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Review Research

AUGMENTATION TECHNIQUES OF CONVECTIVE HEAT TRANSFER OF HEAT SINKS: A COMPREHENSIVE REVIEW

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Abstract: A heat sink is a heat exchanger that is commonly attached to an electronic device in order to remove excess heat. It cools circuit components by dissipating excess heat, thereby preventing overheating and premature component failure and enhancing component dependability and performance. The extruded geometries of the heat sink are either flat-plate fins or pin fins. Due to the development of micro-devices and nanotechnology over the past few decades, there has been a substantial emphasis on the miniaturisation of electrical equipment. However, heat dissipation continues to be a significant challenge for improving the thermal performance of the heat sink. This article provides a thorough analysis of the techniques for optimising the heat sinks designed hydrothermally. Therefore, the research that is currently accessible on passive and active methods of augmentation heat subtraction from heat sinks by altering either the solid or fluid domains is covered. This study aims to summarise the research efforts devoted to improving the thermal performance of heat sinks, as well as their limitations and proposed unresolved solutions. The current survey reports the significance of the orientation and shape of fin besides the operating conditions regarding the type of flow and the boundary conditions. The maximum increment in Nusselt number obtained in laminar flow over different orientations and shapes of fins was about two-third while in case of turbulent flow was approximately the double.

Keywords: *CPU cooling; active and passive technical enhancement; forced convection; heat sinks; extended surfaces*

1. Introduction

One of the most important applications in industry is the heat sinks of various shapes and base materials subjected to different fluid flows are the heat removal devices that are most frequently mentioned. These instruments are utilised in electronic devices and high-power electrical components and are regarded as the only and thus most cost-effective cooling solution.

Due to the ever-increasing demand for heat removal, the geometry of the heat sink has become a challenge. The heat sink's improved thermal performance must also abide by logical limitations such pressure difference drop, overall size and dimensions, mass of fins, volume, and value. In addition, the smaller size of the computers raises the system's overall flow resistance and gradually impedes fluid movement between the heat sink's fins. This substantially affects the fan's effectiveness and its capacity to remove heat. Therefore, the heat sink must be adequately constructed to facilitate heat flow and prevent the electrical device from overheating. Researchers are concerned with the thermal management efficiency of heat sinks. Air is the most common coolant for electronic

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systems due to its availability and the simplicity, dependability, and affordability of the equipment required [1]. In order to get adequate knowledge about this method and determine the most efficient one among them and among different conditions, the present review tries to compare and conclude this in last few years to fulfil this gap.

2. Enhancement of convection heat transfer

2.1 Natural convection

Kim and Kim [2] analysed the thermal performance of cross-cut branching fins on horizontal cylinder heat sinks with natural convection. It was tested with different fin heights, fin counts, and variable heat flux. The findings of the study led to the development of a Nusselt number correlation applicable when the Rayleigh number, fin height, and fin numbers fall within the ranges of 190000–10000000, 10–30 mm, and 9–36, respectively. Plate fins were used to determine the thermal resistance of an overall heat sink with cross-cut branching fins on a horizontal cylinder.

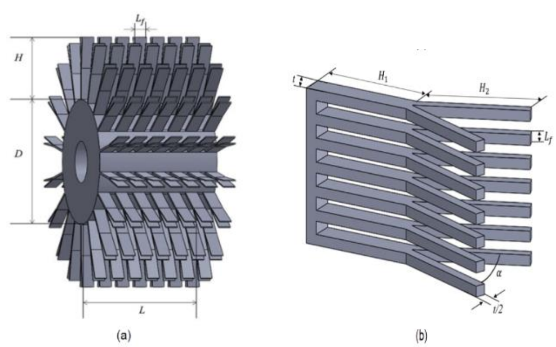

Figure 1. show (a) Cylinder with cross-cut branched fins; (b) single branched fin with cross-cuts.

To be 26% lower than that of a standard heat sink Awasarmol and Pise [3] provided experimentally studied natural convective in array of perforated fins at a variety of inclination angles (0-90˚). Different perforation shapes, perforation diameters, and power sources were investigated. The results showed about 32% enhancement in heat transfer coefficient with perforated fins of 12mm perforation diameter at the angle of orientation 45^{o}. El Ghandouri et al. [4] simulated the thermal efficiency of a longitudinal heat sink with curved fins of variable aspect ratios. In their studied the heat flux that applied at the base of the heat sink was ranged from 811.5 to 4674. 5 W/m^2 . The research showed that augmentation in convective heat transfer about 12. 52% in comparison of the finned plate. Haghighi et al. [5] proposed under natural convection a novel heat sink that included of a plate fin heat sink and several cubical pins arranged in a linear pattern between the plate fins. The input power was changed from 10W to 120W, and the Rayleigh was (8×10^6- 9.5×10^6). The results showed a 10–41.6% increase in convection heat transfer when compared to a plate-fin heat sink. Pathak et al. [6] analyzed numerically the impact of the height of heat sinks on pressure drop as well as heat flux. According to the results, the total Nusselt number was about 25% with decreased fin configuration for nondimensional differential height heat sinks. Furthermore, the overall Nusselt number was decreased by 5.7% and 9.5%, respectively, when a thermally conductive fin was compared to an isothermal fin. On the other hand, adopting variable height heat sinks with lower fin heights of around 0.03 m resulted in a 225% improvement in thermal efficiency. Feng et al. [7] carried out an experimental and computational study on a new design heat sink to improve natural convective heat transfer. A cross fin with a set of long fins and a number of orthogonally arranged short fins was proposed. According to the findings, cross fin heat sinks performed better than plate fin heat sinks in improving heat transfer coefficients by 15%.

Under free convection Rao and Somkuwar [8] studied the heat transfer coefficient of tapered fin heat sinks with different angles of taper fins. A tapered fin heat sink with taper inclinations of 1˚, 2˚ and 3˚ was employed and the heating power input rising from (5 W to 70 W). The result showed that the maximum heat transfer coefficient and lowest thermal resistance was found in the new designs of tapered fin heat sinks with an inclination of 2˚. Lee et al. [9] experimentally proposed correlation of total Nusselt number for enhancing the thermal efficiency of cylindrical heat sink with perpendicularly oriented triangular fins under natural convection. Their study included different fin numbers, different fin heights, and varied base temperatures. They found that the correlation was suitable when the Rayleigh number range from (1000 to120,000) and ratio fin number range from (9 to 72). Natural convection heat transfer in both horizontal and vertical sinusoidal undulating fins was studied by Altun and Ziylan [10]. They change the common fin shape in their study to an undulating fin configuration with a variety of amplitude values while maintaining the fin height. Three different amplitudes were used in their experiment: h/30, h/15, and h/10. The results show that wavy fins improved heat transmission more than rectangular fins. Ten alternative vertical baffles layouts' heat transfer efficacy under natural convection was assessed by Mousavi et al. [11]. The vertical finned has a height of (305 mm) and a thickness of (101 mm). According to the investigation, shortening the distance between interrupted fins had no impact on cooling. The topped fins boosted the rate of heat flow. On the other hand, L-shaped and cut capped fins was lighter and have better heat transfer efficiency than other fins. Li and Byon [12] investigated experimentally and numerically the orientation effect on the performance natural convective of radial heat sinks with a circular base, concentric ring, and rectangular fins. In general, the orientation angle with respect to gravity ($0 \leq \theta \leq 180^\circ$), Elenbaas number ($0.5 < El < 50$), and non-dimensional fins spacing ($0.273 \leq s^* \leq 0.617$). The results showed that the better thermal performance observed in orientation 0˚. Sertkaya [13] et al. conducted an experimental investigation to improve natural convection heat transfer using pin fin, plate, and a plain plate heat sink without any fins. The number, height, spacing, and direction of the pin fins were altered by the study's parameter research. It was used eight circular pin fin and plate heat sinks and heights of pin fin of (30mm and 40 mm) pin and the diameter of pin fins was (6 mm) with three different orientations of (0^o, 90^o and 180^o). The power input was varied from (0 -120) W and Rayleigh number changed between (1×10^6 and 7×10^6). It was discovered that each orientation angle of the (121 40) pin- fin and plate heat sink improved heat transfer. When plate position was established, heat sinks that faced upward and had an angle of 0 degrees achieved the highest heat transfer, while sinks that faced downward and had an angle of 180 degrees produced the least. Consequently, it's been found that co-linear extruded fin and plate heat sinks work best when directed upward and with the ultimate number of pins.

2.2.Forced Convection

Ibrahim et al.[14] investigated experimentally and numerically the effect of lateral perforation on the thermal performance of extended surfaces. The selected parameters of their study were geometrical, hydraulic, and thermal parameters. They obtained that a reduction in temperature of 8.5 °C by introducing a perforated fin. The results showed that the new design has a larger heat-dissipation performance than the nonperforated at low flow rates. Shadlaghani et al. [15] triangular fins with and without longitudinal perforation increased thermal performance. Fins with triangular cross sections were shown to transport convection heat more effectively than fins with rectangular and trapezoidal cross sections. The maximum heat transfer technique in triangular fins was obtained by increasing the height/thickness proportion. Rao and Somkuwar [16] developed numerically the design of a plate fin heat sink to increase the heat transfer coefficient and decrease the thermal resistance. It was used fin heat sink with a taper inclined such as (1˚, 2˚, and 3˚) at constant sloped angle configuration of 10˚. It observed that the enhancement in Nusselt number was 968 for 2˚ taper sloped fin heat sink at a velocity of 12.2 m/s and a lowering in thermal resistance. Tariq et al. [17] numerically and experimentally analyzed benefits of multiple perforations and slots in a plate-fin heat sink. It was established that enhancing of the heat dissipation rate and lower pressure drop with their new design of plat-fin heat sinks. The Nusselt number was 42.8% and 35.9% for perforations, slots plate-fin heat sinks respectively, for a range of Re number 13049 to 52195. Fan et al. [18] The total thermal resistance was lowered by up to 59% with a negligible pressure difference using a new cylindrical oblique fin heat sink. The enhanced thermal performance was attributed to the disruption and initiation of the boundary layer at the leading edge of each fin. The use of streamline-shaped fins, such as ellipse, drop-shaped, and airfoil fins to minimize flow resistance and maximize heat transfer throughout the flow channel, is another experimentally and statistically tested strategy.

Maji et al. [19] numerically improved rate of heat transfer by using different perforated pin fin shapes such as (circular,diamond, and elliptical). The results showed that an increases in Nusselt number about 12.1%, 13.9% and 14.8% for circular pin, diamond form and elliptical perforation pin respectively. Nilpueng et al. [20] experimentally enhanced sinusoidal undulating plate fin and cross-cut sinusoidal wavy plate fin heat convection in heat sinks. It was discovered that changing stage of shift and velocity of flow improved thermal transition and decline in pressure. Furthermore, the larger Nusselt number was ranging from (5.9 - 19.1) % with sinusoidal wavy plate-fin. Sara et al. [21]. The size of the perforations, the angle of the fissure, and the ratio of the open to the holed area have all been shown to have a substantial impact on the heat dissipation potential. Notches in rectangular blocks improve the rate of heat transfer, and the inclination of the perforated block has a positive impact on heat dissipation of up to 60.1% when compared to the straight block, according to the test rig with forced air flow within the tunnel. The inclination angle did not change noticeably, and the pressure drop remained lower for performance-graded blocks. The 77.1% increase in energy performance for perforated blocks over solid blocks was the most notable discovery.

3. Enhancement Geometry of a Heat Sinks

3.1. Pin shape fins

Elmi et al. [22] enhanced the geometrical parameters of a heat sink to improve the pin fin thermal and hydraulic effectiveness. Investigations were done on the pin fin geometry's decreased ratio. Variations in fin design have been shown to significantly affect pressure gradient and heat transfer. Moreover, it is discovered that the entire performance of the pin fin heat sink improves by more than 16.9 % throughout the optimization process. Alfellag et al. [23] performed numerically the thermal dissipation of a Metal Foam Pin-Fin Heat Sink (MFPFHS). The experiment involved reducing the top diameter while simultaneously expanding the bottom diameter. It was highlighted that the

MFPF optimizes thermal dissipation and eliminates frictional losses. Furthermore, the ultimate Nusselt number and friction factor of 740 and 0.63, respectively, were obtained at pins' height ratio is 2.5 and Re is 12000. Junaidi et al. [24] used (CFD) modeling and simulation to compare the fluid flow and heat transfer properties of conventional, splayed, and hybrid pin fins. Comparing the splayed pin fin heat sink arrangement to the typical heat sink configuration for the same pumping power, a (20–30) % improvement was noted using the splayed pin fin heat sink.

Kaladgi et al. [25] analyzed the temperature dispersion and heat flux of rectangular fins with and without perforations. The rectangular fins with 10 circular perforations were used and this circular perforations with embossing's and holes to compared between them. A considerable reduction in temperature was recorded, as well as an enhancement in heat transmission. The findings may be used to heat exchangers with rectangular fins.

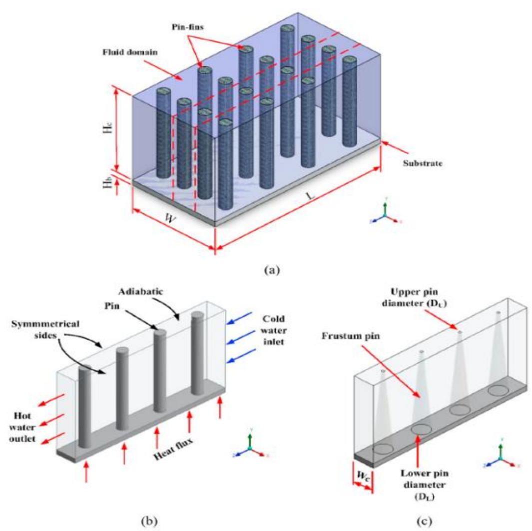

Figure 2. Heat sink with dimensions, computational domain with boundary conditions, and non-uniform pins are shown in the schematic diagram. [23].

Tsai et al. [26] PFHS performance was computationally shown to be impacted by plate shield configuration. To lessen the impact of air bypass, a plate shield was developed. They revealed that fin heights of 30 mm and 45 mm were appropriate candidates for a 90o inclination angle. Chingulpitak [27] analyzed numerically the rate of heat transfer through a perforated (PFHS). It was shown how the diameter and number of perforations changed. They discovered that the horizontally perforated (PFHS) with 75 circular perforations and a diameter of 3 mm had heat transfer rates that were almost 11% greater than those of the PFHS.

3.2. Mini Channel

Ghasemi et al. [28] studied experimentally and theoretically the effect of a hydraulic diameter of minichannel heat sink on thermal resistance. Three different hydraulic channel diameters were considered (D = 4 mm, D = 6 mm, and D = 8 mm). They obtained the highest heat transfer coefficient with a 4 mm diameter. They remarked that an increase in hydraulic channel diameter increases thermal resistance and decreases pressure drop. Chiu et al. [29] The impact of configurations and pressure drop on the thermal performance heat sink was researched numerically and empirically. In their study, the diameter of micro pin fin and porosity of fin array was employed. This experiment was performed under heat flux as high as 300 kW/m2 with a constant pressure about 3000 Pa. For varied pressure decreases, it was discovered that the effective thermal resistance would approach an optimum value. Kumar et al. [30] performed a numerical and experimental study to improve the thermal performance of the microchannel heat sink. Shapes were used in innovative designs straight, wavy, and branch wavy channel heatsinks. Generally, two mode of heat transfer was used conduction and convection. Reynolds number range was 300 to 1900, and the power input in the base of heat sink was 20W to 30 W.

The results showed that progress in Nusselt number more than 127% for the wavy channel heatsink and 148% for the branch channel heatsink. Li et al. [31] conducted a simulation study to optimized microchannel heat sinks. In their work used dual split cylinder. The Re ranges from (50 to 300) and a uniform constant heat flux of (5×105 W·m^{-2}) supplied at the microchannel. They concluded that the largest thermal performance was 3.1 at Re =300, and at Re=250, the largest relative increase in thermal performance from prototype to optimized model was attained, resulting in a 63.41% increase.

Through numerical simulation, Yan et al. [32] proposed a micro pin fin array heat sink with fin-shaped strips for flow heat transfer characteristics of single phase fluid. The micro fin shaped A pin fin (SMFAP) was the better performance of hydro-thermal than in-line micro cylinder pin fin (IMCP) which was SMFAP two times of IMCP at Re 1200 and pressure drop 1.49.

Hajmohammadi and Toghraei [33] analytically improved a double-layered microchannel heat sink using Al2O3-water nanofluid as cooling media by using the lowest possible thermal resistance as the objective for a certain pumping power rate. The results indicated that the double-layered microchannel heat sink had about 10% of the thermal resistance lowered. Zhang et al. [34] investigated a new design of double-layer microchannel heat sinks (DMHSs) with a top layer of dense, narrow fins and a bottom layer of thick fins with a relatively large space between them. They found that as compared to typical DMHSs with the same pumping power, our design was decreased the system's thermal resistance by 9.42 %. Ambreen and Hoe Kim [35] confirmed the best thermal performance of the circular fins by using nanofluid (TiO2) while the water-cooled square fins depicted the lowest heat transfer characteristics. This enhancement was obtained with nanoparticle concentration of 4.31 vol% of TiO2 nanofluid and Reynolds number range $250 \leq Re \leq 550$. Vasilev [36] et al. enhanced the efficiency of microchannel heat sink (MCHS) by using circular pin-fins in laminar fluid flow with varying diameters (0.26, 0.51 mm), heights was (0.1, 0.25, 0.4, and 0.5 mm), and different pin spacing to pin diameter ratios (3, 6, 12, and 24) Reynolds number from (100 to 1000). In consideration of pressure drop, Nusselt number, and total thermal resistance, the thermal and hydraulic performance of MCHS with no pins was studied. Furthermore, an efficiency factor was developed to evaluate the heat transfer efficiency of different types of MCHS in a comprehensive manner. The heat transfer efficacy factor considers both the increase in heat transmission and the reduction in energy consumption. They concluded that the greatest pin placement step sp was showed as six diameters dp of the pin: sp = 6 dp for the height of the pins hp (0.1 to 0.26) mm; for hp = 0.5 mm the effectiveness factor of MCHS has the maximum value at sp 3 dp. Bhandari and Prajapati [37] varied the fin height of square pin fins microchannel which owns open modification as a numerical study to enhancement the thermal convection and fluid properties. Fin height varying from (0.5 to 2.0) mm with a 0.25 mm spacing. Reynolds number ranges from 100 to 800, and heat power supplied at the base of heat sink was ranged from 75 to 150 kW/m2. They concluded that the better augmentation thermal performance was with 2.0 mm height. Furthermore, open microchannel heat sinks more thermal performance 75–80% as a compared with closed heat sink. Aliabadi and Nozan [38] performed an experimental study to investigate the cooling performance of minichannel heat sinks. The study compared various designs to the straight minichannel heat sink, including sinusoidal, trapezoidal, and triangular shapes. The findings demonstrated that the trapezoidal had a stronger effect than the triangular and sinusoidal on convection heat transfer. The Nusselt number of the trapezoidal, triangular, and sinusoidal heat sinks was improved by roughly 50%, 45%, and 32%, respectively, by increasing the corrugation amplitude from (0.5 mm to 1 mm). Saad et al. [39] investigated briefly a water cooled mini-channel heat sink that simulates a microchip with a high heat output. The effect of sink shape on water was studied. With a flat plate heat sink, the fin spacing of the five heat sinks was (0.2, 0.5, 1.0, and 1.5) mm, respectively. By lowering the fin spacing and increasing the volumetric flow rate of water that circulates through the heat sink, the base temperature and thermal resistance of the heat sinks was lowered. Chai et al. [40] evaluated rectangular ribs put into transverse (interrupted) microchannels. The ribs' position and length were the two variables, along with their width. Only at Re=600 did the researchers come to the conclusion that the interrupted microchannel with ribs was a successful passive technique for improving heat transmission. It has been established that, the peak power consumption of high-performance desktops will increase by 96.2% (147–288 W) in 2016 and by 95% (91–158 W) for low-end desktops. They inspired the researchers to adapt this technique to other engineering fields, such as pharmaceutical applications, refrigeration, and chemical engineering. Chandra et al. [41] accomplished a cutting-edge investigation that showed the results of changing the periodic cross-section of microchannels. A convergent divergent micro channel flow was examined using numerical simulation, and improvements in heat transfer were shown for samples with different cross-sections. It was determined that the proposed microchannels with varied cross-sections exhibit a large pressure drop but a significant improvement in heat transfer. In such sections, the average Nusselt number was (1.5 - 2) times higher than in normal microchannels with uniform dimensions.

4. Enhancement of heat sinks by porous media

To increase heat transmission, Rehman and Ali [42] examined metallic foams made of copper and nickel with phase change material (RT-54HC). When they applied a copper foam combined with phase change material, their testing findings revealed that the surface temperature of the heat sink was reduced. According to their conclusions, when power was applied at 24 W, copper foam with a 0.8 volume concentration of phase change material decreased the surface temperature by about 26% more than nickel foam without phase change material. Farahani et al. [43] examined three different geometries microchannels such as (circular, square and flattened circular) numerically. To enhanced the thermal and hydraulic performances they used nanofluid, porous material and phase change material (PCM) filled up microchannels. The result showed that square geometry of microchannels achieved the best heat transfer compared to the other two shapes. Additionally, the heat transfer coefficient of MCHS with PCM was typically 47% and 17% better than that of a microchannel with a porous substrate and a microchannel with a porous layer and nanofluid, respectively. Ranjbar et al. [44] numerically examined the impacts of force convection heat transfer on the porous metallic pin fins with varied configuration and forms. In this study, five fin forms (rectangular, decreasing, increasing wedge-shaped, and V-shaped, with two assorted fin configurations (aligned and staggered) were considered. They found that the best performance was from the lowering -aligned pin fin. Kumar et al. [45] studied the effects of various PCM materials on heat transfer in heat sink layouts with varying numbers of slots (1 to 36), created by the combination of cross plate fins. The heat flux values were varied (1, 1.5, and 2 kW/m^2). A maximum temperature decrease of 10.1˚ C was attained when comparing HS with 25 cavities to HS with a single cavity. When the heat flux values are increased from 1 to 2 kW/m^2, the melting time of the PCM is reduced by 47 % for HS with 36 cavities. According to the results of the study on the impact of PCM type, paraffin wax was best for electrical equipment with crucial set point temperatures (SPT) between 60˚C and 70˚C. Behi et al. [46] presented a composite configuration of heat pipe and PCM for cooling electronic equipment. According to experimental and computational data, this hybrid system offers more than 87 % of the provided thermal efficiency in the (50 to 80)W. Hosseinizadeh et al. [47] investigated experimentally and numerically the effects of various parameters, on PCM based heat sinks. It has been demonstrated that increasing the number and elevation of fins improves the cooling efficiency significantly. However, the increase in fin thickness is only marginally beneficial. In addition, it has been discovered that there exists an optimum value for fin thickness, above which the effectiveness of the heat sink degrades.

5. Enhancement of Heat Sinks by Working Fluid

Bahiraei et al. [48] The hydraulic and thermal performance of a heat sink with (miniature round, triangular, and drop-shaped) pin fins and a coolant formed of green graphene nanosheets nanofluid was examined. The results showed that in terms of thermal performance, circular fins outperformed triangular and drop-shaped pin fins. Additionally, a concentration increases from 0.026 to 0.08 percent lowers thermal resistance by 3.4 percent. Additionally, the power needed to pump heat away from the water when nanoparticles were added had little impact. The impact of TiO_2 and SiC-water nanofluids (0.8 - 4 vol %) on the thermal performance of (MiCHS) was investigated by Moraveji et al. [49]. They demonstrated that employing nanofluids increased the rate of heat transmission, especially as the concentration and number of nanoparticles increased. With an inaccuracy of roughly 5% for both equations, they correlated two correlations: one for the Nu number and the other for the friction factor. In their correlations, they took the concentrations of nanoparticles into consideration.

Usman et al. [50] carried out an experiment on 64 pin-finned triangular heat sinks filled with paraffin wax, RT/44, and RT/35HC with volume fractions of 9% and PCMs of 90%. The range of the overall power output was 5 to 8 W. The triangular inline pin-fin was said to be the most efficient and consume the least CPU power. To accomplish the greater improvement, a passive cooling technique utilizing the (RT-44) PCM was applied. Alhusseny et al. explored graphitic foam heat sinks statistically to create convective heat transfer. [51] . The heat sinks were made of staggered foam baffles that allowed the coolant stream to be (horizontal or vertical), reducing pressure loss while maintaining high thermal dissipation. It was discovered that the proposed heat sinks were adequate to handle the high-performance electronics' excessive thermal needs. Ho et al. [52] investigated the impact of varying concentrations of Al_2O_3 nanoparticles dispersion on the hydrodynamic and cooling parameters of the minichannel heat sink experimentally. For heating the heat sink, a uniform heat flux in the limit of (1 to 7) W/cm^2 was used, with a Reynolds number in the range of (238 to1549). They revealed that the best thermal performance with Al_2O_3/water nanofluid. Additionally, the highest values of heat transfer performance were 1.39 when Reynolds number of 1549. Al-Damook et al. [53] used different nanofluids to simulate the forced convection heat transfer performance of mini-pinned heat sinks. In their study, they considered various pin heat sinks such as (circular, square, triangular, strip, and elliptic) as well as without pin heat sinks with three different types of nanofluids—Al_2O_3water, SiO_2water, and CuOwater. The concentrations of nanofluid ranged from 0 to 5 vol percent, with Reynolds numbers ranging from (100 to 1000). They discovered that an elliptic-pinned heat sink with a reasonable pressure drop had the best energy and exergy efficiencies, which were approximately 76.1% and 57.1%, respectively. Mahdieh et al. [54] conducted experiments to determine the impact of nano- phase change materials (NPCM) on the heat removal capabilities of electronic circuits operating under free and forced air convection regimes. 1000–4000 W/m^2 heat fluxes were applied to an inorganic salt hydrate composed of PCM, (NO3)2, and (Fe3O4) as a nanoparticle filled heat sink. The behavior of constant temperature, operational duration, and temperature against time was explored. It was determined that heat sinks with (PCM and NPCM,) reduced the steady temperature by 14.1^{o}C and 10.51^{o}C, respectively, compared to heat sinks without PCM under free and forced convection scenarios with a (4 kW/m^2) heat flow. It was also revealed that, for intermittent use, NPCM heat sinks with 2000 W/m^2 have superior performance due to their longer working life, whilst PCM filled heat sinks proved to be more modern for fluxes of approximately (3 kW/m^2).

6. Conclusion

In this paper, the methods used to improve the hydrothermal performance of heat sinks are examined. In order to optimise the thermal design of heat sinks, this article investigates fin forms as well as orientations, the addition of porous media, and additives to traditional working fluids. The inclination angle, orientation, and Ra number each play a significant role in enhancing energy transfer from the heat sink. Researchers must continue to concentrate on natural heat transfer convection in order to speed up the heat transfer rate of heat sinks. The amount of heat released from a heat sink may increase in response to an external stimulus, such as agitation and pulsation flow. The most cutting-edge cooling design for heat sinks can be achieved by adjusting the number of fins, fin layout, and channel form. Great heat transfer was demonstrated by heat sinks with porous media and perforated fins, but the rise in pressure drop should be appropriately taken into account, especially when working with dense and high concentration nanofluids, such those containing nanoparticles. The miniaturisation of heat sinks yielded outstanding results in both hydraulic and thermal effectiveness.

Conflicts of interest

The authors have no conflicts of interest.

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Summary of survey

№	Author name	Type of study	Type of heat sinks	Type of flow	Type of boundary conditions	Boundary conditions	Nusselt number increase (%)
1	Tariq et al. [17]	Numerical and experimental	plate-fin heat sink	Turbulent	Constant heat flux	Reynolds number(13 049 to 52195)	42.8% and 35.9%
2	Alfellag et al. [23]	Numerical	Pin-Fin Heat Sink	Laminar	Constant heat flux	Reynolds numbers= 12,000	174
3	Kumar et al. [30]	Numerical and experimental	straight, wavy, and branch wavy minichannels	Laminar	variable heat flux	Reynolds number(30 0-1900)	148% and 127%
4	Ho et al. [52]	experimental	minichannel heat sink	Laminar	uniform heat flux in the limit of 1.2–6.8 W/cm2	Reynolds number=(2 38–1549)	1.4
5	Al-damook et al. [53]	Numerical	mini-pinned heat sinks	Laminar	Nanofluid concentratio ns ranged from 0 to 5 vol %	Reynolds number= (100 – 1000)	76 % and 57%

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