International Journal of Advanced Technology in Engineering and Science
Vol. No. 12, Issue No. 03, March 2024
www.ijates.com
ijates
ISSN 2348 - 7550

HEAT TRANSFER ENHANCEMENT TECHNIQUES FOR HEAT SINK: A COMPREHENSIVE REVIEW

Mr. Amol More[1 a, b], Dr. Sanjeev Kumar[2], Dr. Sandeep Kore[3]

[1a]*Research Scholar, Mechanical Engineering Department, SunRise University, Alwar, Rajasthan*

[1b]*Assistant Professor, Mechanical Engineering Department, AISSMS'S Institute of Information Technology, Pune email – amolmorecoep@gmail.com*

[2] *Dr. Sanjeev Kumar, Associate Professor, Mechanical Engineering, Sunrise University, Alwar (Rajasthan), email - er.sanjeevkundu@gmail.com,*

[3] *Dr. Sandeep Kore, Associate Professor, Mechanical Engineering Department, Vishwakarma Institute of Information Technology, Pune email - sandeep.kore@viit.ac.in*

ABSTRACT

The effective dispersal of thermal energy from mechanical and electronic devices is a critical function of heat sinks, especially in the dynamic electronic industry. The convergence of rising power efficiency and the need for miniaturization has underscored the significance of creating heat sink configurations that are not only efficient but also capable of maintaining performance without necessitating expansion. This review article provides an exhaustive examination of recent developments in heat transfer enhancing methods, with a specific emphasis on a range of heat sink configurations and design approaches. Thermal efficiency expressed as a pin termination circular and pin fin square is assessed in the present research, Pin Fin Elliptical, and Channel Heat Sink designs. Comparative results indicate that Pin Fin Circular exhibits good performance, while Pin Fin Elliptical shows better results. The numerical analysis includes considerations of thermal performance, surface area, manufacturing complexity, and 2D models. Pin Fin Circular, with its efficient heat dissipation and moderate

INTRODUCTION

A heat sink works as a silent heat transfer mechanism designed specifically to absorb and released heat generated by mechanical or electronic equipment. Heat sinks, that are frequently built from high thermal conductivity materials like metal or copper, are fixed to heat-generating regions that require the effective heat dispersion[1]. For the complexity, emerges as a promising option. The paper evaluates the applicability of additional manufacturing processes, including EDM, etching, casting, extrusion, and machining, for prototyping and mass production. A detailed investigation of manufacturing methods shows that, contingent upon the method used, Pin and Channel designs possess unique merits and demerits. In addition, the study emphasises the importance of cost aspects

during the design process. Also, the assessment examines the current status and potential future advancements of heat sink technology, placing particular emphasis on the necessity for unique designs, materials, and versatile manufacturing methods. The incorporation of Nano fluids technology and the exploration of structural design perspectives are identified as potential avenues for future research. This work aims to provide a comprehensive overview of recent developments in heat sink technology, offering insights into thermal performance enhancement and guiding future studies in this critical field.

Keywords: Heat Sink; Heat Transfer, Optimization, flow Structure Design, PCM, Nano fluids, Pins Foil Oval, Pin Fins purpose of increasing heat dissipation, fins augment the outer area of heat sinks.

As an effect of the electronic industry's progression towards miniaturization and higher electrical density, The amount of heat flow per area has risen significantly. As a result, in order to ensure the continuous and secure functioning of electronic components, quickly and efficiently reducing produced heat was fundamental[2]. A wide range of heat sinks is present mainly defined according to their design and construction. Prominent examples include disc fin or pin fin heat sinks. This Disc Fin Heat Sink is visually represented in Figure No.1, that indicates its dimensions in terms of length, width, and height (L, W, H). Plate fin and circular pin fin thermal collection devices have been significantly applied in electronic cooling applications owing to their basic design and manufacturing easiness. In addition, sources of heat can be divided in accordance to the methods of transferring heat, such as forced convective transfer of heat and natural heat transfer[3]. The decreased amount of surface area and high heat flux have emerged as a fundamental concept in the quest to enlarge and diminish the mass of electronic components. A significant number of scholars are now occupied in exploring the potential of heat sinks with the aim of augmenting heat transmission. Increasing flow interruption and decreasing the temperature of the boundary layer are both strategies. Flow infringement, the boundary layer division, interface aerodynamics, and airflow turbulence, and variations in structure all affect the efficiency in heat transfer[4]. Manufacturing processes for heat sinks encompass extrusion, machining, and skewing, predominantly utilizing highly conductive materials like Copper and Aluminum To enhance the transmission of heat, the thermal boundary layer has to be reduced and flow interruption is needed via the strategic positioning about obstructions in the flow path An in-depth comprehension of the transfer of heat and fluid flow originating from thermal sinks is essential for its effective functioning and design.[5].

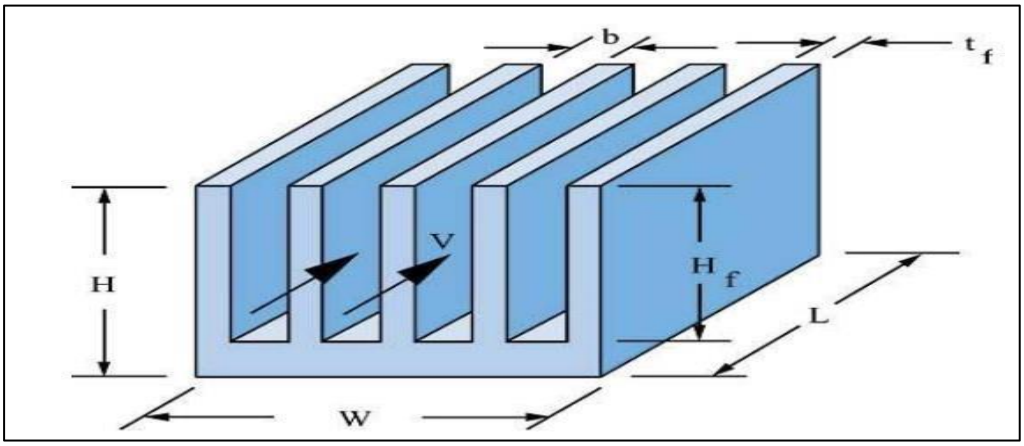


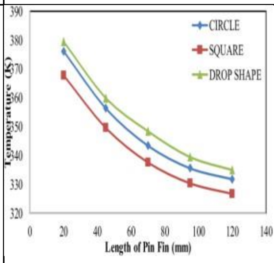
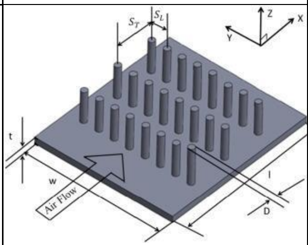
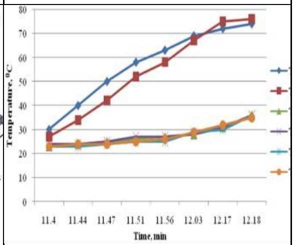
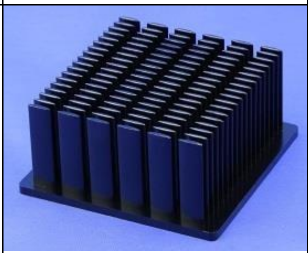
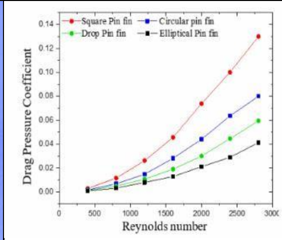
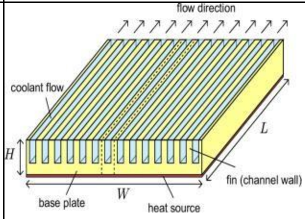
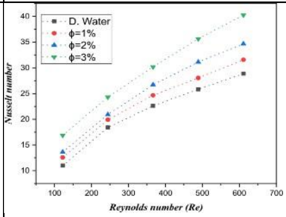
Figure No.1 Typical view of Plate Fin Heat Sink

The purpose of this article is to classify the fundamental exchange of heat principals and structural features of the different heat sinks, give an overview of these heat sinks, and analyse the remaining difficulties before concluding with recommendations regarding subsequent investigations and heat sink optimisation.

Development of Heat Sink

As a result of the growth of numerous industries, there is a greater need for efficient thermal has risen constantly over the course of recent years. The application of heat dissipation technologies that are highly efficient is critical over the chilling process of gas turbine blades. Due to their susceptibility to variations in temperature, lithium-ion batteries require effective heat dissipation dissipation to prolong the useful life of devices within these industries. The resolution of temperature dissipation issues posted significant obstacles to the development of a wide range of apparatus, including spacecraft, electronic devices, gas turbines, and lithium-ion batteries. Critically associated with extreme temperatures, thermal damage is a fundamental factor contributing to malfunctions[6]. The operating fluid's boiling point in gas turbines systems to maintain an extended cycle life Significant quantities of heat produced by satellites must be dispersed into space mainly via atmospheric radiation; under certain conditions, heat dispersion becomes hazardous [Add Comparison of Pin fin circular, square, elliptical with Channel Heat sink graphically and 2D figures] and These appliances are able to produce heat fluxes between 80 as well as 1000 W/cm2 while having operational durations between 5000 hours and two decades. Highly varied environmental conditions occur for high-temperature applications, such as open environments, limited channels, and high vacuums. As a result, a significant amount of research has been devoted to improving the overall cooling efficiency of diverse heat sinks through structural design modifications.

Table No.1 Comparison of Pin Fin Circular, Square, Elliptical with Channel Heat Sink

Criteria	**Thermal Performance**	**Surface Area**	**Manufacturing Complexity**	**2D Model**	**Graphical Comparison**
Pin Fin Circular	- Efficient heat dissipation due to increased surface area	- High surface area due to radial arrangement of fins	- Moderate complexity due to circular fin arrangement		
Pin Fin Square	- Good thermal performance	- High surface area with a square layout	- Moderate complexity due to square fin arrangement		
Pin Fin Elliptical	- Enhanced performance compared to circular fins	- Increased surface area with elliptical shape	- Moderate complexity due to elliptical fin arrangement		
Channel Heat Sink	- Effective cooling through fluid flow	- Surface area depends on channel geometry	- Complex manufacturing due to channel structure		

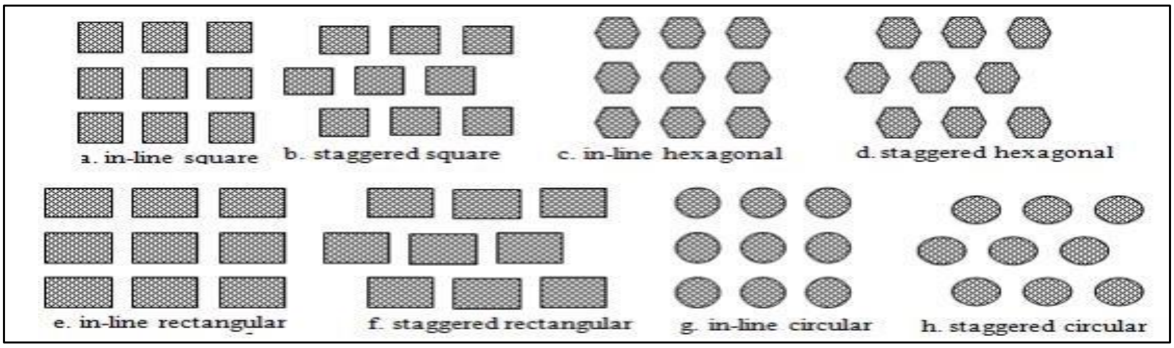


Figure No.2 Configuration of a Pin fin Heat sinks and Variable Forms

Evolution of the Heatsink Technology

The development of condensation technology has been an extraordinary one, characterized by ongoing developments in methods to improve heat transfer. Electronic devices, including computer systems and electronic components, depend significantly on heatsinks to avoid thermal damage and disperse heat generated during operation[15]. Over the years, the demand for more efficient and compact electronic devices has driven the need for innovative heatsink designs. Early heatsinks primarily relied on simple finned structures to increase surface area and facilitate heat dissipation through natural convection. However, as electronic devices became more powerful, traditional heatsinks faced limitations in their ability to handle higher heat loads[16]. This prompted researchers and engineers to explore and develop novel heat transfer enhancement techniques. One significant advancement is the integration of heat pipes into heatsink designs. Heat pipes are highly efficient in transferring heat over long distances with minimal temperature gradients[17]. By incorporating heat pipes into heatsinks, thermal conductivity is significantly improved, leading to enhanced overall heat dissipation. This breakthrough allowed for the development of heatsinks that could handle more demanding thermal requirements[18]. Another noteworthy evolution is the use of advanced materials with superior thermal conductivity properties. Materials such as copper and aluminum have been commonly employed in heatsink manufacturing, but the quest for better performance has led to the exploration of materials like graphene and carbon nanotubes. These materials offer exceptional thermal conductivity, paving the way for heatsinks that are not only more effective but also lighter and more compact[19]. Furthermore, the design of heatsink fins has undergone significant optimization. Engineers have explored different fin shapes, sizes, and arrangements to maximize surface area and improve heat dissipation efficiency. Additionally, the introduction of advanced manufacturing techniques, such as additive manufacturing, has enabled the production of intricate heatsink designs that were previously challenging or impossible to achieve[20]. The evolution of heatsink technology has been characterized by a continuous quest for improved heat transfer performance. From traditional finned structures to the integration of heat pipes and the use of advanced materials, each advancement has contributed to the development of heatsinks capable of meeting the escalating thermal demands of modern electronic devices[21]. As technology continues to progress, the future holds the promise of even more innovative and efficient heatsink designs[22].

The fundamental principles of heat transfer in heat sinks

The amount of distribution of heat within structures is regulated by various types of heat sinks through the application of the three fundamental heat transfer principles. The principles of conduction, radiation, and conduction are as follows. The supplementary law of thermodynamics states that thermal energy flows inherently from areas of higher temperature to areas of lower temperature. This process is influenced by temperature differences[23]. By applying this theory of heat transfer, an investigation to heat diffusion can be performed. Thermal conduction occurs when energy is transferred from an area of higher temperature to an area of lower temperature within a body that varies in temperature. The relationship between the thermal transmission velocity and the thermal differential in the straight line is inversely proportional, as denoted by $c/\boldsymbol{G}\partial T/b$. In order to measure that association, a proportionality constant is utilized.

$$q = -KA\frac{\partial T}{\partial x} \quad (1)$$

dynamics, heating is not the exclusive means of transfer of heat; thermal convection encompasses both the direct conveyance and transmission of q and H represent the heat transfer flux and the path of the temperature gradient, respectively, through which the heat flows. Since thermal conductivity ($\boldsymbol{\Psi}$) is an essential characteristic of materials, it is customary for it to have a positive value. The equation (1) illustrates Fourier's principle of heat conduction. Within the realm of fluid

$$q=hA(Tw-T\infty) \quad (2)$$

The heat transfers between a fluid and a stationary wall is affected by both the surface area and the temperature difference (denoted as A). The heat transfer flux, expressed as h, is correlated with the positive constant convection heat transfer coefficient. In general, the determination of h requires experimental measurements. In a vacuum environment, transmission of heat is also possible via a distinct mechanism referred to as thermal radiation. In contrast with convection and conduction, which relate to the transfer of heat via material mediums, radiation from heat works in the atmosphere vacuum. The rate at which a black body emits thermal energy correlates with the fourth factor of its actual temperature, as stated in the thermodynamic rule. The surface area of the body also exerts an influence on this rate. energy through mass. Convection that is generated in response to an outside force is called "forced convection." Conversely, natural convection pertains to the generation of flow through a disparity in temperature and density gradient. To explain all of the thermal convection effect, the theoretical method known as Newton cooling was utilized conduction. Contact thermal resistance becomes a vital indicator for evaluating heat transfer efficiency between interfaces, influencing the heat dissipation capacity. In general, thermal power is transferred to the source of heating to the heat sink base via conduction. This highlights the importance of considering contact thermal resistance when striving to achieve optimal heat sink performance. Seven thirteenth, twentieth, and nineteenth (20) sections of the MDPI The reduction of thermal resistance in contact is a cross-scale, multidisciplinary problem. One approach to accomplish this is by filling the contact gaps with materials that possess varying thermal conductivities. Due to ongoing progress in contact thermal conductivity research in recent years, a variety of scholars have implemented findings from previous investigations into the fields of aerospace, aviation, mechanical manufacturing, and microelectronics. Jingnan Li et al. (2023) In order to enhance the heat dissipation qualities pertaining to an Insulated Gate Bipolar Transistor (IGBT) Press-Pack, a study had been done to the thermal properties of its $qemitted=\sigma AT$ (3) contact with the substrate.

The Stefan–Boltzmann constant, indicated as σ, functions as the constant of proportionality.

Heat transfer-based solutions for heat sinks

In order for thermal energy to be dissipated in an alternative heat source, the heat sinks' electrical conductivity must be increased. Difficulties often manifest on solid-solid surfaces, rather than being attributable to the conduction of the substrate materials. As a consequence of discrete local areas introduced by machining limitations, the actual region of contact between the source of heat and heat sink might be significantly less than that of the macroscopic contact area. This discrepancy gave rise to a barrier to the transfer of heat called contact thermal resistance. It consists of the extra resistance generated by the contact gap-induced contraction of the heat path, which negatively impacts heat To ensure that interface thermal resistance is a limitation on IGBT heat dissipation and to demonstrate that interaction thermal resistance can be calculated by pressure, a comparison was made between a mathematical simulation that established interaction interface thermal resistance and the results of simulations generated by the simplified framework. By depositing just a small amount of graphite through the contact area interface, the contacting thermal resistance was decreased, thereby increasing the overall dissipation of heat of the Press- Pack IGBT[24].

Anusha A et.al (2023): While changing the rate at which energy is transferred from a heated fluid to a frigid fluid, the Heat Exchanger demands the smallest amount of initial expenditure and ongoing maintenance. This method guarantees that no fluids

are combined. Due to the elevated temperatures and pressures at which they are operated, Shell Energy as well as Tube Heat Exchangers continue to experience advancements in both heat transfer rate and efficiency. A construction method for a tube and shell heat exchanger that improves the rate and efficiency of heat transfer is proposed in this study. A tube, a shell, an internal tube inlet, a shell departure, barrier plates, and an oval tubular bundles, as well as a baffle pitch comprise its construction. The design of the heat exchanger outlined in this document incorporated three alternative pitches—Pitch-80, Pitch-60, and Pitch-40—which exhibited comparable temperatures of both heated and chilly water. In the present invention (Fluent), the helical baffle configuration is altered with different specifications utilizing Pitch-80, Pitch-60, and Pitch-40. The simulation of the invention is conducted using ANSYS R19.2[25]. **Abhay Gudi et.al (2022)** The ongoing reduction in the size and shape of electronic devices has created a significant challenge in the realm of effective heat dispersion. The primary goal of the present investigation is the implementation of a novel hybrid methodology that enables enhanced heat transfer.

Solutions Utilizing Convection for Heat Sinks

The passage provides an analysis of the prevailing techniques utilized in modern heat sinks to dissipate heat, with an emphasis on air and liquid cooling. Heat sink design is highly dependent on the principles of convective heat transfer. The categorization of heat sinks is predicated on the particular force that drives of convection. These encompass conduction-forced heat sinks, convection from the air heat collapse, transitional phase heat sinks, and Nanofluid-based heat sinks. Each classification signifies a distinct methodology for enhancing heat dissipation efficiency in the design of heat sinks.

Muhammad Zarif Bin Shaharudin et.al (2023) Over an extended period, the electronic goods industry has tried to boost the efficiency of heat sink cooling by developing ever more advanced and efficient cooling technologies. However, the main obstacle continues in the design of heat exchange as an outcome of the complex structure and excluded surface area marked for cooling equipment. The impact of the direction of flow on the thermal fortitude of each of the suggested layouts is examined in this paper. The fillet material that was removed from the lower portion of the fin was used again in order to create a half-circular pin with an asymmetrical and corrugated connection to the plate- fin. This study examined plate-fin heat drains with and without joint morphologies and proposed two novel designs for plate-fin heating drains featuring half-round pins affixed to the fin.

Radiation Solutions for Heat Sinks

In outer space, where there is no atmosphere, the process of heat disposal by convection is almost impossible. The majority of the heat that is produced by the components of the spaceship is subsequently transported into space by thermal radiation. This occurs when the components are in touch with each other, which causes the heat to be conducted by the components. In radiative heat sinks, the most important metrics to consider are the heat transfer area and the electromagnetic that is released by the body. Currently, the heat sinks that are used in spacecraft’s have a significant mass and volume, which has a negative impact on the overall architecture of spacecraft's as well as the entire weight of the launch.

Yiqi Zhao et.al (2023) The passage examines the urgent need for the advancement of high-power spacecraft in the pursuit of deep space exploration. Placing considerable importance on the development of lightweight and efficient space-based cooling systems, this research suggests that the heat from the radiant source flow rate per unit mass can be increased by incorporating surface microstructures such as "wave rib," "triangular rib," and "arc rib" onto conventional plate radiation fins. The investigation employs COMSOL Multiphasic simulates the impact of parameters on the efficiency of heat dissipation, uncovering the most effective configurations and mechanisms related to radiation dissipation and thermal conductivity.

Yuxin You et.al (2021) The utilization of heat absorbers considerably in electronic equipment with a high heat expulsion. The placement and manufacturing of microstructures onto heat sinks have been demonstrated to be extremely beneficial in increasing their heat dissipation powers. Four distinct methods of treatment were used in this research to alter the microscopic characteristics of heat drain surfaces. Furthermore, to augment the heating and cooling capacities for the heat sink surfaces, a layer of thermal reflection coating was implemented. An examination was undertaken to assess the heat dissipation efficacy, surface irregularity, and thermal emissivity of the heat sinks, both in the presence and absence of a thermal radiation coating. The findings indicate that an increase in surface irregularity can lead to a 2.5-fold increase in thermal emissivity.

Xuejian Wang et.al (2023) Incorporating infrared heat exchange among fins, experiments and a self- constructed three-dimensional multiphasic model investigate the effect of shaped heat sink parameter variations on the performance of thermoelectric systems. The quantity, roots, as well as tip width of fins influence the loss of heat and electrical output, according to the findings. The optimal configuration consists of seven fins, a root width of 4 mm, and a terminal width of 4 mm. The research paper presents two design schemes that optimize the fins. One of these schemes increases power density by 30%, while the other adds 50.83% of electrical power without compromising the original power density. Important insights regarding the design of heat sinks for thermoelectric systems are provided.

Heats Sinks with Phase Change Material :

Huang et al. (2020) For enhanced flow boiling trials with ammonia, a revolutionary circular micro pin-fin heat sink was proposed, which combined an internal inlet jet configuration with a micro pin-fin structure. Through the investigation of various parameters such as pressure, inlet conditions, heat and mass fluxes, and saturation temperature, they provide major benefits to the field

Ling Tao et.al (2022) Enhancing the transmission of heat performance has emerged as an urgent issue that requires immediate attention during the development of fusion apparatus on a large scale. It is crucial to conduct research on heat transfer performance enhancement in order to figure out the design parameters of high heat flow elements of fusion reactors in a scientific and reasonable manner. This is accomplished through an in-depth and efficient investigation into the process of heat transfer and its sensitive factors. I The improvement of heat transmission effectiveness has grown into a pivotal issue necessitating urgent consideration throughout the large-scale development of fusion apparatus.

Gennaro Criscuolo et.al (2010) Experimental characterization of the transfer of heat in micro-milled multi-microchannel metal heat sinks working with flow boiling is the objective of this research, which is aimed at contributing to the creation of novel power electronics thermal management systems with high heat flux. The investigation was carried out with R-134a as the working fluid and an approximate output concentration temperature of 30

C. The microchannel measured 1 centimeter in length and occupied a 1 centimeter square footprint.

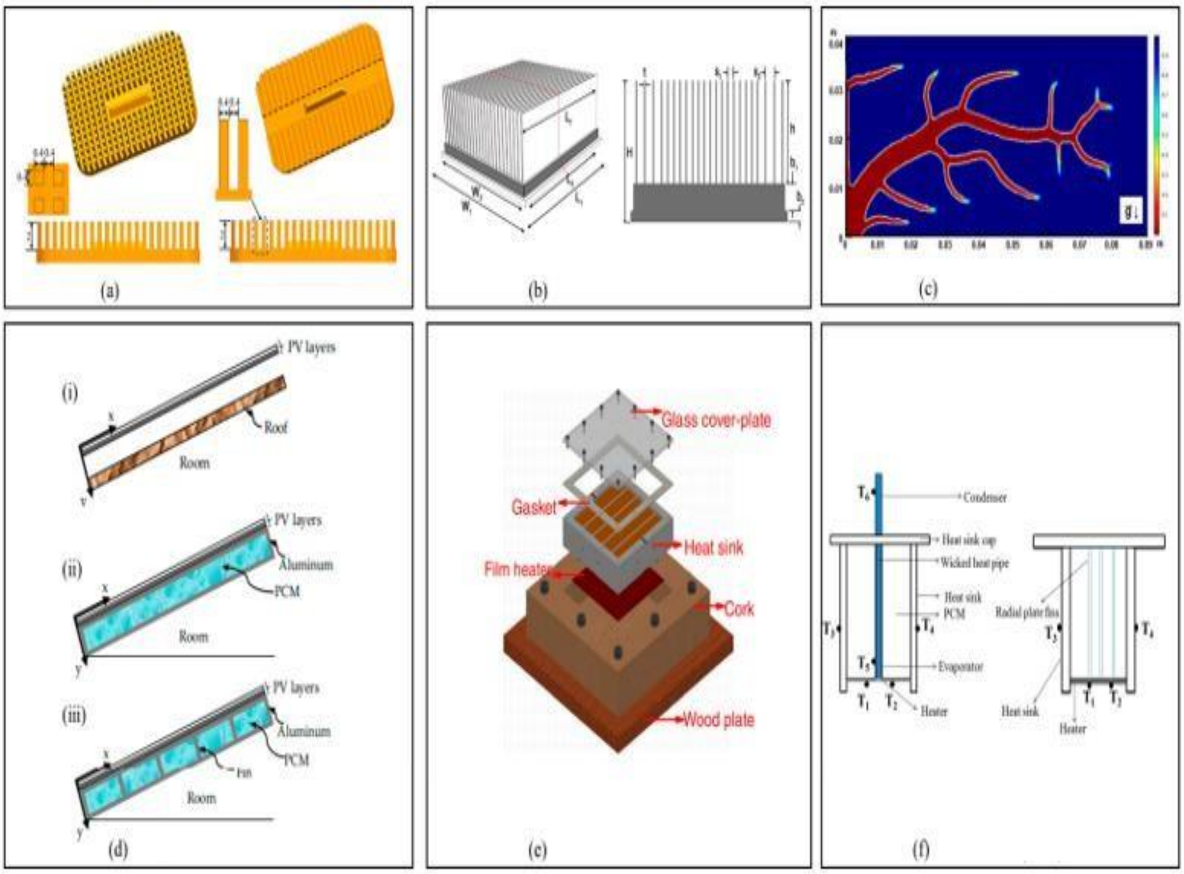


Figure No.3 Phase Change Heat Sinks

Table 2 Typical characteristics of N/MPCS operating in mini/microchannels found in experimental studies.

References	Base Fluids	Core Materials	Shell Materials	Size Distributions	Phase Change Enthalpy, Kj/Kgs
Rao et. al.	water	n-octadecane	PMMA	4.97 µm	241
Kuravi et. al.	water	n-octadecane	PMMA	1-5 µm	120
Dammel and Stephan	water	n-eicosane	PMMA	1.5-12 µm	247.3
Wu et. al.	PAO	tetraethoxysilane	silicon	150-1000 nm	19.6
Sinha-Ray et. al.	alpha-olefin oil	wax or mesoerythritol	carbon nanotubes (CNTs)	nano	200

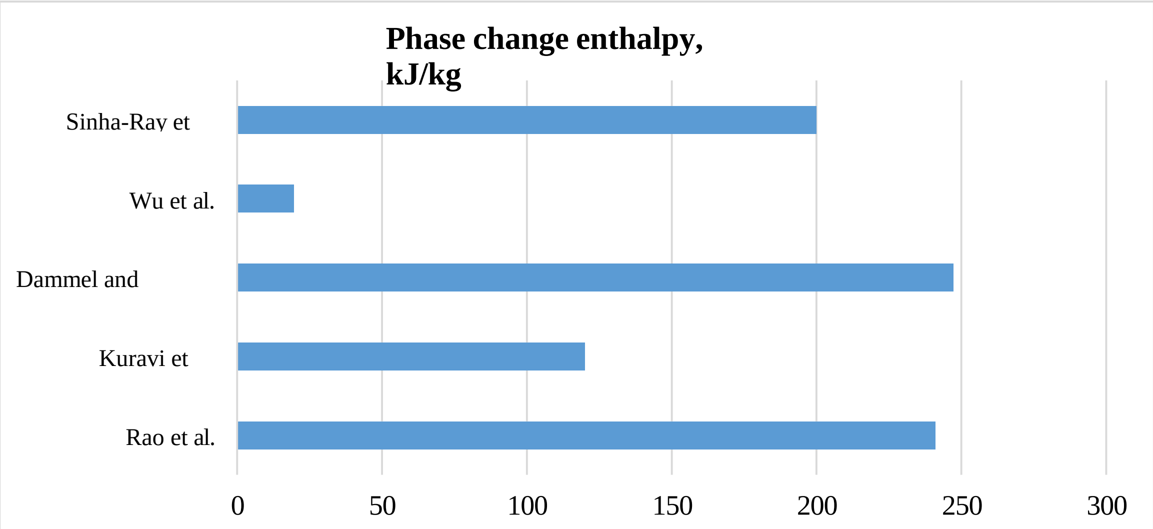


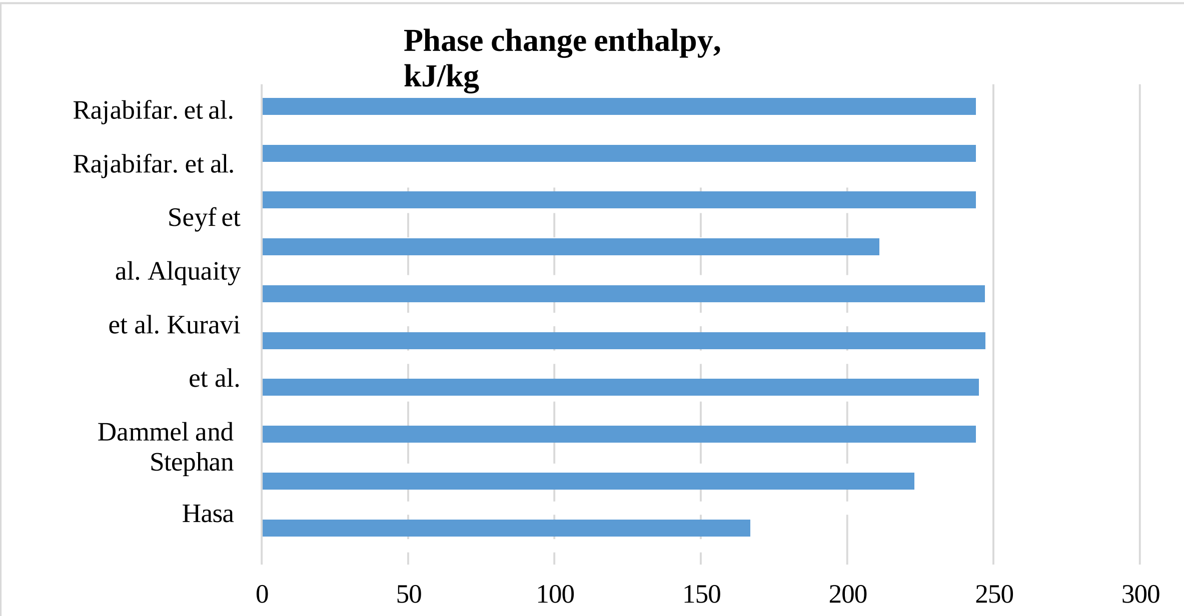
Figure No.4 Phase change enthalpy, kJ/kg in studies of different authors

Table 3 Exemplary characteristics of N/MPCS circulating in mini/microchannels derived from analytical along with numerical studies.

References	Base Fluids	Core Materials	Shell Materials	Size Distributions	Phase Change Enthalpy,

					Kj/Kgs
Hao and Tao	water	n-octadecane	melamine-formaldehyde resinous	0.244-10 µm	167
Xing et. al.	water	n-octadecane	melamine-formaldehyde resinous	6.3 µm	223
Kuravi et. al.	water and PAO	n-octadecane		4.97 µm	244
Hasan	water	n-octadecane	PMMA		245
Dammel and Stephan	water	n-eicosane	PMMA	1.5-12 µm	247.3
Kuravi et. al.	PAO	n-octadecane		nano	247
Alquaity et. al.	water	lauric acid		nano	211
Seyf et. al.	water	PAO			244
ajabifar. et. al.	water	n-octadecane		nano	244
Rajabifar. et. al.	water	n-octadecane		100 nm	244

Figure No.5 Phase change enthalpy, kJ/kg in studies of different authors



Abhijeet Gaikwad, et.al (2022) This article offers a comprehensive examination of the design and optimisation of thermal heat sinks. Strategies for enhancing heat transfer are described in depth, followed by trends and geometries in fin design and an evaluation of the merits of various fin configurations. A summary of significant experimental results and breakthroughs pertaining to the optimisation and design of fin geometries has been provided. To optimize the performance of heat sinks for complicated heat dissipation applications,

The review incorporates a wide array of studies collected from respected publications, with the "Other" category comprising the largest proportion (32%) of the literature. This category seems to comprise contributions from diverse sources that were not overtly identified in the data, indicating that the comprehensive assessment adopted a broad and encompassing approach. 15% of the journal's content is devoted to Advanced Thermal Engineering, a reputable publication that indicates an emphasis on the implementation of thermal transfer enhancement methods in the context of heat sinks. Part A: Applications of Numerical Heat Transfer scientists have been investigating various fin configurations, particularly inclined fins. In addition to inventive fin designs, these are also attracting interest as microchannel for thermal dissipation. Recent developments have been discussed in this field. Technological advancements in technology and control systems are leading to the improvement in the size and complexity of new components. Consequently, this article also addresses the utilization and enhancement of heat sinks for contemporary applications.

makes a 3% contribution, emphasizing the importance of numerical simulations for comprehending and optimizing heat dissipation. Prominent scholarly publications, namely Powder Technology (4%) and International Journal of Thermal as well as Fluid Flow (3%) among others, offer valuable perspectives on the subject of heat transfer and the influence of particulate matter, respectively. The considerable proportion of 17% devoted to Experiment Thermos and Fluid Science signifies a robust focus on empirical investigations that provide tangible verifications of techniques for augmenting heat transfer. By including studies that address both heat and mass transfer aspects, International Communications in Heat and Mass Transfer (14 percent) and International Journal of Heat and Mass Transfer (5 percent) contribute to a broader scope. In conclusion, the International Magazine of Thermal Sciences maintains a 7% market share and offers an equitable distribution of thermal sciences and fluid dynamics content. The review's comprehensiveness is highlighted by the fact that it is distributed across numerous periodicals, encompassing a wide range of methodologies and perspectives pertaining to advanced improved heat transfer methods for heat sink applications.

Comparing The Coefficient of Heat Transfer of Three Distinct Fin Geometries

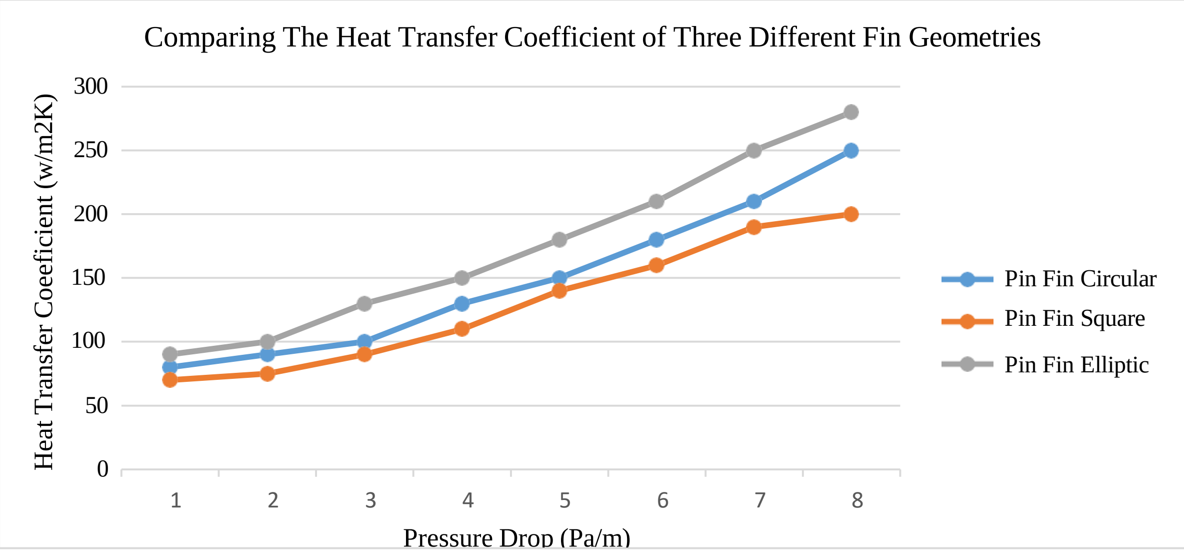


Figure No.5 Comparing The Coefficient of Heat Transfer of Three Distinct Fin Geometries

A chart comparing the heat transmission coefficients of stepped oval, staging rectangle, staging oval, as well as staged parallel plate fin geometries is depicted in the image. The pressure decrease is denoted on the x-axis in Pa/m, while the thermal transfer coefficient is represented on the y-axis in W/m²K.

Result and Discussion -

With increasing pressure decrease, the heat transfer coefficient increases in all three geometries. This is due to the fact that increased fluid velocity results from a greater pressure decrease, thereby facilitating increased exchange of heat between the liquid and its fins. At every pressure decrease, the staged elliptical fins exhibit the greatest heat transfer coefficient. This is probable due to the fact that the elliptical configuration enhances fluid mingling in the vicinity of the fins, thereby facilitating improved heat transfer Stepped straight plate fins demonstrate the highest energy transfer factor, with staged circular fins securing the second position in relation to heat transfer coefficient. The observed phenomenon may be ascribed to the increased surface area of the staged geometries compared to the flat plates and fins. At reduced pressure decreases, the disparity in heat transfer coefficients between the geometries diminishes. This indicates that at modest flow rates, the staged geometries might not be worth the additional complexity. In general, staged elliptical fins appear to be the optimal selection for applications where the principal objective is to optimize heat transfer, particularly when operating at elevated flow rates, as indicated by the graph. However, in cases where pressure drop is a significant limitation, stacked square fins or parallel plate fins might be more appropriate.

Conclusion

This comprehensive review highlights the significant advancements in heat transfer enhancement techniques for heat sinks, focusing on diverse designs and methodologies. The comparative literature study revealed valuable insights into the effectiveness of different methods, offering a nuanced understanding of their performance. Pin fin structures, particularly circular, square, and elliptical configurations, were analyzed in conjunction with channel heat sinks. The thermal performance, surface area, manufacturing complexity, and cost were key criteria for comparison. The study found that pin fin circular configurations demonstrated good efficiency in heat dissipation due to increased surface area, while elliptical fins exhibited enhanced performance compared to circular ones. Channel heat sinks, relying on fluid flow, proved effective but were associated with complex manufacturing processes. Numerical analyses were conducted to quantify the thermal performance, and the results indicated that pin fin circular structures were deemed good, pin fin square structures were better, and pin fin elliptical structures were considered the best. Channel heat sinks, though effective, were comparatively more complex. The manufacturing methods were also evaluated, considering factors such as mass production suitability, prototyping suitability, and cost. Various methods, including EDM, etching, casting, extrusion, and machining, were compared for both pin and channel heat sinks. It was observed that the choice of manufacturing method depended on factors such as production volume, prototyping requirements, and cost considerations.

The integration of innovative approaches, such as Thermal Performance Monitoring Systems (TPMS), bionic structures, and topology optimization, showcased promising results for future heat sink designs. The geometric approach, incorporating bionic structures, demonstrated substantial cooling effects, emphasizing its potential as a compelling research direction. This review provides a comprehensive understanding of recent developments in heat sink technology, offering valuable insights for researchers and engineers working on heat dissipation challenges. The comparative analysis presented here can guide the selection of appropriate heat sink configurations and manufacturing methods based on specific requirements and constraints. The future of heat sink design appears promising, with ongoing exploration of advanced methodologies and materials to further enhance thermal performance.

REFERENCES

1. J. Xiang, L. Deng, C. Zhou, H. Zhao, J. Huang, and S. Tao, ―Heat Transfer Performance and Structural Optimization of a Novel Micro- Channel Heat Sink,‖ *Chinese J. Mech. Eng. (English Ed.*, vol. 35, no. 1, 2022, doi: 10.1186/s10033-022-00704-5.
2. Amol More, et.al ―Experimental Study of High Heat Removal by Aluminum Pin Fin Heat Sink Using Multi-Jet Air Impingement,‖ *Int. J. Mech. Prod. Eng. Res. Dev.*, vol. 4, no. 5, pp. 13–20, 2014, [Online]. Available: http://www.tjprc.org/view- archives.php?year=2014&id=67&jtype=2&page =3

3. A. A. Mohammed and S. A. Razuqi, ―Performance Of Rectangular Pin-Fin Heat Sink Subject To An Impinging Air Flow,‖ *J. Therm. Eng.*, vol. 7, no. 3, pp. 666–676, 2021, doi: 10.18186/THERMAL.889174.
4. Amol More, et.al ―Experimental Investigation on Pin fin heat sink using multi jet impingement,‖ *Int. J. Earth Sci. Eng.*, vol. 6, no. IV, April, pp. 4908–4915, 2012.
5. R. Xiao, P. Zhang, L. Chen, Y. Zhang, and Y. Hou, ―Experimental Study on Cooling Performance of a Hybrid Microchannel and Jet Impingement Heat Sink,‖ *Appl. Sci.*, vol. 12, no. 24, 2022, doi: 10.3390/app122413033.
6. O. Heating, ―Efficient Sensitivity Analysis for Enhanced Heat Transfer,‖ 2022.
7. Amol More, et.al ―Experimental Investigation of Multi Jet Air Impingement on Circular Pin Fin Heat Sink for Electronic Cooling,‖ *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 6, no. 4, pp. 4908– 4915, 2018, doi: 10.22214/ijraset.2018.4803.
8. B. A. Jasperson, Y. Jeon, K. T. Turner, F. E. Pfefferkorn, and W. Qu, ―Comparison of micro- pin-fin and microchannel heat sinks considering thermal-hydraulic performance and manufacturability,‖ *IEEE Trans. Components Packag. Technol.*, vol. 33, no. 1, pp. 148–160, 2010, doi: 10.1109/TCAPT.2009.2023980.
9. Y. Li, Q. Wang, M. Li, X. Ma, X. Xiao, and Y. Ji, ―Investigation of Flow and Heat Transfer Performance of Double-Layer Pin-Fin Manifold Microchannel Heat Sinks,‖ *Water (Switzerland)*, vol. 14, no. 19, 2022, doi: 10.3390/w14193140.
10. D. A. Petrov and V. A. Karachinov, ―Modeling the influence of heat sinks on the structure of the temperature field of a profile heat pipe,‖ *J. Phys. Conf. Ser.*, vol. 2388, no. 1, pp. 1–8, 2022, doi: 10.1088/1742-6596/2388/1/012118.
11. K. Sadegh, ―CFD Modelling and Visual Analysis of Heat Transfer and Flow Pattern in a Vertical Two-Phase Closed Thermosyphon for,‖ 2022.
12. E. M. Abo-Zahhad *et al.*, ―A Micro-Metal Inserts Based Microchannel Heat Sink for Thermal Management of Densely Packed Semiconductor Systems,‖ *Sustain.*, vol. 14, no. 21, 2022, doi: 10.3390/su142114182.
13. E. Storage, ―Development and Tests of the Solar Air Heater with Thermal Energy Storage,‖ 2022.
14. F. G. Al-Amri, T. Maatallah, R. Zachariah, A. T. Okasha, and A. K. Alghamdi, ―Enhanced Net Channel Based-Heat Sink Designs for Cooling of High Concentration Photovoltaic (HCPV) Systems in Dammam City,‖ *Sustain.*, vol. 14, no. 7, 2022, doi: 10.3390/su14074142.
15. D. Dadi and V. Introna, ―Decarbonization of Heat through Low-Temperature Waste Heat Recovery : Proposal of a Tool for the Preliminary Evaluation of Technologies in the Industrial Sector,‖ 2022.
16. J. A. S. Del Rio *et al.*, ―Numerical Study of the Efficiency of a Solar Panel with Heat Sinks,‖ *CFD Lett.*, vol. 15, no. 4, pp. 43–52, 2023, doi: 10.37934/cfdl.15.4.4352.
17. M. Amol, et.al ―STUDY OF PULSATING (SYNTHETIC) AIR JET HEAT SINK COOLING,‖ *IJRAR-International J. Res. Anal. Rev.*, vol. 6, no. 2, pp. 273–276, 2019.
18. Amol. More et.al ―A Review: Advances in Heat sink Cooling Systems,‖ vol. 4863, pp. 21–26, 2020.

19. Y. Wang, J. Wang, and X. Liu, ―Topology Optimization Design of Micro-Channel Heat Sink by Considering the Coupling of Fluid-Solid and Heat Transfer,‖ *Energies*, vol. 15, no. 23, 2022, doi: 10.3390/en15238827.
20. K. Poulsen and N. T. Zinner, ―Dark-State- Induced Heat Rectification,‖ vol. 1, no. c, pp. 1– 7, 2022.
21. A. J. et. More, ―Advance Heat Sink Geometries and Technologies for Enhanced Cooling of High Power Chips I Heat Sink Technologies :,‖ 2015, [Online]. Available:

https://www.researchgate.net/publication/280312 320

22. D. Y. Taha, D. S. Khudhur, and L. M. Nassir,

―the Behavior of Heat Sink-Impingement Cooling With Flat Plate and Arced Fins Models,‖ *J. Eng. Sustain. Dev.*, vol. 26, no. 1,

pp. 1–14, 2022, doi: 10.31272/jeasd.26.1.1.

23. A. H. D. K. Rasangika, M. S. Nasif, W. Pao, and

R. Al-Waked, ―Numerical Investigation of the Effect of Square and Sinusoidal Waves Vibration Parameters on Heat Sink Forced Convective Heat Transfer Enhancement,‖ *Appl. Sci.*, vol. 12, no. 10, 2022, doi: 10.3390/app12104911.

24. J. Li and L. Yang, ―Recent Development of Heat Sink and Related Design Methods,‖ *Energies*, vol. 16, no. 20, 2023, doi: 10.3390/en16207133.
25. Anusha A, D. Sathya Narayana Rao, and G. D Saxena, ―Enhancing the efficiency and speed of heat transfer using shell and tube heat exchanger design,‖ *Int. J. Sci. Methods Eng. Manag.*, vol. 01, no. 02, pp. 01–12, 2023, doi: 10.58599/ijsmem.2023.1201.
26. A. Gudi, ―International Journal of Heat and Technology: Foreword,‖ *Int. J. Heat Technol.*, vol. 26, no. 1, p. 107, 2022.
27. Y. Lu and X. Lu, ―An Overall-Optimized Heat Dissipation Enhancement Design Scheme for Automation Systems Based on Microchannel Units and the Evaluation of Heat Dissipation Performance,‖ *Int. J. Heat Technol.*, vol. 40, no. 3, pp. 821–827, 2022, doi: 10.18280/ijht.400322.
28. M. S. Mohd Shawal, M. R. Abdul Rahman, M. M. Mahat, J. Saedon, and M. S. Meon, ―Numerical Investigation on Thermal Performance of Plate-Fin Heat Sink Designs Subjected to Parallel and Impinging Flow,‖ *J. Appl. Eng. Des. Simul.*, vol. 3, no. 1, pp. 27–39, 2023, doi: 10.24191/jaeds.v3i1.54.
29. D. Debbarma, K. M. Pandey, and A. Paul, ―Performance Enhancement of Double-Layer Microchannel Heat Sink by Employing Dimples and Protrusions on Channel Sidewalls,‖ *Math. Probl. Eng.*, vol. 2022, 2022, doi: 10.1155/2022/2923661.
30. M. Salem, G. Sultan, A. Hegazi, and W. El Awady, ―Enhancement of Heat Transfer for Electronic Components in Horizontal Channel by Passive Cooling.(Dept.M),‖ *MEJ. Mansoura Eng. J.*, vol. 46, no. 2, pp. 1–12, 2021, doi: 10.21608/bfemu.2021.171081.
31. Y. Li, S. Roux, C. Castelain, Y. Fan, and L. Luo, ―Design and Optimization of Heat Sinks for the Liquid Cooling of Electronics with Multiple Heat Sources: A Literature Review,‖ *Energies*, vol. 16, no. 22, 2023, doi: 10.3390/en16227468.

32. Z. Zhang, X. Wang, and Y. Yan, ―A review of the state-of-the-art in electronic cooling,‖ *e- Prime - Adv. Electr. Eng. Electron. Energy*, vol. 1, p. 100009, 2021, doi: https://doi.org/10.1016/j.prime.2021.100009.

33. S. S. M. Ajarostaghi, M. Zaboli, H. Javadi, B. Badenes, and J. F. Urchueguia, ―A Review of Recent Passive Heat Transfer Enhancement Methods,‖ *Energies*, vol. 15, no. 3, 2022, doi: 10.3390/en15030986.

34. C.-H. Huang and W.-Y. Chen, ―A natural convection horizontal straight-fin heat sink design problem to enhance heat dissipation performance,‖ *Int. J. Therm. Sci.*, vol. 176, p. 107540, 2022, doi: https://doi.org/10.1016/j.ijthermalsci.2022.10754 0.

35. C. S. Meena, A. Kumar, S. Roy, A. Cannavale, and A. Ghosh, ―Review on Boiling Heat Transfer Enhancement Techniques,‖ *Energies*, vol. 15, no. 15, pp. 1–15, 2022, doi: 10.3390/en15155759.

36. N. Baobaid, M. I. Ali, K. A. Khan, and R. K. Abu Al-Rub, ―Fluid flow and heat transfer of porous TPMS architected heat sinks in free convection environment,‖ *Case Stud. Therm. Eng.*, vol. 33, p. 101944, 2022, doi: https://doi.org/10.1016/j.csite.2022.101944.

37. M. Krstic *et al.*, ―Passive cooling of photovoltaic panel by aluminum heat sinks and numerical simulation,‖ *Ain Shams Eng. J.*, vol. 15, no. 1, p. 102330, 2023, doi: 10.1016/j.asej.2023.102330.

38. A. J. Obaid and V. M. Hameed, ―An experimental and numerical comparison study on a heat sink thermal performance with new fin configuration under mixed convective conditions,‖ *South African J. Chem. Eng.*, vol. 44, no. October 2022, pp. 81–88, 2023, doi: 10.1016/j.sajce.2023.01.009.

39. M. Abuşka, ―The heat sink and test bed | Download Scientific Diagram.‖ 2023.

40. M. Fathi, M. M. Heyhat, M. Zabetian Targhi, and S. Bigham, ―Porous-fin microchannel heat sinks for future micro-electronics cooling,‖ *Int. J. Heat Mass Transf.*, vol. 202, p. 123662, 2023, doi: https://doi.org/10.1016/j.ijheatmasstransfer.2022. 123662.

41. P. Bhandari, K. S. Rawat, Y. K. Prajapati, D. Padalia, L. Ranakoti, and T. Singh, ―Design modifications in micro pin fin configuration of microchannel heat sink for single phase liquid flow: A review,‖ *J. Energy Storage*, vol. 66, p. 107548, 2023, doi: https://doi.org/10.1016/j.est.2023.107548.

42. A. Maheswari and Y. K. Prajapati, ―Thermal performance enhancement and optimization of double-layer microchannel heat sink with intermediate perforated rectangular fins,‖ *Int. J. Therm. Sci.*, vol. 185, p. 108043, 2023, doi: https://doi.org/10.1016/j.ijthermalsci.2022.10804 3.

43. K. Tang, G. Lin, Y. Guo, J. Huang, H. Zhang, and J. Miao, ―Simulation and optimization of thermal performance in diverging/converging manifold microchannel heat sink,‖ *Int. J. Heat Mass Transf.*, vol. 200, p. 123495, 2023, doi: https://doi.org/10.1016/j.ijheatmasstransfer.2022. 123495.

44. Y.-H. Pan, R. Zhao, Y.-L. Nian, and W.-L. Cheng, ―Numerical study on heat transfer characteristics of a pin–fin staggered manifold microchannel heat sink,‖ *Appl. Therm. Eng.*, vol. 219, p. 119436, 2023, doi: https://doi.org/10.1016/j.applthermaleng.2022.11 9436.

45. Y. Zhao *et al.*, ―Microfluidic Actuated and Controlled Systems and Application for Lab-on- Chip in Space Life Science,‖ *Sp. Sci. Technol. (United States)*, vol. 3, 2023, doi: 10.34133/space.0008.

46. Y. You *et al.*, ―Effect of Surface Microstructure on the Heat Dissipation Performance of Heat Sinks Used in Electronic Devices.,‖ *Micromachines*, vol. 12, no. 3, Mar. 2021, doi: 10.3390/mi12030265.

47. X. Wang, W. Deng, X. Tang, and H. He,―Experiment and simulation study on the specification

parameters of finned heat sink for thermoelectric system in consideration of radiation among fins,‖ *Int. J. Therm. Sci.*, vol. 185, p. 108097, 2023, doi: https://doi.org/10.1016/j.ijthermalsci.2022.10809 7.

48. Y. Huang *et al.*, ―Experimental investigation on flow boiling characteristics of a radial micro pin– fin heat sink for hotspot heat dissipation,‖ *Appl. Therm. Eng.*, vol. 219, p. 119622, 2023, doi: https://doi.org/10.1016/j.applthermaleng.2022.11 9622.
49. Z. Rehman *et al.*, ―Study of thermal characteristics of energy efficient micro channel heat sinks in advanced geometry structures and configurations: A review,‖ *Front. Energy Res.*, vol. 10, 2022, doi: 10.3389/fenrg.2022.951066.
50. Y. Huang, ―Experimental Study on Flow Boiling Heat Transfer Characteristics of Ammonia in Microchannels.‖ 2020. [Online]. Available: https://ui.adsabs.harvard.edu/abs/2018AGUFM.P53F3028M/abstract
51. Y. Wang, J. Wang, and X. Liu, ―Topology Optimization Design of Micro-Channel Heat Sink by Considering the Coupling of Fluid-Solid and Heat Transfer,‖ *Energies*, vol. 15, no. 23, 2022, doi: 10.3390/en15238827.
52. A. Gaikwad, A. Sathe, and S. Sanap, ―A design approach for thermal enhancement in heat sinks using different types of fins: A review,‖ *Front. Therm. Eng.*, vol. 2, no. January, pp. 1–13, 2023, doi: 10.3389/fther.2022.980985.
53. G. Criscuolo, W. Brix Markussen, K. E. Meyer, B. Palm, and M. Ryhl Kærn, ―Experimental Characterization of the Heat Transfer in Multi- Microchannel Heat Sinks for Two-Phase Cooling of Power Electronics,‖ *Fluids*, vol. 6, no. 2, 2021, doi: 10.3390/fluids6020055.
54. W. Wang, Y. Li, Y. Zhang, B. Li, and B. Sundén, ―Analysis of laminar flow and heat transfer in an interrupted microchannel heat sink with different shaped ribs,‖ *J. Therm. Anal. Calorim.*, vol. 140, no. 3, pp. 1259–1266, 2020, doi: 10.1007/s10973-019-09156-x.
55. Z. Zhao, L. Xi, J. Gao, L. Xu, and Y. Li, ―Numerical Study on Cooling Performance of a Steam-Cooled Blade Based on Response Surface Method,‖ *Appl. Sci.*, vol. 13, no. 11, 2023, doi: 10.3390/app13116625.
56. M. Lal Rinawa *et al.*, ―Numerical investigation of modified fin shapes for the improved heat transfer,‖ *Mater. Today Proc.*, vol. 62, pp. 1854– 1860, 2022, doi: https://doi.org/10.1016/j.matpr.2022.01.007.
57. S. Sushma, T. K. Chandrashekar, S. B. Nagesh, and H. Naresh, ―A Performance Study on Heat Transfer using Different Heat Sink by Experimentation and Optimization Method,‖ *J. Mines, Met. Fuels*, vol. 70, no. 8, pp. 41–48, 2022, doi: 10.18311/jmmf/2022/32008.
58. S. S. S. Muzhaimey *et al.*, ―Numerical Investigation of Heat Transfer Enhancement in a Microchannel with Conical-Shaped Reentrant Cavity,‖ *Mathematics*, vol. 10, no. 22, 2022, doi: 10.3390/math10224330.
59. C. Map, ―Plate Fin Surface Geometries.‖ 2023. [Online]. Available: https://hedhme.com/content_map/?link_id=3010 9&article_id=298