam pieces. The effect of using and adding several pieces of metal foam with heat fluxes 68 W/m² and a speed of 2 m/s for 60 minutes. The metal foam has 95 % porosity. The inclusion of copper metal foam significantly and visibly impacts the heat dissipation process.

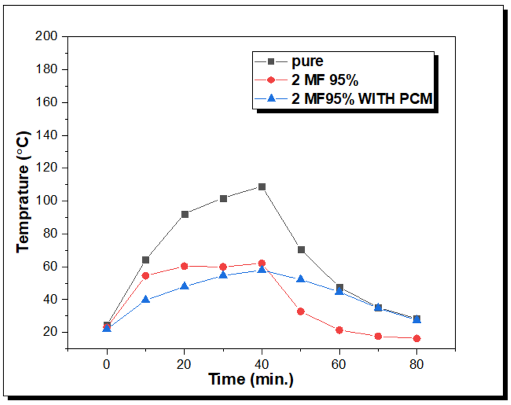


Fig. 9. Cooling process at 2 m/s and power 68 W/m2.

As shown in Figure 7a shows that the improvement rate in the second case (one piece) was 35.3%. Figure7b illustrates the improvement rate in the third case, which involved two pieces of metal foam. 66.4%. Because of its physical properties, copper metal foam is used in heat sinks to improve heat dissipation. This is because of its high heat conductivity. Copper's strong thermal conductivity allows for effective heat transfer from the heat source to the foam structure. The foam's high surface area enhances heat dissipation and eliminates isolated hot spots. Increased The porous nature of metal foam increases the surface area accessible for convection, hence improving heat exchange. This leads to enhanced heat transmission in the surrounding air. The open-cell shape promotes airflow and convection cooling. Because of the turbulent airflow inside the pores, natural or forced convection cooling is more efficient.

Effect added PCM. The effect of using and adding paraffin as a phase change material with metal foam with heat fluxes 68 W/m², a velocity of 2 m/s for 60 minutes, Figure 8 demonstrates that employing copper metal foam immersed in paraffin as a phase change material significantly impacts heat dissipation. Figure 8a shows that in the fourth case (one piece of metal foam with PCM), the improvement rate was 10.77%. Figure 8 b shows the improvement rate in the fifth case (two pieces of metal foam partially immersed in PCM the improvement rate was 57.46%.

Use metal foam immersed with paraffin as a phase change material (PCM) to regulate heat. Improved thermal conductivity, paraffin has limited thermal conductivity, which limits heat absorption and emission. Copper metal foam has a high thermal conductivity, which improves heat conduction through the paraffin. Furthermore, the metal foam's linked pores create a huge surface area, allowing for quicker energy transmission. Increased thermal storage capacity. Paraffin retains latent heat throughout the melting process, allowing for greater temperature control

4.2. Cooling process

Figure 9. The analysis concentrates on the initial cases (without metal foam or PCM), the third case (two foam pieces made of metal), and the fifth case (metal foam that is partly submerged in paraffin). For the study, the effect during the 80-minute cooling period at a heat flux of 68 W/m². After shutting off the heating in the 40th min. and starting the cooling operation, the improvement rates for cases 3 and 5 . The improvement rates for cases 3 and 5 were 34.7% and 43.5%, respectively. Copper foams transfer the sensible heat to the heat sink duct and exit a heat sink utilizing the forced air convection mechanism. Until the temperature reaches approximately 57°C, at which point the paraffin begins to solidify, this trend maintains a precipitous inclination. As the paraffin begins to solidify, the rate at which the temperature decreases. This is because the heat sink's power is primarily directed toward the taking away of the solidification's latent heat as soon as the paraffin begins to solidify. Consequently, the rate at which the temperature on the copper plate decreases is slowed. The metal foam quickly conducts the produced heat from the source to the paraffin according to its great thermal conductivity. Upon the giving of heat to the paraffin, it begins melting once the temperature achieves its transition point. Throughout this process, the paraffin absorbs significant heat, so limiting the temperature increase inside the system. As the system's temperature decreases, the paraffin commences solidification and subsequently emits the accumulated heat. This enhances thermal stability and mitigates abrupt temperature fluctuations.

5. Conclusion

This study describes an experiment that used RT55 partly paraffin-filled copper foam and solely metal foam with forced airflow convection to transport heat around in the heat sink. To do this, they tested five different heat sink samples under various situations. Here is an overview of the key findings and conclusions.

1. Because it its Copper foam has good heat conductivity. reduced the temperature of the heat sink by 66.4% throughout the heating process, whereas partly paraffin-filled copper foam decreased by 57.46%.
2. Copper's strong conductivity improves heat dispersal over heat sinks. While paraffin may contribute to great heat absorption during the

temperature increase phase, its thermal conductivity is inferior than copper makes it possible to lower the heat sink's temperature while using less airflow.

3. Copper foam (sample 3) resulted in a 43.5% temperature reduction compared to a heat sink partially filled with paraffin (sample 5), which was 34.7%.

4. Copper foam can immediately and effectively adapt to excess heat in the system. Paraffin takes longer to convert from solid to liquid, delaying heat dissipation.

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