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# Enhancement the Performance of Heat Sink by Using Metal Foam

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## Article Informations

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### Key Words:

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copper foam,  
thermal conductivity.

## ABSTRACT

Portable electronic devices must have effective thermal management to maintain low enough working temperatures for dependability, expanded installed functionality, and user comfort. In certain situations, using heat sinks made of metal foam has the potential for heat dissipation. In the research, three cases were employed with and without copper foam, forced air convection into the device's duct, and electric heating of the copper plate under the heat sink. For each of the three heat sink scenarios, which happen again with different porosities throughout the heating and cooling processes, the effects of the thermal power and input air velocity parameters of metal foam were investigated. The findings indicate that the copper plate in case 3, which features two copper foams, has the lowest temperature among the three cases. The temperature dropped during the heating process in cases 3 (two pieces of copper foam) and 2 (one piece of copper foam) at porosity 90% (198%) and 95% porosity (197.6%) for case 3 and 45.2% and 46.8% for case 2, respectively, compared to case 1 (no copper foam). Because of its high heat conductivity, the copper plate in case 3 maintained its temperature during the cooling process. Compared to case 1, the improvement rates in the copper foam example were 86% and 77% lower, respectively. Temperature was less affected by increasing the input air velocity.

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## **1. Introduction**

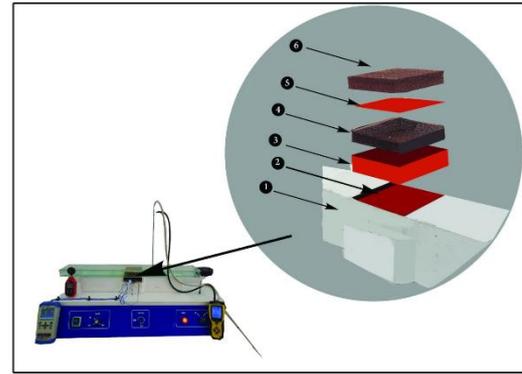
The previous research studies give the reader an overview of heat sinks. In today's digital age, increasingly integrated and quickly reduced electronics assure device performance efficiency and lifetime. Several electrical devices' performance times have decreased due to insufficient thermal management (TM). According to the paper, heat generated in electrical circuits must be dissipated quickly to improve elec-tronic equipment's cooling efficiency [1][2][3][4] [5][6][7][8][9]. Four simulated electronic packages with varying heat dissipations were cooled in personal digital assistants (PDAs) utilizing a heat storage unit (HSU) packed with neicosane phase change material. The positioning of the H SU within the PDA significantly affected the temperature distribution, found that the system temperature was regulated using HSU to achieve an appropriate operating temperature of 50. This research experimentally investigates the heat dissipation of the chips within a PDA and the orientation of the HSU. Various orientations of the HSU within the PDA were shown to substantially influence the temperature distribution exam by Tan and Tso [10]. They conducted an experimental study to investigate the potential improvement in PCM's thermal performance by using a honeycomb structure instead of machined solid fins. They proposed replacing machined fins with honeycomb structures, which would result in weight and expense savings. To evaluate the impact of PCM Also, the use of honeycomb inserts to replace machined finned structures has shown comparable thermal performance by Mahmoud et al. [11]. Found that for the PCM type, the material with the lowest melting point had the best performance in terms of the lowest operating temperature and the longest time of low heat sink temperatures an investigation of the solidification behavior of PCM-metal composites by experimental methods. Samples exhibiting diverse metal foam properties were compared. The two principal procedures for solidifying foam samples are pore front solidification and single-phase front solidification Beynet et al. [12]. The investigation focused on the metal-foam/PCM composite embedded in a heat sink. The integration of phase change material (PCM) with aluminum foam enhances a thermal management system (TMS). A slender, rigid layer of high-temperature copper oxide (CuO) functions as a thermal conductivity enhancer (TCE) for the copper metal foam. The findings indicated that the integration of neicosane into the pinfin heat sink efficiently regulated mobile device temperatures within an acceptable range. Under reduced thermal inputs and stable operating circumstances, the uniform charging of phase change materials (PCM)

necessitates a prolonged period, leading to an increased phase duration of latent heat. The improvement ratios indicated that the 2 mm thick pin-fin heat sink exhibited superior thermal performance, ensuring the appropriate functioning of the electronic package examined by Arshad et al[13]. Utilizing aluminum foam combined with phase change material (PCM) to enhance a thermal management system (TMS). The copper metal foam has a thin, stiff layer of high-temperature copper oxide (CuO) that improves its thermal conductivity (TCE). The aluminum foam/PCM composite is attached to a heat sink. The research investigates many variables, including the volumetric percentage of PCM, the number of input power levels, and the filling thickness ratio. The findings indicate that heat sinks composed of phase change materials or metal foam may efficiently disperse heat during heating and heat transfer activities. The results demonstrate that a metal foam/PCM-based heat sink significantly lowers the base temperature during the heating phase, with heat transfer improvements steadily growing as the filling height ratio increases. For passively cooling portable electronics,

PCM-filled CuO-coated metal foam heat sinks with a filling thickness ratio of 0.5 work very well at removing heat, as investigated by Arshad et al. [14]. To create a PCM-based heat sink optimized for both the natural convection of the liquid PCM and the enhanced heat transfer provided by the fin structures. Engineered The new heat sink was produced via additive manufacturing, followed by thorough experimental research to assess its thermal performance. To illustrate the superior performance of our novel heat sink design, comparisons are conducted with a traditional heat sink design and a preexisting topology-optimized heat sink, optimized just for heat conduction. In the PCM melting phase, the natural convection topology-optimized heat sink exhibits a lower base temperature than the traditional heat sink; however, a higher base temperature than the second topology-optimized heat sink. The natural convection topology-optimized heat sink operates 31.0% longer than all other heat sinks with upgraded structures. Observing the melting process reveals that the primary reason the topology-optimized heat sink utilizing natural convection operates more efficiently over time is the movement of the melt front, which decelerates the melting rate while enhancing the natural convection of the liquefied material. These systems sustain a relatively low heat sink base temperature was investigated by See et al. [15]. The integration of these materials may yield highly intricate, thermally optimized, PCM-based heat sinks. Evaluated the thermal performance of a heat sink incorporating

metal foam and nanoenriched phase change material (NEPCM). The thermal enhancement of PT-58 PCM was investigated experimentally using copper foam combined with graphene nanoplatelets and magnesium oxide nanoparticles, which were categorized as metallic and nonmetallic, respectively. This study evaluated the cooling performance of two nano-phase change materials (PCMs), GNPs/PT-58 and MgO/PT-58, in conjunction with copper foam for electronic equipment, was studied to identify the optimal configuration for reducing the base temperature, prolonging the system's operational duration, and enhancing system reliability by increasing the heat transfer rate, thereby improving the cooling performance of heat sinks. The study of heat sink enhancement ratios showed that heat sinks made of NEPCM and copper foam were the most common, with GNP-NEPCM and copper foam standing out. At all power levels, MgO-NEPCM/copper foam demonstrated performance comparable to that of GNP-based composites. The research indicated a comparable trend in the enhancement ratio throughout the operation. The results indicate that incorporating copper foam into NEPCM effectively reduces the heat sink base temperature and enhances cooling efficiency across both low and high heating loads. It was done by Hassan et al. [16]. The thermal effects of metallic foam heat sinks, regular foam heat sinks, and circular pin-finned heat sinks with different amounts of RT54HC/AlO<sub>1</sub> for different heating loads were studied. The performance times of nano-enhanced phase change materials (NePCM) sinks were evaluated against those of a standard empty heat sink under defined operating conditions. The integration of NePCM and supplementary AlO<sub>3</sub> nanoparticles enhanced heat transfer efficiency and sustained the system's baseline temperature within the working parameters of the electronic device. Cu foam heat sinks demonstrated SPTs of 45°C and 60°C during charging, using a heat flow of 0.98 kW/m<sup>2</sup> and 0.25 wt%. The base temperature of Al<sub>2</sub>O<sub>3</sub> nanoparticles (NPs), simple circular pin fins, and Cu foam were measured. The heat sink had contractions of 21.3%, 25.03%, and 36.2%. Copper foam heat sinks demonstrate enhanced thermal conductivity relative to non-copper foam counterparts. Therefore, NePCMs are advised. Electrical apparatus for the enhancement of thermal management.

Zahid et al. [17]. Performed a study, simulations of the phase transition properties of paraffin/copper foam composite materials and the melting characteristics of pure paraffin were conducted. Direct numerical modelling of the melting of composite phase transition materials with a reduced three-dimensional model of tetradecahedron metal foam. Copper foam enhances the thermal conductivity of phase change materials (PCMs). Pure paraffin has a melting rate of 3.44% slower than composite PCM, taking 870 seconds.



**Fig. 1.** (1) Insulation (2) Stainless steel heater (3) Copper plate with thickness 5 mm (4) Copper metal foam (5) copper plate with a thickness of 1 mm (6) Copper metal foam.

The results of the simulation and the experimental data are congruent. The temperature root mean square errors for pure paraffin and composite phase transition material were 0.0223 and 0.0179, respectively. Experiments indicate that copper foam enhances thermal conductivity and decreases melting duration. The melting duration for the composite phase transition material is 870 seconds, which is 3.44% shorter than pure paraffin. This study enhances comprehension of composite phase transition materials and informs the design of thermal energy storage devices You et al.[18]. A thorough review of the open literature shows that there is limited research on the heat dissipation problem. Therefore, this study aims to investigate how metal foam may be used to investigate pore structure changes and how different velocities might improve heat conductivity. This was subsequently utilized to analyze the heat distribution and efficacy for the standard case.

## 2. Experiment 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) cm<sup>2</sup>, in length and width but different thicknesses (1 and 5) mm. 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. The setup includes four pieces of copper metal foam, each measuring (10 × 10 × 2) cm<sup>3</sup>, in length, width, and height respectively with densities of 90% and 95%. 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, thermestone 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.

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. Each of these locations is thought to be around the same distance from the one following it, as seen in Figure 2.

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. Three laboratory cases, sometimes known as cases, were created for this experiment, and each one used copper foam differently. Figure 3 displays.

**Case 1:** No copper foam was used. In this instance, no copper foam is present, and the channel's airflow directly transfers the heat input to the copper plate (Figure 4.a).

**Case 2:** Making use of a single copper foam. In this instance, a single metal foam is positioned in the lowest portion of the chamber. Only the effects of copper foam have been examined in this case (Figure 4.b).

**Case 3:** Two copper foams are used. In this instance, the copper plate is positioned within the chamber between two metal foams stacked on top. The effects of copper foam have been examined in this case (Figure 4. c).

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

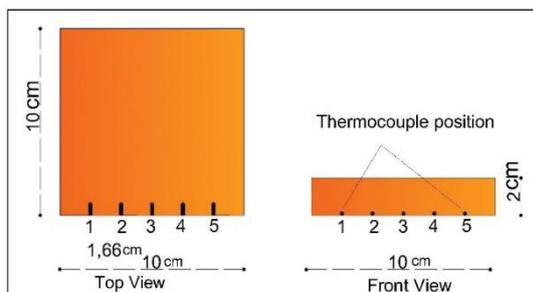


Fig. 2. illustrates the thermocouple position.

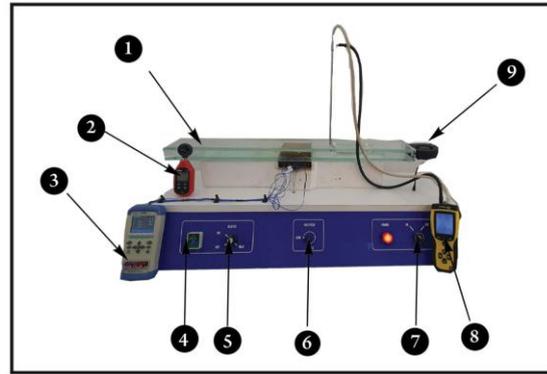


Fig. 3. (1) Plexiglas duct (2) Anemometer device (3) Thermocouples device (4) Wattmeter device (5) Voltage change (6) Speed change (7) Button ON-OFF (8) Thermocouple device (9) Centrifugal fan.

## 2.2. Material

Metal foams are cell formations with a substantial proportion of fluid-filled pores and a solid metal matrix. According to [19], the pores can be sealed (closed-cell metal foam) or made up of ligaments that create an interconnected network (open-cell metal foam). Figure 5 displays a sample of both closed- and open-cell metal foam.

How well the porous structure transfers heat. Among the factors that define the foam structure are [21]. 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 [22]. 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. Higher fluid velocities through the foam causes 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  $m^2/m^3$ [20]. Copper foam's 400 W/m.K. conductivity enables it to easily boost the fluid's heat inside transfer. Two pieces of open-cell copper foam with pore densities of 40 PPI and porosities of 90% and 95% were selected for this study. As Figure 6.

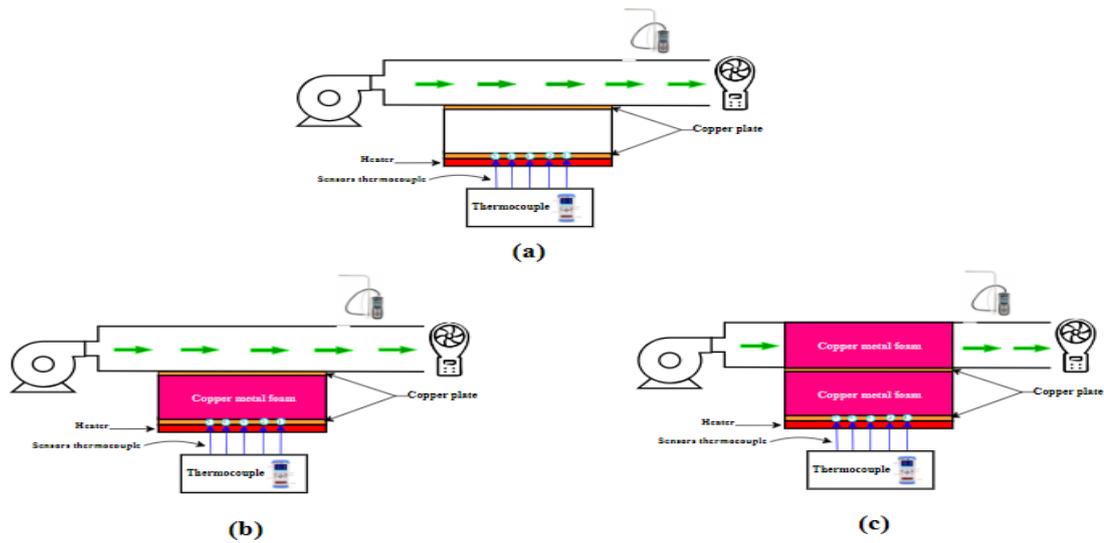


Fig. 4. (a) No copper foam (b) A single copper foam (c) Two copper foams.

### 2.3. Experiment procedure

Three distinct test samples were created to examine temperature variations and heat transmission in copper foams during heating and cooling operations. The input heat flux of (68) w/m<sup>2</sup> 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 the same time, the inlet airflow velocity is then changed by adjusting the voltage with an electric dimmer attached to the fan motor. An anemometer measures the temperature and velocity of the airflow at the heat sink channel's output. A pitot tube is also used to monitor the air pressure decrease in the channel experiment had a 60-minute duration. In the course of the experiments.

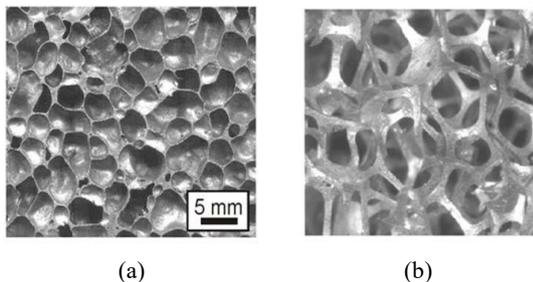


Fig. 5. Types of metal foams: (a) Closed-cell foam (b) open-cell Foam [20].

### 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.
2. Accuracy of thermocouples.
3. The heat sink loses heat.
4. 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 [23]: s

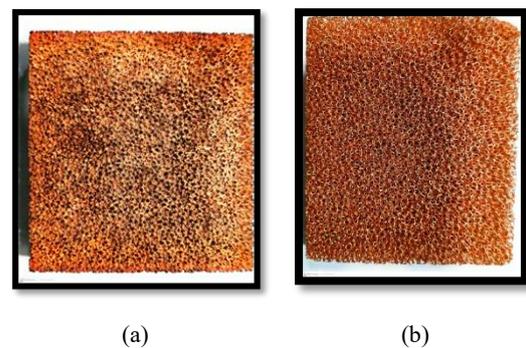


Fig. 6. (a) Copper foam with porosity 90% (b) Copper foam with porosity 95%

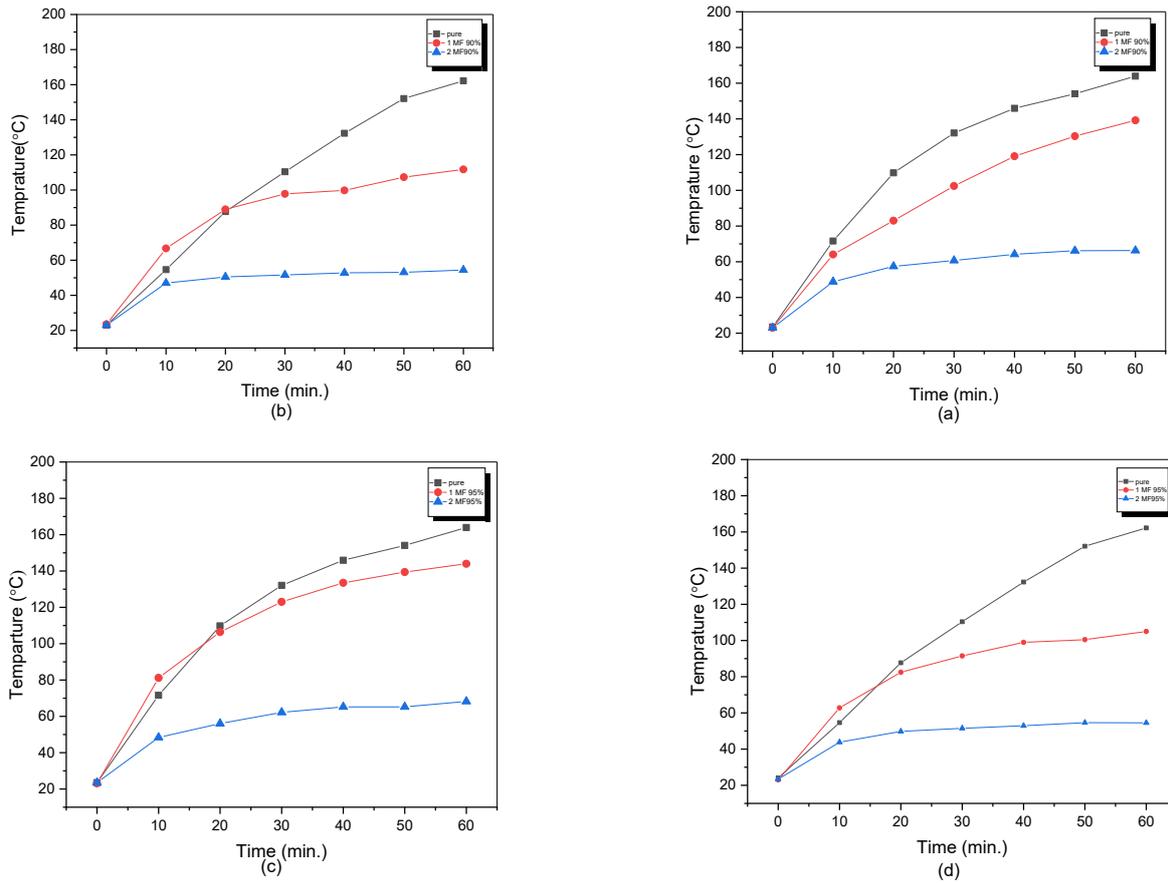


Fig. 6. (a) 90%MF and 1.6 m/s (b) 90%MF and 2m/s (c) 95 MF% and 1.6 m/s (d) 95% MF and 2 m/s

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

## 4. Results and Discussion

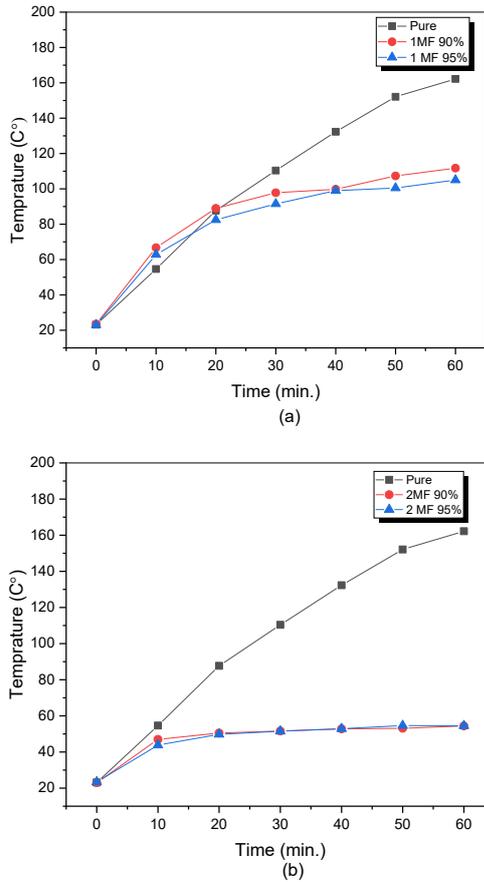
### 4.1. Heating process

Effect changes of velocity. Figure 7 depicts the effects of changing velocity from 1.6 m/s to 2 m/s at a heat flux of 68 W/m<sup>2</sup> across three cases over 60 minutes. The rate of improvement for velocity change in the first case (absent metal foam) is 1%. Employing a metal foam with 90% porosity results in an improvement rate of 24.6% for the second case (one piece of metal foam) and 21.8% for the third case (two pieces of metal foam). Furthermore, the enhancement rate for the case involving 95% metal foam is observed. The second and third percentages are 37% and 25%, respectively. Figure 7.(b)(d) shows cases 1 and 2 have a bigger temperature difference. This is because the heat exchange mechanism speeds up, encouraging natural convection. This mechanism generates turbulence in flowing fluids, thereby reducing boundary layers and facilitating mixing to improve thermal performance.

Effect added metal foam pieces. As seen in Figure 8, the heat dissipation process is significantly and visibly impacted by the inclusion of copper metal foam. According to Figure 8.a, the improvement rate in the second case (one piece) has been 45.2% when using metal foam with a porosity of 90%, and it has been 198% in the third case (two pieces of metal foam). In contrast, the improvement rate in the second and third cases is 46.8% and 197.6%, respectively, when using metal foam with a porosity of 95%. Heat transmission has been enhanced by the high pore count metal foams in Figure 8. b. Higher pore counts in metal foams allow for better heat transmission since they have a greater contact surface area than copper plates. More pores result from the higher porosity, and their size can be improved by particular forms and geometries. These foams also exhibit high heat conductivity and enormous surface areas per unit volume. The graphic illustrates how, in both cases, a bigger surface area results in increased heat dissipation porosity. airflow via the upper.

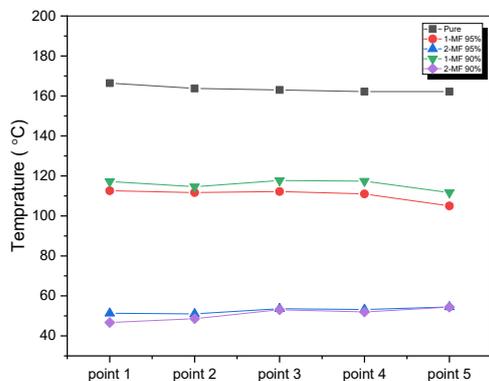
Effect position. Figure 9 illustrates the temperature change throughout the sixty minutes with a speed of 2 m/s. Velocity has a noticeable impact on heat dispersion in the first example, but in the third sample, and for both kinds of metal foam, the impact of speed is minimal. This makes the impact of metal foam more noticeable at the five

points that serve as the reference for both the first and second.



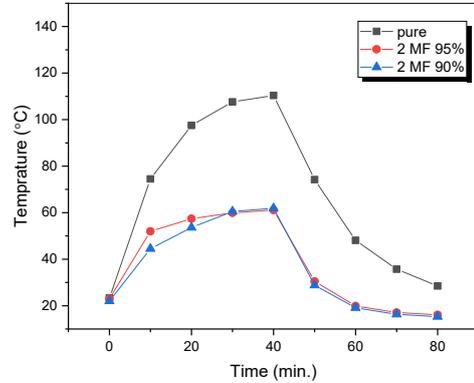
**Fig. 8.** (a) 2 m/s with 1 piece of metal foam for 90% and 95 % (b) 2 m/s with 2 pieces of metal foam for 90% and 95 %.

Cooling process. Figure 10. According to the analysis of the first and third cases, using metal foams with porosities of 90% and 95% had an impact during the 80-minute cooling period and at a heat flux of 68 W/m<sup>2</sup>. The improvement rates were 86% and 77%, respectively. High thermal conductivity and a large surface area-to-volume ratio enhance the overall performance of thermal systems.



**Fig. 7.** The temperature of six points of copper plate in five sample.

Increased porosity has been found to reduce the time required to achieve steady-state temperature and to generate stronger convective effects. Furthermore, foams with reduced porosity facilitate improved heat conduction. A lower heater temperature is therefore required compared to the greater porosity foam.



**Fig. 10.** Cooling process at 2 m/s and power 68 W/m<sup>2</sup>.

## 5. Conclusion

In order to improve heat transmission in a heat sink, an experimental study of copper foam with forced convection of airflow was studied in this paper. Three distinct heat sink enclosures under various test settings were used for this purpose. The following is a summary of the primary findings and conclusions:

1. Due to its high surface-to-volume ratio and much better thermal conductivity than pure case or one piece, using two pieces of metal foam accelerates the pace of heat transfer throughout the heating and cooling process.
2. The heat sink temperature dropped throughout the heating process of two copper metal foams because of the copper foam's forced air convection mechanism. At 90% MF, case 3 has a 198% improvement, and at 95% MF, a 66% improvement.
3. By adding two pieces of copper foam, the heat sink's temperature may be lowered at a reduced airflow velocity due to the foam's high specific surface area and strong thermal conductivity.
4. In comparison to the heat sink with copper foam (case 1), two pieces of copper foam (case 3) reduced the temperature during the cooling process by 198% in case 90% MF and 66% in case 95% MF.

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