"ADVANCEMENTS IN HEAT TRANSFER ENHANCEMENT TECHNIQUES FOR HEAT SINK AND RELATED DESIGN METHODS: 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 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; Optimisation; Structure Design; PCM; Nanofluids; Pins Foil Oval, Pin Fin Square, or Pin Fin Elliptical.

I. 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 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].

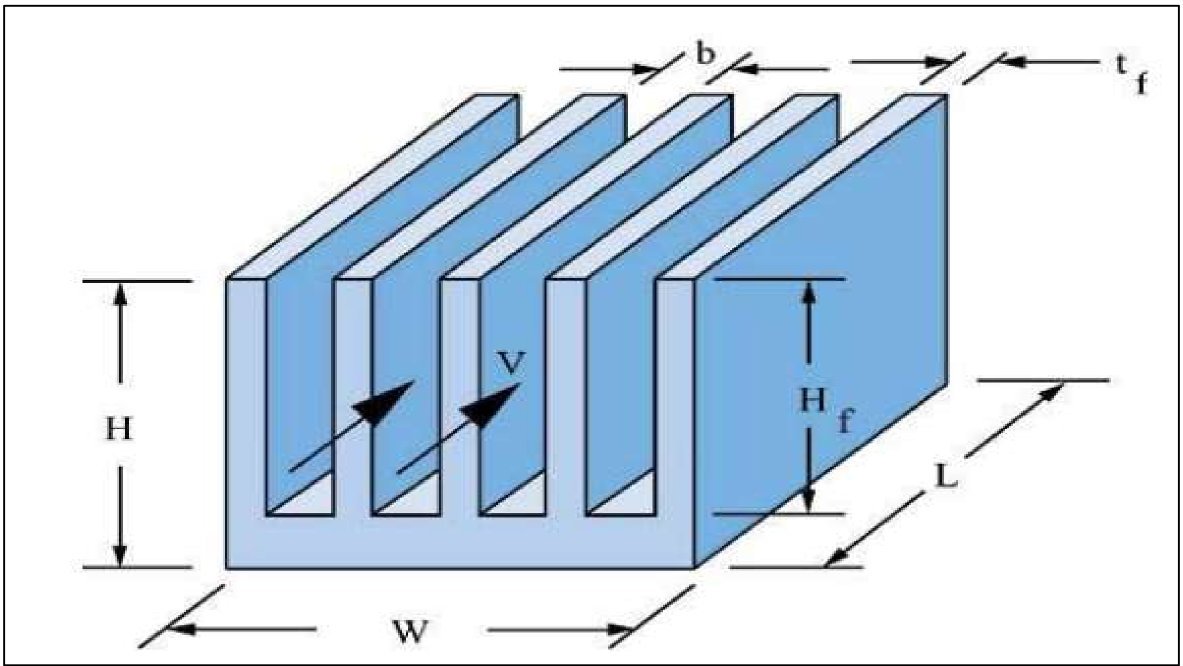


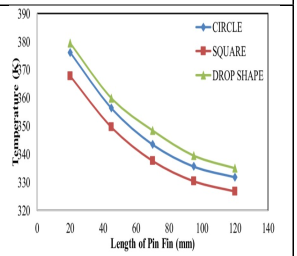
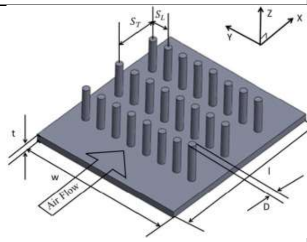
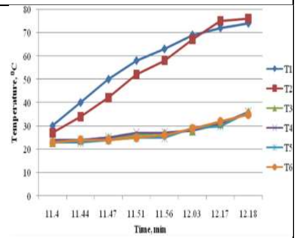
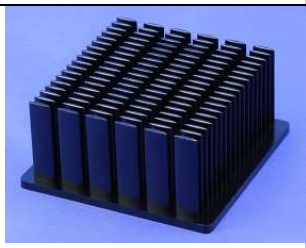
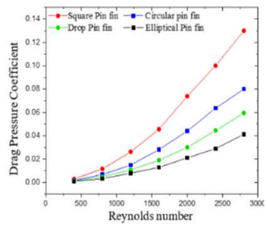
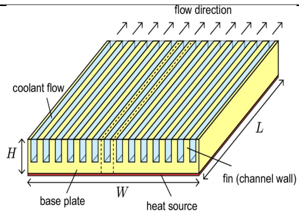
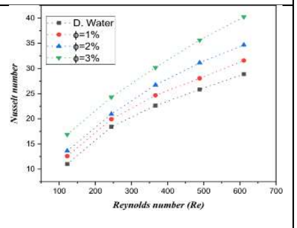
Figure No.1 Typical view of Plate Fin Heat Sink

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.

1.1 Development of Heat Sink

As a result of the growth of numerous industries, there is a greater need for efficient thermal 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 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 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[7].

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		

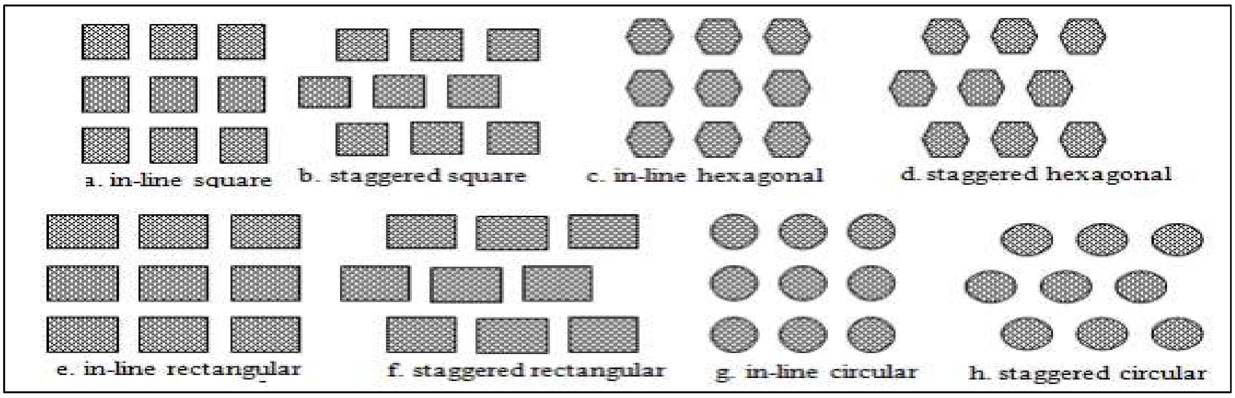


Figure No.2 Configuration of a Pin fin Heat sinks and Variable Forms

Table No. 1. A Variety of Methods for Creating Micro Heat Sinks

Source:[8]

Mfg. Method	**Can Mfg.**	**Mass Production Suitability***	**Prototyping Suitability***	**Cost Comparison of Designs**
EDM				
Wire	Channel	Poor	Average	NA
Plunge	Both	Poor	Average	Pin ≈ Channel
Etching				
LIGA/Electroforming	Both	Good	Good	Pin ≈ Channel
Casting	Both	Very Good	Poor	Pin ≈ Channel
Extrusion	Channel	Very Good	Poor	NA
Machining				
End Mill	Both	Average	Very Good	Pin > Channel
Slot/Form Mill	Channel	Good	Very Good	NA
Sintering	Both	Very Good	Poor	Pin ≈ Channel

To achieve this, flow turbulence must be raised to improve the heat transfer coefficient. The development of heat sinks is a multifaceted and intricate undertaking, that includes the following objectives: efficient heat transfer, minimal resistance, low weight, compactness, and durability. Present challenges in enhancing the electric power efficacy of heat sinks highlight the need for innovative methods of construction, materials, and designs.[9]. The configuration of the heat radiators is an essential component in their design, and prior research indicates that improvements in cooling efficiency can be attained by modifying the geometry, that in return impacts fluid flow in the context of complex structures. The framework of this assessment is displayed in Figure No. 3.

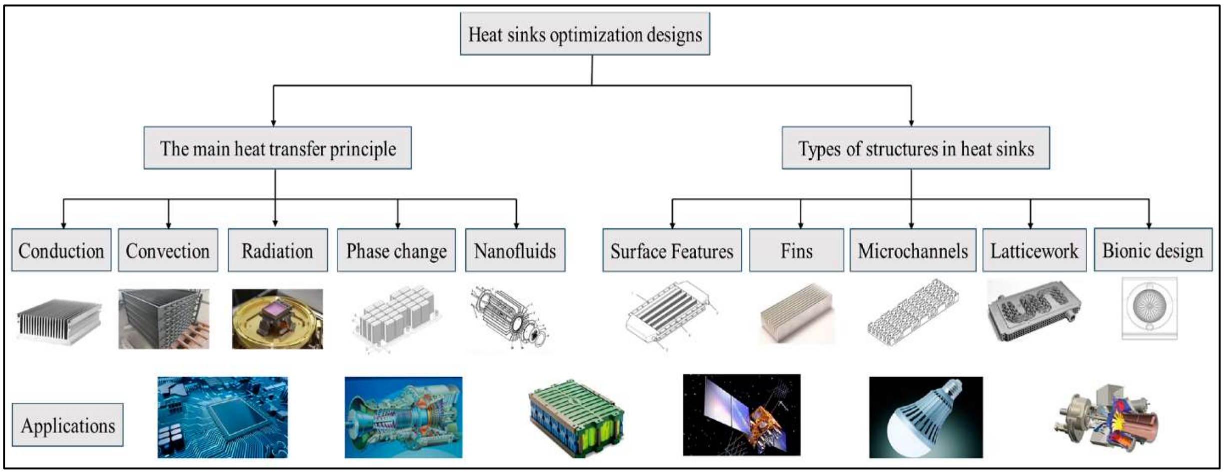


Figure No.3 The fundamental structure and implementation of heat sinks.

1.2 Requirement of Heatsink

While being powered on, the electrical system and electronic module as a whole generates heat. For example, within the electrical circuit board of a computer, heat is generated by power transistors along with other high-power semiconducting parts. Further, optoelectronics, such as light-emitting diodes and lasers, produce a substantial quantity of heat. 3 Similarly all the electronic systems develop heat right from computer to household items every day that we are using[10]. So these heat need to be removed immediately for continuous operation of electronic component. If not, accumulation of heat may cause spontaneous breakdown or failure of complete system connected to it. Since the construction of these heat-generating components is insufficient to dissipate heat, heat sinks must be utilized for freezing functions. In today's world, in which parts of devices are growing thinner and lighter, it is essential to have a heat sink with less surface area for effective heat removal[11]. These reasons attributed the need of heat transfer improvement study in heat sink. Many research outcomes show that thermal boundary layers play vital role in heat transfer[12]. In addition, many variables can affect the transmission of heat in a heat sink, including the structure of the material, the elements of the cooling medium, the heat sink's design, flow its impact, pressure drop, as well as fin physical characteristics, surface roughness, foundation plate dimension, fin segregation, warming dimension, speed boundary level, the direction of flow, flow turbidity, and thermal conductivity of the material. Movement distraction as well as the texture of the surface variation in a heat sink are essential for the two primary reasons outlined below: (a) Enhancement of heat transfer efficiency; and (b) Removal of the greatest amount of heat discharge from the lowest possible surface area. A high heat flux is produced in a designated location by the most recent powerful electronic equipment as an effect of component size reduction[13]. All the power operated devices right from computers, LED’s, Medical Instruments, Radio Frequency devices emits heat when is in operation. It is very difficult to achieve heat dissipation limit of 200W/cm2 in 1990’s but it is viable at present due to 4 technical advancements. The modern equipment need a challenging heat dissipation limit of 600–1000W/cm2. This superior heat dissipation range entail a reduction in the heat sink dimensions with appropriate cooling systems to attain high heat dissipation[14].

1.3 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].

1.4 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.

$$\mathrm{q} = -\mathrm{K}A\,\frac{\partial T}{\partial x} \tag{1}$$

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 dynamics, heating is not the exclusive means of transfer of heat; thermal convection encompasses both the direct conveyance and transmission of 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

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

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.

$$q_{emitted}=\sigma AT^4 \tag{3}$$

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

2.1. 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 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 contact with the substrate. 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. An experiment is undertaken to ascertain the impact of a brief pulse of air emission on the distribution of heat transfer in the vicinity of a flat surface. The effects of valve-to-plate distance ($z/d = 2$ to 6), Reynolds amount (5000 to 9000), pulsation velocity ($f = 0.07$ to 2.03 hz), and Strouhal frequency ($Sr = 6.7e{-5}$ to 0.0029) have been studied while the nozzle diameter remained constant. Through the utilization of a thin foil technique and infrared thermal infrared imaging, localized transfer of heat properties are estimated. In order to represent each instance, the Nusselt, who distribution of value is graphed using infrared image data. At lower Strouhal numbers and frequency rates, a more efficient transfer of heat rate is observed. Through the combination of vortex and a pulse methodology, this research paper presents an innovative hybrid method that improves the rate of transmission of heat. This technique is executed by introducing spirals into an orifice exposed to an air discharge in a particular ratio of twists. Experiments indicate that the heat transfer rate is enhanced under each of the aforementioned conditions by the hybrid method that was recently developed[26]. **Yongfang Lu et.al (2022)** Microchannel have found extensive application in the cooling process, exchange of heat, and thermal management modules of automated devices owing to their numerous advantages, including energy conservation, efficient heat transfer, and the ability to fully exploit latent and sensible heat. Regarding simulations of the heat movement and transfer characteristics of microchannel heat sinks, meanwhile, the quality of the overall-optimized dissipation of heat improvement design for systems for automation using microchannel units is extremely limited, and few prior studies have addressed this topic. In these conditions, the purpose of this research is to evaluate the efficiency of a design scheme which improves heat dissipation in automation systems through the use of a microchannel heat exchange units as well as an overall optimisation scale. This paper began by constructing a Microchannel Heat Sink (MHS) designs and detailing the design scheme's implementation steps. Following that, the thermodynamic field of the heat dispersion procedure for the internal elements of automated machinery was simulated and analysed, and an experiment was conducted to validate the scientific validity and efficacy of the suggested layout scheme. Finally, an analysis was conducted on the correlation between the pressure decrease of microchannel units and the fluid temperature. A comparison was made in terms of the heat dissipation performance, and the evaluation outcomes were presented[27].

2.2 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. A numerical analysis using ANSYS FLUENT R21 has been carried out in order to evaluate the heating efficiency of the proposed designs. The grid independence test was executed in order to determine the optimum amount of elements for the element optimisation. As the input parameter, a fixed heat flux of 18.75 kW/m2 was utilized on the bottom plate of heat sinks. In order to explore the based temperature, thermal resistance, and Nusselt value of these designs, two distinct flow directions (i.e., impacting flow and parallel flow) were utilized at varying mass flow rates. The study indicates plate-fin heat sinks using a fillet profile and folded half-round pin structure (PFHS 4) for identical flows and plate-fin heat sinks in a filler profile and arranged in half-round pins (PFHS 3) for impinging flow conditions. These arrangements have superior thermal performance as compared to the alternative layouts. Therefore, while these plate-fin configurations display advantages for usage as heat sinks for electronic equipment[28]. **Dipak Debbarma (2022)** An examination of Thermal stress, which is caused by a high temperature gradient, indirectly contributes to the occurrence of various drawbacks in no stacked microscopic channels. A substantial temperature gradient can be overcome through the implementation of dual layers within the heat sink. The present numerical inquiry improves the overall efficiency of a double-layered washbasin through the implementation of depression and protrusion. Before proceeding with the implementation of projections and imperfections on the washbasin's sidewalls, the ideal channel diameter and depths have been discovered. An examination is conducted of micro sinks featuring protruded dimpled layers on top and protruded dimpled layers at the bottom. An assessment has been conducted on various parameters, including the maximal bottom layer temperature variation (ΔTb), the Nusselt value proportion (Nu/Nuo), and thermal devices performance factor (γ)[29]. **M.I. Salem et.al (2021)** A numerical investigation is undertaken in this study to examine heat transfer via mixed convection in the context of air conditioning via a rectangular horizontally oriented duct that contains three heat sources. The heat sources in question are rectangular segments featuring varying small aspect ratios. Each heat source produces a uniform heat discharge, and the distance between them is minimal. By inserting natural convection through perforated apertures positioned between each heat source and forcing convection generated by a blower with a rectangular horizontal conduit, this investigation aims to improve forced convection. The research investigates the impact of air ingress through apertures with varying open hole ratios (β) (0.04720, 0.02618, 0.04091, 0.05891, 0.08017) and Reynolds numbers Re (376, 900, 2073, 3428, and 6170), as well as a Gr value of 0.371 x 107, on the temperature of each heat source. The optimal performance was observed at an open hole ratio of 0.04091, where the temperature without dimensions dropped by 5% for the initial radiator, 15% for the subsequent heater, and 6% over the third heater[30]. **Yijun Li et.al (2023)** The present article presents an extensive literature review concerned the thermal management difficulties found by electronic devices, with a particular focus on reducing irregular heating and overheating concerns. With a specific concentration on power electronics, this course highlights the layout and structural optimizing of heat sinks to facilitate efficient a single-phase liquid cooling. Illustrative examples are used to underscore the prevalence and implications of electronic device overheat in the paper. This article explores research that classifies heat sink optimisation techniques according to flow passage, channel cross-section, identical linear pathways, pin-fin design, and overall flow configuration. The review highlights a significant deficiency in addressing the issue of irregular heating resulting from multiple sources, as opposed to homogeneous or single-peak heating. Although numerous optimisation methods have been investigated, topology optimisation has emerged as a highly promising technology for the efficient management of asymmetrical heating. This article becomes a valuable resource for future advancements in this area of thermal management of electronics with its critical evaluation, ending in an analysis of research concerns and potential future developments related to liquid-cooling heat sink innovations[31].

A. Natural Convection Heat Sink

Ke Zhang et.al (2023) Convection from nature's dissipation of heat is a frequent thermal control method utilised in passive air conditioning for cooling electronic parts. Passive cooling systems perform with the substances in use as working parts, removing the requirement for external power sources. Conversely, the fluid passes the heat sinks in accordance with the asymmetrical fluid density resulting from the influence of buoyant or gravitational forces. In the field of convection from the air heat sinks for device cooling, recent research has placed significant emphasis on the optimisation of fins. Improving the natural convection of heat sinks primarily involves addressing the internal circulation defects that prevent the induction of additional airflow through straight fin channels, increased fluid turbulence, and achieving temperature uniformity within the heat sink[32]. **Seyed Soheil Mousavi Ajarostaghi et.al (2022)** Innovative techniques to improving heat transmission are required to promote miniaturization development and raise the heat impact of energy conservation systems. The manufacturing sector has shown considerable interest in techniques that enhance heat transmission. This is due to potential advantages their supply, including lower energy use, better utilization of sources of renewable energy, and raised practicality of thermal systems. The methods mentioned beyond are easily described as active, passive, or complex. This article presents a comprehensive examination of current quiescent heat transfer enhancement techniques. These techniques are preferred over active methods for enhancing the thermal effectiveness of systems that convert energy because of their reliability, affordability, and minimal power consumption. Passive methodologies encompass the utilization of various elements along the heat transmission or work fluid flow path in an effort to improve the rate of energy transfer. The non-invasive thermal transmission improvement methods examined in this article include introduced structures (such as bent adhesives, curved segments, and baffles with fin wings), extending surfaces (fins), filled with liquid resources, coil/helical/spiral tubes, abrasive interactions (corrugated/ribbed areas), and Nanofluid technology solution (including mono and hybrid nanofluids**).**[33]. **Muneeshwaran et al. (2023)** It was noted that naturally generated convection heat sinks allowed air to enter from the side without further permeating the channels. In actuality, the majority of air that entered the parallel fins heat sink did so from the side, bypassed the cooling system, and did not actively take part in heat transfer; thus, the heat sink's capacity to enhance heat transfer performance through simple adjustments to fin dimensions and alignments was limited. They introduced a unique internally angled fin design, as shown in Figure 3a, in which part of the fins were cut in the middle of the heat sink to improve airflow into the surface. Their study concentrated on the height as well as spacing of the fins. Based on their examination of the outcomes of the numerical simulations, they arrived at a heat sink configuration that exhibited a greater heat transfer efficiency and decreased thermal resistance during the natural convection event[24].

Rao et al. (2021) As illustrated in Figure 4b, a curved fin configuration was suggested in order to improve greatest heat transfer while decreasing thermal resistance. 1°, 2°, and 3° tapered angles were examined. The investigation involved submitting the heat sink's base to electricity levels varying compared to 5 to 80 W. The findings indicated that an increased inclined angle did not lead to improved heat dissipation due to air accumulation at the origin of the fins. In comparison to the standard straight fins, the tapered fin heat sink exhibited a substantial increase in its overall heat transfer coefficient[24]. **Cheng-Hung Huang et.al (2022)** By altering the change in displacement of the immovable fins on the heat sink, it was possible to reconstruct the thermodynamic boundary layers between the fins. Their research had been revolutionary and inventive in that they combined prior dissipating heat technological innovations into straight-fin heat sinks used in convectional conditions; in this configuration, design variables including the length and shift of the fins were considered simultaneously. A numerical analysis of three different straight-fin heat drain designs, which includes the novel structure illustrated in Figure 4c, revealed that for minimizing the base surface temperature, fin displacement was significantly more important than fin height[34]. **Chandan Swaroop Meena et al. (**2022Boiling is widely recognized as a significant method for expanding heat transfer (HT) and finds applicability in various industrial cooling processes. Heat exhibits the capacity to decreased the loss of energy in HT devices as contrasted with alternative methods of high-frequency expansion, like conduction or convection. The objective of this review was to execute a review, discussion, and assessment.and comparison of prior research conducted in recent decades that focuses on techniques for enhancing simmering heat transfer. Our objective was to comprehend the impact of places of nucleation on curved and flat surfaces, as well as on the enhancement of HT, in order to propose potential guidelines for future research. This would facilitate the identification of the optimal structure of the surface and interface manufacturing method for a specific fluid by the research and industry communities. In addition to discussing the boiling pool HT enhancement, we provide recommendations and conclusions for future research**.**[35].

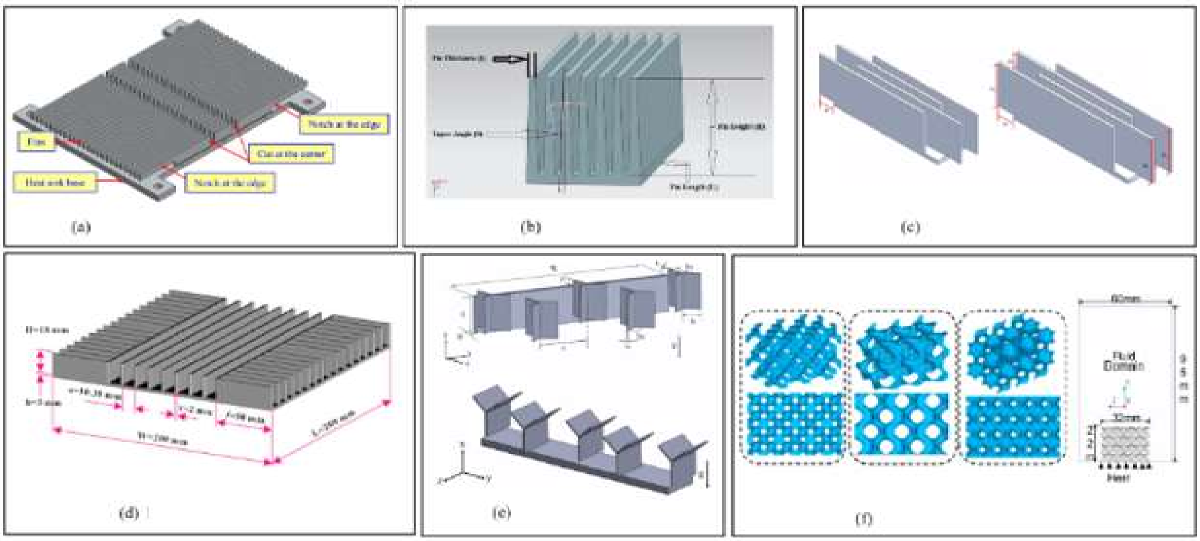


Figure 4. (a) The heat sinks under consideration are the following: (a) the natural convection heat sink with a notched fin and an inner opening; (b) the thermal absorber featuring tapered fins; (c) the fins' shift displacement designs; (d) the thermal drain with a cross-fin design; (e) the innovative Y-shaped-shifted thermal drain; and (f) the heat sinks, shown in isometric and side views as Diamond-Solid, Gyroid-Solid, and Gyroid-Sheet.

Following the advent of additive manufacturing, scientists have begun to explore intricate geometries that were previously challenging to produce using traditional manufacturing techniques. It was observed that convection heat sinks produced natural caused air to pass through from opposite sides without entering the channels further. **Cheng-Hung Huang et al. (2021)** An experimental and numerical study of an optimisation problem was done. A Y-shaped heat sink shifted through natural convection was created as illustrated in Figure 4e. The purpose of their research was to identify the optimum fin stem height, branched width, branched angles, and shift distance for the fins in order to improve cooling performance while reducing the degree of heat of the base of the fin relative to certain conditions. The obtained results validated the accuracy provided by the Y-shape-shifted heat sink's optimal geometry[34]. **Nada Baobaid et al. (2022)** As shown in Figure 4f, the researchers studied three distinct kinds of heat sinks that applied a TPMS supports: Gyroid-Sheet, Diamond-Solid, and Gyroid-Solid. The examination was conducted in an array of enclosure designs under the influence of natural convection. As a consequence of their higher effective thermal conductivity, TPMS heat sinks demonstrated a 35–50% improvement in thermal performance, according to the findings. The temperature of the air is typically regarded as typical for the atmosphere, as well as the heat coefficient of transfer associated with natural convection is comparatively low. So as that of prevent electronic devices from overheating, the experimental configuration of the aforementioned references utilized a source of thermal power that was less than 80 W. The experiments produced a mean thermal transfer coefficient of less than 15 W/m2·K[36].

B. Forced Convection Heat Sinks

Li Yang et.al (2023) Products that have high heat fluxes that necessitate supplementary power sources to operate functional substances employ heated by forced convection dispersion as an effective cooling management technique. By conveying the excess heat to the materials via components exposed to high temperatures, this is achieved. Active cooling produced greater heat transfer coefficients in factors comprising heat dissipation as a result of the increased flow velocity caused by an outside energy source. Therefore, heated by forced convection sinks find widespread application in electronic components. The heating capacity of the experimental segment in the papers referenced in this section varies between 33 W and 1000 W, employing forced convection cooling technology. The corresponding heat exchange flux ranges from 25 to 400 (W/cm2·K)[37].

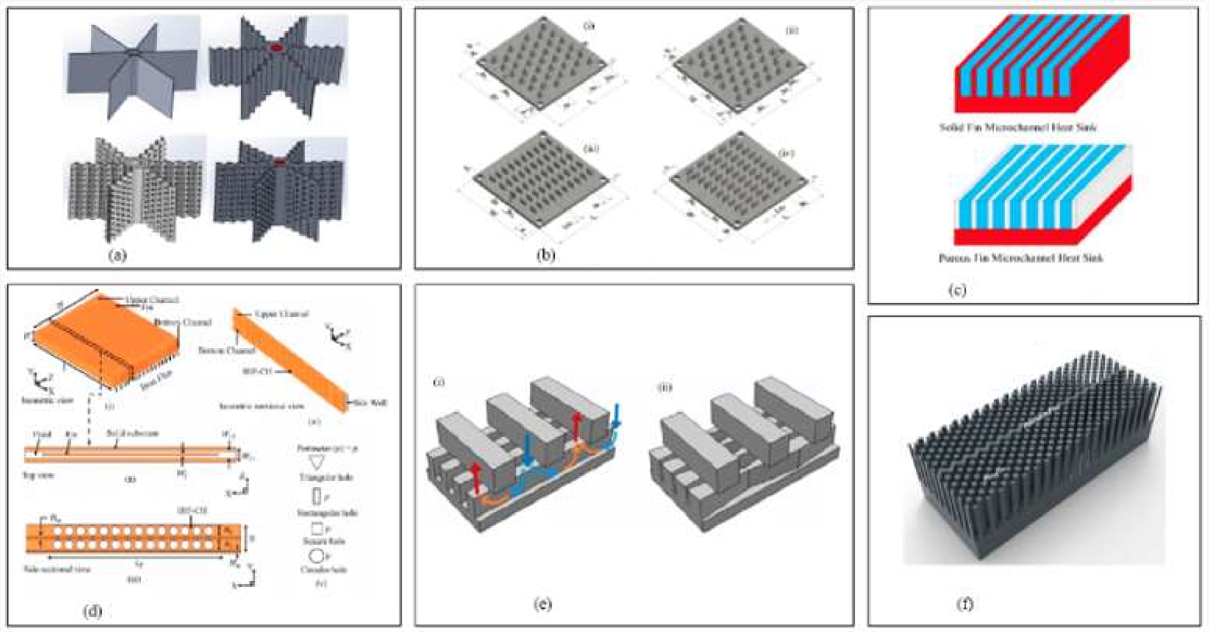


Figure No.5 Forced Convection Heat Sinks

Marko Krstic et.al (2023) Photovoltaic panels face a significant efficiency challenge as 80% of solar energy is converted to heat, leading to decreased performance. This study passively cools panels with aluminum heat sinks, resulting in a 7.5 °C temperature reduction and a 0.27 V increase in open-circuit voltage. Simulation software validates the experiment, identifying the second heat sink as most efficient. The study informs heat sink design optimization for enhanced photovoltaic panel cooling efficiency[38]. **Ali J. Obaid et.al (2023)** The research analysed the thermal efficiency of a heat sink featuring four configurations of aluminium fins operating at three voltage levels under mixed convection. Straight, curved, folded with a curved opening as well as ribs, and perforated in arrangement perforations and rib were among the configurations. A measurement of its temperature dispersion in conjunction the fins was conducted at an air velocity of 1.5 m/s. Applying ANSYS18 software for theoretical analysis, the percentage of differences between experiment and numerical results were minimal. Cases 3 and 4 demonstrated improved heat transfer coefficients, decreased material charges and weight, and consequently minimized the necessary space for the heat sink[39]. **Mesut Abuşka et.al (2023)** The objective of this study is to compare and evaluate the thermo-hydraulic characteristics of conical pin-fin heat sinks featuring different configurations, such as staggered (CPFHSmst) and refined staggered (CPFHSmst) fins. The outer and junction temperatures of the modified placement are 2–7 °C lower than those of the staggered placement, with a 5.3–5.8% lower R^{th}. CPFHSmst is considered to have superior thermo-hydraulic efficiency compared to other variations[40]. **Mostafa Fathi et.al (2023)** Porous-fin microchannel heat sinks, with expansive solid-fluid interfaces, hold promise for future microelectronic cooling systems by mitigating pressure drop issues in straight plate-fin designs. This study investigates the viability of porous fins for enhancing both thermal and hydraulic efficiencies. Findings indicate superior performance at small channel heights, but diminished effectiveness at higher heights due to weak vertical thermal diffusion. Porous fins excel at wider ratios, attributed to increased coolant flow, presenting potential for improved microchannel heat sink performance[41]. **Prabhakar Bhandari et.al (2023)** An examination of The challenges associated with heat flux dispersion have been significantly increased by recent technological developments, resulting in adverse effects on efficiency and even permanent failures. In order to tackle this issue, ongoing advancements in chilling techniques are imperative. Increased convection region, supplementary fluid flow, vortex generation, and smaller boundary layers have contributed to the increased prominence of microchannel heat sinks, specifically those featuring micro pin fin configurations. Aspects of microfins fins, such as cross-sectional geometry, configuration, density, and design parameters, are systematically examined in this article. Exhaustive explanations and ideal intervals were furnished for design parameters including the ratio of aspects, partition gap, and tip clearance. The formation of a vortex downstream of the pin fin has a significant effect on the thermohydraulic performance, as indicated by a simplified fluid flow plot. A microscopic pin fins heat drain with a sharp-edged intersection, pin fin density of 0.5–0.6, tip clearing of the 15–25% of canal height, staggered and graduated arrangement is recommended by conclusive findings. Pin fins featuring novel configurations such as piranha, circular ring, and lattice demonstrate enhanced cooling capabilities in comparison to traditional pin fins, thereby indicating substantial potential for future developments[42].

Anurag Maheswari et.al (2023) This research examines a unique configuration of double-layer microchannel thermal sinks (DL MCHS) through the integration of intermediate rectangular fins featuring a variety of aperture configurations. The results of numerical simulations, which account for variations in the Reynolds value and heat flux, indicate the use of the modified DL MCHS increases the transfer of heat rates by an estimated range of 45–60%. In spite of the high pressure drop, as well as the overall thermal efficiency exhibits a minor edge over the conventional design, particularly in the case of circular and triangular apertures. Increased heat exchange in the redesigned DL MCHS is the result of improved fluid mingling and asymmetrical flow passages, as determined by coolant flow analysis. The process of optimisation reveals a distinct heat sink configuration featuring circular apertures, which exhibits a substantial enhancement in heat transfer rate of around 51%–64% when compared to the traditional approach[43]. **Kai Tang (2023)** A novel design to create a microchannel heat absorbent that improves the transfer of heat in electronic devices is proposed. The improved level of thermal-hydraulic performance can be achieved by substantially optimizing two significant parameters, namely the manifold intake to outlet ratio (α) and the canal's inlet to outlet ratio (β), according to numerical investigations of a single- phase flow and heat transfer. Under non-uniform heating flux, the optimal configuration, α = 1/9 and β = 9, decreases temperature resistance by 19.18%, surpassing the performance of the initial design[44]. **Yu-Hui Pan, Rui Zhao et.al (2023)** The research paper describes a revised microchannel (PFSMMC) thermal sink for the manifold, built on the success of the microchannel (MMC) heat sink. The newly developed heat sink has been designed to aid in the effective management of thermal energy in high-heat-flux electronic devices. As determined by single-phase flow numerical simulation, the PFSMMC heat sink exhibits higher heat transfer qualities and a more uniformly heated surface as compared to the rectangle manifold microchannel (RMMC) and pin-fin manifold microchannel (PFMMC) configurations The examination of length–width ratios for staggered dividers demonstrates that the ideal ratio is 0.32, which causes a decrease in the optimum surface temperature for heating. Furthermore, the research investigates the influence of irregular heat sources on the heat properties of PFSMMC. It reveals a compromise between the uniformity of heating surface temperature and obtaining of the greatest temperature at the optimum length–width ratio of 0.32[45].[Add graphically comparison between natural convention and forced convection by different researchers, add comparison between cross flow impingement flow and axially impingement flow single and multiset flow]

2.3 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[46]. **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. The application of thermal radiation coating onto a microstructure surface resulted in an additional enhancement of heat dissipation due to the heightened heat conduction at the interface between the coating and heat sink. As a result, surface treatment can substantially enhance the heat sink's heat dissipation capabilities through the enhancement of thermal convection, radiation, and conduction[47].

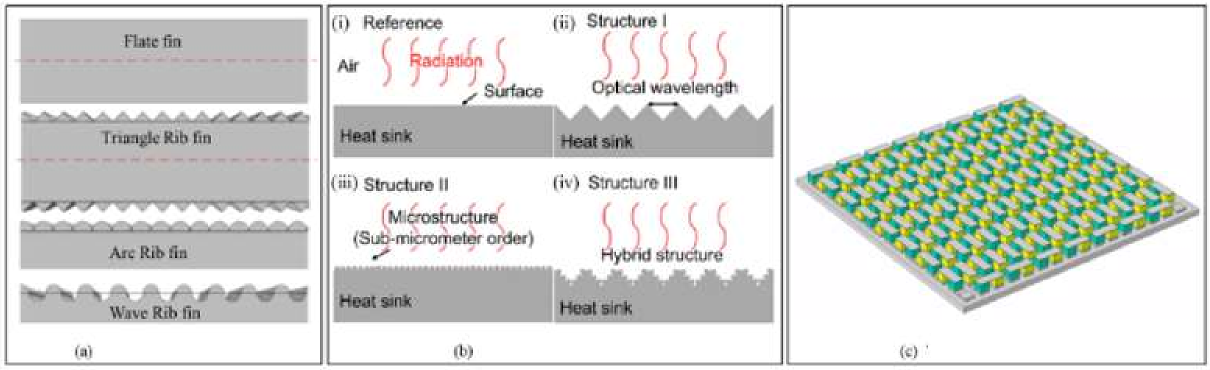


Figure No.6 Radiation Solutions for Heat Sinks

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[48]. **Yanpei Huang et al. (2023),** A micro radial pin-fin heat absorbent is suggested as A resolution to a problem of moderating high-temperature-flux regions that have developed as a result of the quick development of integrated circuit technology. Experiments involving flow boiling with ammonia were performed in order to compare the suggested layout to that of a parallel rectangular microchannel structure. An investigation was conducted into the impact of different parameters, including heat flow, biomass transition, temperature of saturation, and intake condition with respect to the characteristics of thermal transfer and pressure reductions. Under a wide variety of testing conditions, a radial micro pin-fin thermal sink shows remarkable and uniform heat transfer performance, suggesting that it's the capacity of dispersing regions with high heat flux[49]. **Zabdur Rehman1 et.al (2022)** The conversion and energy consumption processes have an inherent connection to economic development and sustainability. In light of the escalating demand for energy and environmental concerns, policy regulators have mandated energy recovery and conservation in addition to the utilization of renewable energy. Heat exchangers are critically important operational components in all energy conversion processes and have been such as the nineteenth century. However, space as well as material constraints, increased energy demand, and the need for highly efficient heat exchangers continue to necessitate miniaturized, lightweight thermal radiators that have proper heat transfer characteristics. Standard heat exchangers have been considered insignificant as a consequence of their significant requirement for space and comparatively slow rate of transmission of heat. The creation of miniaturized micro channel heat sinks (MCHSs) comprising tubes in a length of less than 1 mm shows significant potential to improve the efficiency of heat transfer. However, its simplistic design fails to meet the contemporary demands of heat dissipation. As a result, numerous researchers have attempted to enhance its efficacy through the application of various methods. This study provides an overview of several critical techniques that are implemented in MCHS. The techniques encompassed in this research are the coolant types employed in MCHS, the geometries of MCHS, the flow conditions, the materials utilized in their fabrication, and the numerical methods utilized. Furthermore, several suggestions have been provided to afford researchers prospects for upcoming features[50].

2.4 Sinks for phase change heat

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. Enhancing heat transfer performance is essential for establishing the configuration parameters of the high temperature flux (HHF) elements in fusion reactors in a logical and scientific manner. This can be done through the execution of a complete yet effective review of the temperature conduction mechanism and its pivotal variables. Utilizing subcooled boiling, the current study presents a liquid-vapor flow in two phases model for a high-temperature furnace (HHF). The calorimeter element has a rotating tubes configuration with a significant length-to-diameter ratio. The aim of this study is to ascertain the impact of critical design parameters on the heat transfer efficiency of the component, such as the vortex tube structure parameters and the temperature of the inlet of the coolant water flow. The present study introduces a liquid-vapor flow within two phases model for an HHF a thermometer component having a swirl tunnel configuration with an extensive length-to-diameter ratio, which incorporates subcooled boiling. The goal is to determine the impact of critical design factors on the component's heat transfer performance, such as the swirl tube construction characteristics and the cooling water flow's entrance temperature. Subsequently, with the aim of enhancing effectiveness of the sensitivity evaluation involving these design parameters and accounting for the substantial computational expense associated with the one that powers the liquid-vapor flow in two phases model, a Latin hypercube sampling-based polynomial problems reaction surface substitute model of the thermal transfer efficiency function was developed. By combining the suggested surrogate model with a Sobol global vulnerability assessment approach, the reaction index of each design component could be effectively determined. This method might greatly improve the computation efficiency of an engineering parametric sensitivity study for HHF components in the fusion reactor. This analysis plays a critical role in informing subsequent rapid design optimisation of associated components[51]. **Yue Wang, Jiahao Wang et.al (2022)** In order to examine the impact of the desired weight coefficients on the microchannel heat sink's structure design, a novel approach is implemented for optimizing the topology of microchannel structures featuring various bifurcation angles. By utilizing an improved estimates function, a density filtration, and hyperbolas and tangent projection techniques, this investigation generates a transparent image that illustrates the microchannel heat sink's topological structure. In distinct divergence angles, the temperatures and fluids of the micro-channel cooling drain are compared. The simultaneous evaluation of a pair of different aim functions—heat transfer as well as the energy conservation—occurs at the optimisation of a microchannel heat sink topology. The results suggest that the micro-channel thermally sink experiences its highest levels of transfer of heat and average discharge temperature at a branching angle of 135 degrees. Moreover, at this angle, the thermal transmission effect is at its maximum. An increase in the thermal transfer weighting coefficient leads to a simultaneous refinement of the branch channels and a more pronounced concentration of significant heating sources inside the main channel. Notwithstanding its superior heat exchange system, the micro-channel thermally sink necessitates a more substantial flow energy input.[19]. **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. The average heat transmission coefficients and boiling curves for fictitious canals bulk flows that range from 250 kg/m 2 s to 1100 kg/m 2 s were calculated, with low vapour quality serving as the starting point. To conduct the measurements, the energy consumption of a serpentine heater attached to the bottom of the multi-microchannel was increased gradually until it reached a maximum temperature of 150 degrees Celsius. The temperatures of the heaters were measured by means of infrared thermography, while rapid photography through the transparency upper cover provided visual inspection of the entire length of each channel. Prior to a decrease caused by hydrodynamic effects occurring, the heat transfer efficiency's standard deviation exhibited a positive correlation with the flux of released heat. The observed decline may potentially be ascribed to insufficient wall permeation.[52].

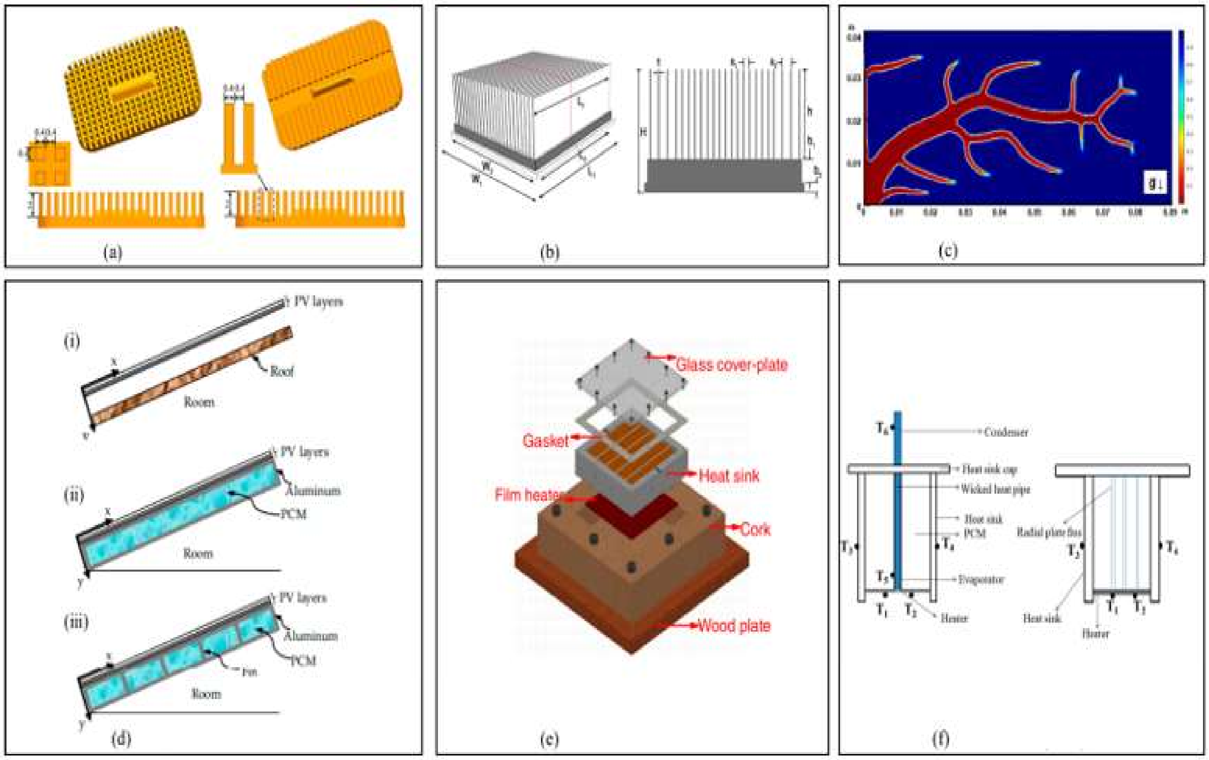


Figure No.7 Phase Change Heat Sinks

Table 1 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

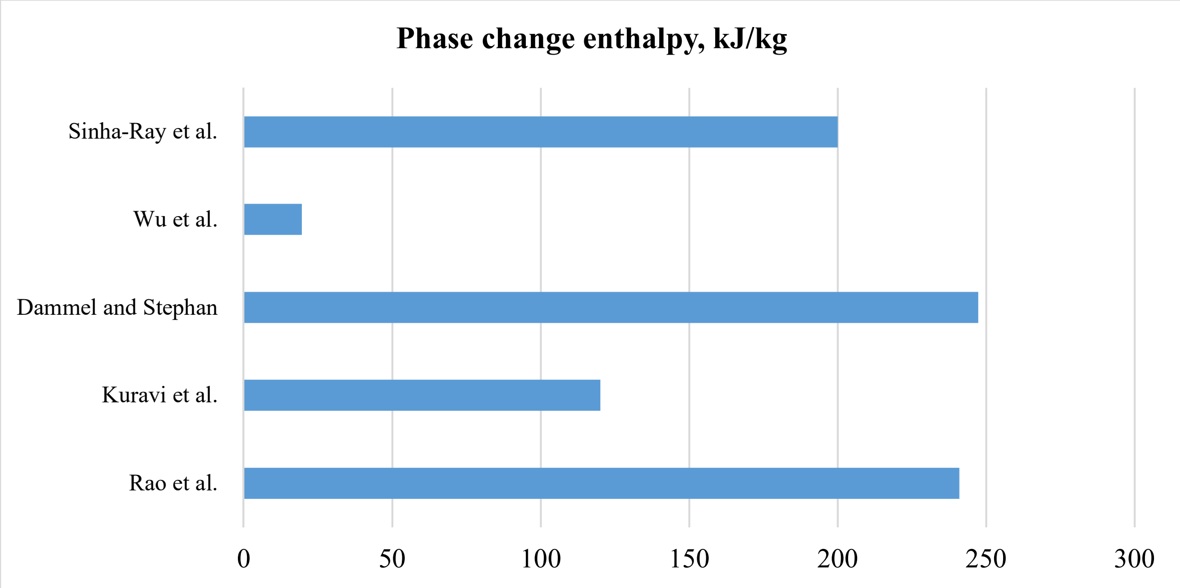


Figure No.8 Phase change enthalpy, kJ/kg in studies of different authors

Table 2 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
Rajabifar. et. al.	water	n-octadecane		nano	244
Rajabifar. et. al.	water	n-octadecane		100 nm	244

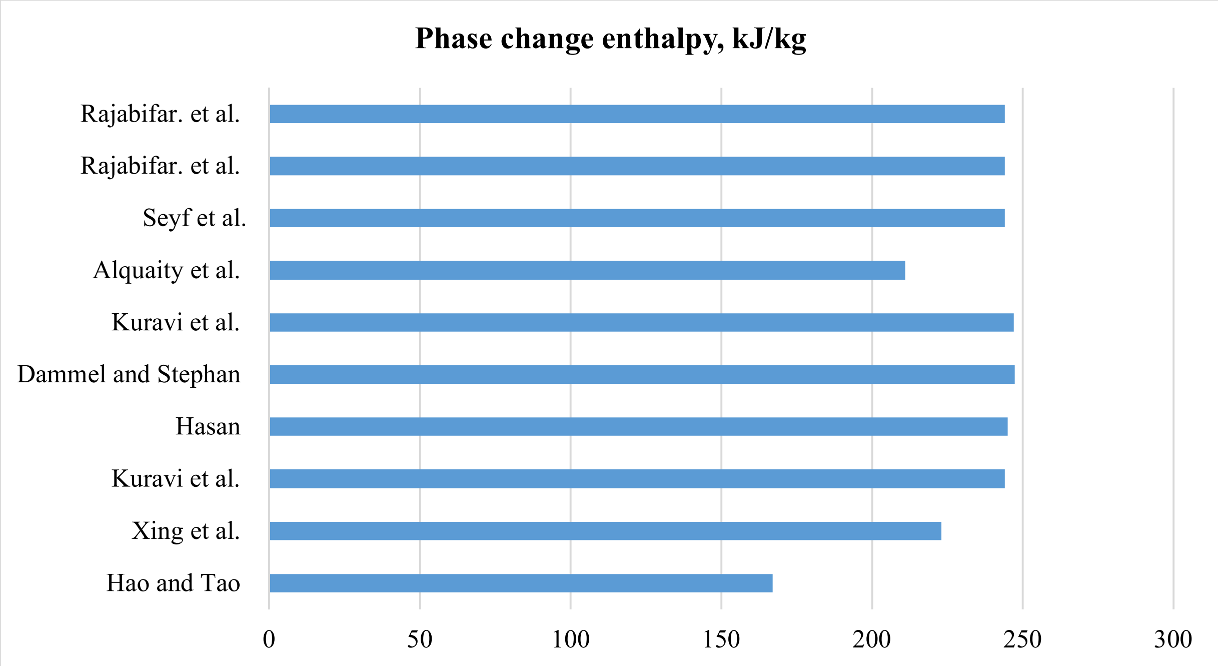


Figure No.9 Phase change enthalpy, kJ/kg in studies of different authors

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, 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[53].

IIIA Fundamental Literature Review on Optimisation Techniques and Structure Designs

This segment categorizes publications according to the structures employed in heat sinks. Various structures are utilized to enhance heat dissipation, adapt to diverse application scenarios, meet economic constraints, or minimize device weights. Optimization methods for heat sink structures include incorporating surface features, altering fin shapes, modifying microchannel internal structures, and incorporating lattice structures within heat sinks. These approaches collectively contribute to the improvement of heat sink functionality and efficiency, catering to a spectrum of thermal management requirements in different contexts, from technological advancements to economic considerations and weight reduction in devices.

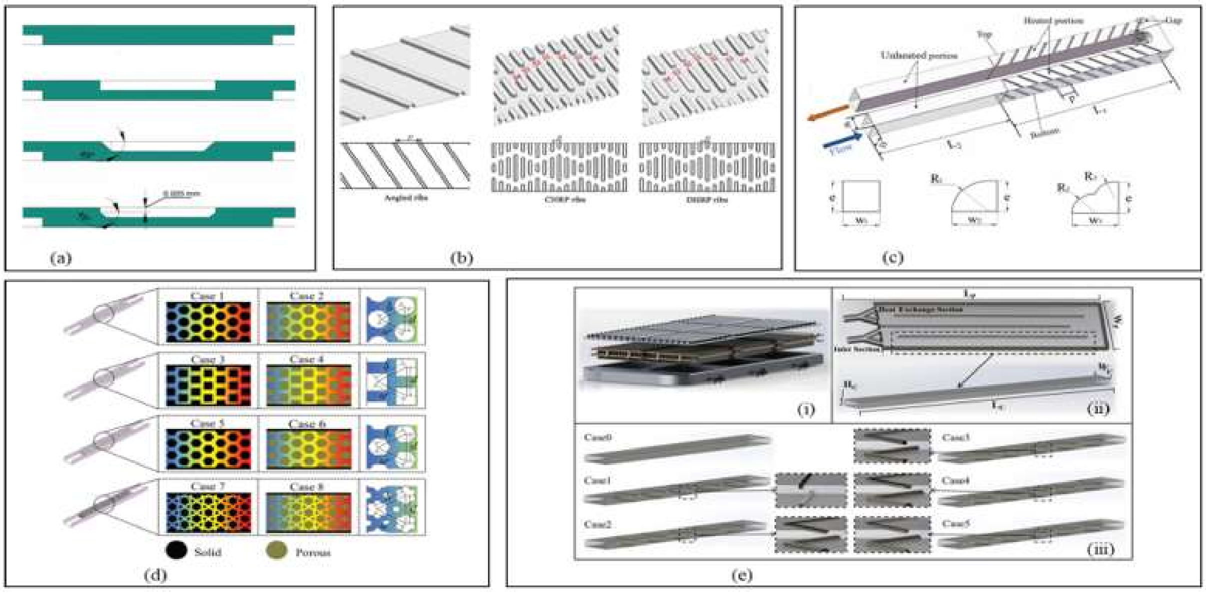


Figure No.10 Structure Designs and Optimization Approaches

Wei Wang et.al (2019) At Reynolds values between 100 and 900, a numerical study investigated the enhancement of laminar flow and heat transmission in an intermittent microchannel heat sink (IMCHS) featuring diverse rib configurations. Trapezoid ribs demonstrated the highest overall performance in terms of local transfer of heat and friction, as evidenced by the significant improvements observed. A positive correlation was observed between the size of chamfers on ribs and the transfer of heat and friction performance. The highest possible changes in Nu and f over IMCHS in rectangle ribs were 2.59 and 1.81, respectively[54]. **Zhen Zhao et.al (2023)** This reaction spectrum concept was applied in a numerical study aimed at studying the refrigeration mechanism of a five-channel steam-cooled turbine blade. Factors like mainstream temperature, outlet pressure, and steam flow ratio were examined. Results revealed significant improvements in cooling efficiency with increased pressure ratio, temperature ratio, and steam flow. The study compared air-cooled and steam-cooled blades, finding the latter to have superior performance and providing a precise correlation equation[55]. **Moti Lal Rinawa et.al (2022)** This study aimed to optimize heat transfer rates by examining different fin surface geometries. The investigation included normal fins with rectangular cross-section (R-Fin), fins with multiple steps (S-Fin), and multiple step fins with dimples (D-Fin). The analysis, incorporating conceptual and numerical approaches, revealed that fins with larger surface areas exhibit enhanced heat transmission. Based on numerical data, the execution of dimpled fins measured 5 mm, 4 mm, and also 3 mm in diameter has improved heat transmission and surface area. Spherical grooves with different diameters outperformed other fin shapes, and the study highlighted that creating notches was more effective in increasing heat transmission than enlarging the stepped fin's depression[56].

Sushma. S et.al (2022) Recent electronic devices have undergone greater dimension reductions as a result of technological advancements, which has increased heat dissipation. Consequently, electronic cooling has emerged as a pivotal concern within this domain. This work is predicated on optimisation and experimental analysis. A comparison is made between the experimental analysis results for concave and congruent heat sinks, which are constructed from aluminium and copper, respectively. The experiment is executed with varying heat inputs, and the heat sink's efficiency is assessed. The results indicate that a concave-shaped heat sink has a greater heat transfer coefficient and a lower thermal resistance; this investigation into the experimental performance of various heat sink shapes demonstrates its utility in electronic devices[57]. **Syarif Syahrul Syazwan Muzhaimey et.al (2022)** Technological advancements contributed to more substantial reductions in the dimensions of contemporary electronic devices, thereby increasing heat dissipation. As a result, electronic cooling has become a critical issue in this field. On the basis of optimisation and experimental analysis, this work is built. An examination is conducted on the experimental analysis outcomes pertaining to curved and congruent heat sinks, respectively, fabricated from copper and aluminium. The experiment is conducted with different levels of heat input, and the efficacy of the heat sink is evaluated. The findings suggest that a concave-shaped radiator exhibits superior heat transfer efficiency and reduced thermal resistance; thus, its applicability in electronic devices is demonstrated by this research regarding the practical performance of different heat sink geometries[58].

Sr No	Title	Materials	Technology Used	Parameters	Results
1	Jingnan Li et.al (2023)	Press-Pack IGBT, Graphene	Heat Dissipation Optimization	Contact Thermal Resistance, Pressure	Reduced Contact Thermal Resistance with Graphene, Enhanced Heat Dissipation
2	Anusha A et.al (2023)	Shell and Tube Heat Exchanger	Fluids, Baffle Plates, Tube Bundle	Pitches (Pitch-80, Pitch-60, Pitch-40), Hot/Cold Water Temperatures	Design Enhancement for Efficiency and Heat Transfer Rate
3	Abhay Gudi et.al (2022)	Electronic Equipment, Pulse Air Jet	Hybrid Heat Transfer Enhancement	Nozzle to Plate Distance, Reynolds Number, Pulsating Frequency, Strouhal Number	Novel Hybrid Method Improves Heat Transfer Rate
4	Yongfang Lu et.al (2022)	Microchannel Heat Exchange Units	Microchannel Heat Sink Model	Pressure Drop, Fluid Temperature	Overall-Optimized Heat Dissipation Design for Automation Systems
5	Muhammad Zarif Bin Shaharudin et.al (2023)	Electronic Industry, Plate-Fin Heat Sinks	Novel Designs, Pulse Air Jet	Nozzle to Plate Distance, Reynolds Number, Pulsating Frequency, Strouhal Number	Improved Thermal Performance in Plate-Fin Designs
6	Dipak Debbarma (2022)	Nonstacked Microchannels	Double-Layered Heat Sink with Dimples and Protrusions	Optimum Width, Depth, Dimple/Protrusion Parameters	Enhanced Overall Performance and Heat Transfer
7	M.I. Salem et.al (2021)	Rectangular Horizontal Duct	Mixed Convection, Air Cooling	Open Hole Ratio, Reynolds Number, Grashof Number	Improved Heat Transfer at Specific Hole Ratio
8	Yijun Li et.al (2023)	Electronic Devices, Liquid Cooling	Heat Sink Optimization Techniques	Channel Cross-Section, Flow Passage, Pin-Fin Shape	Emphasis on Topology Optimization for Liquid-Cooling Heat Sinks
9	Ke Zhang et.al (2023)	Natural Convection Heat Sinks	Passive Cooling, Fin Optimization	Fins, Fluid Turbulence, Heat Sink Temperature	Focus on Improving Natural Convection Heat Sink Efficiency
10	Seyed Soheil Mousavi Ajarostaghi et.al (2022)	Heat Transfer Enhancement Techniques	Passive Methods (Inserts, Fins, Porous Materials)	Various Inserts, Extended Surfaces, Nanofluids	Comprehensive Review of Passive Heat Transfer Enhancement Techniques
11	Muneeshwaran et al. (2023)	Natural Convection Heat Sinks	Inward Notched Fin Design	Fin Height, Fin Spacing	Improved Heat Transfer Coefficient with Inward Notched Fins

12	Rao et al. (2021)	Natural Convection Heat Sinks	Tapered Fin Configuration	Tapered Angles	Improved Heat Transfer Coefficient with Tapered Fins
13	Cheng-Hung Huang et.al (2022)	Natural Convection Heat Sinks	Shifted Fin Design	Fin Displacement, Fin Height	Displacement of Fins More Decisive for Minimizing Base Surface Temperature
14	Chandan Swaroop Meena et al. (2022)	Boiling Heat Transfer	Various Surface Structures	Nucleation Sites, Surface Structure	Analysis of Boiling Heat Transfer Enhancement Techniques
15	Cheng-Hung Huang et al. (2021)	Natural Convection Heat Sinks	Y-Shape-Shifted Heat Sink	Fin Parameters (Stem Height, Branch Length, Angle)	Optimized Geometry for Y-Shape-Shifted Heat Sink
16	Nada Baobaid et al. (2022)	Heat Sinks with TPMS Bases	TPMS-Based Heat Sinks	TPMS Bases (Diamond-Solid, Gyroid-Solid, Gyroid-Sheet)	Improved Thermal Performance with TPMS Heat Sinks
17	Li Yang et.al (2023)	Forced Convection Heat Sinks	Various Fin Configurations	Fin Types (Flat, Corrugated, Perforated)	Enhanced Heat Transfer Coefficients with Specific Fin Configurations
18	Marko Krstic et.al (2023)	Photovoltaic Panels	Aluminum Heat Sinks	Passive Cooling	Temperature Reduction and Voltage Increase in Photovoltaic Panels
19	Ali J. Obaid et.al (2023)	Heat Sink with Aluminum Fins	Mixed Convection	Fin Configurations	Enhanced Heat Transfer Coefficients with Specific Fin Configurations
20	Mesut Abuşka et.al (2023)	Conical Pin–Fin Heat Sinks	Various Placements	Staggered vs. Modified Staggered Fins	Modified Placement Shows Superior Thermo-Hydraulic Performance
21	Mostafa Fathi et.al (2023)	Porous-Fin Microchannel Heat Sinks	Porous Fins	Channel Heights	Superior Performance at Small Channel Heights
22	Prabhakar Bhandari et.al (2023)	Micro Pin Fin Heat Sinks	Various Pin Fin Configurations	Aspect Ratio, Sidewall Gap, Tip Clearance	Systematic Analysis and Optimal Ranges for Micro Pin Fin Design Parameters
23	Anurag Maheswari et.al (2023)	Double-Layer Microchannel Heat Sinks	Intermediate Rectangular Fins	Hole Shapes	Modified Design Enhances Heat Transfer Rates
24	Kai Tang (2023)	Microchannel Heat Sink	Non-Uniform Heating Flux	Manifold and Channel Ratios (α and β)	Optimized Ratios Improve Thermal-

					Hydraulic Performance
25	Yu-Hui Pan, Rui Zhao et.al (2023)	Pin–Fin Staggered Manifold Microchannel Heat Sink	Heat Transfer Capabilities	Divider Length–Width Ratios	Superior Heat Transfer and Uniform Heating Surface

Bibliography Survey

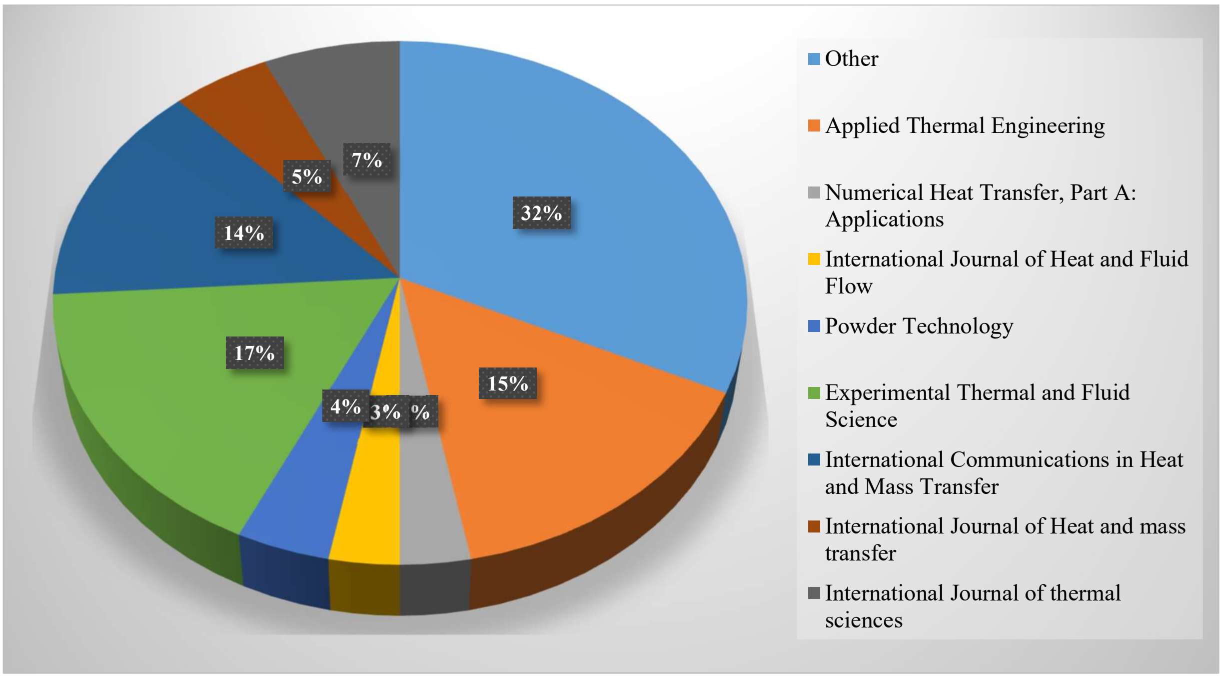


Figure No.11 Studies done by other authors

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 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.

Plate Fin Surface Geometries Source: [59]

Figure 12 shows the common surface geometries employed in compression plate-fin heat exchangers to facilitate heat transfer to gases. The figure shows six categories of fundamental surface geometry and provides descriptions of the geometric variables associated with each type. It's possible to generate an extensive number of unique surface geometries by modifying the basic geometric parameters associated with each surface type. Although average fin pitch varies between five to eight fins per meter, the highest number of fins necessary for automotive applications is 1,200 per meters. Typical fin thicknesses vary between 0.11 and 0.25 centimeters. The fin heights vary from 0.25 to 2 centimeters. An approximated 1,300 m2/m3 per cubic meter of volume is the heat transmission surface area of plate-fin exchangers with 600 fins per meter. An increase of tenfold in the transmission of heat area per unit volume could distinguish this heat exchanger from its conventional shell-and-tube equivalent, which utilizes tubes with a diameter of 19 mm. Consider the prime surface area, the coefficient of heat transfers at a horizontal speed of 3 meters per second would be approximately 1,800 W/m2 K.

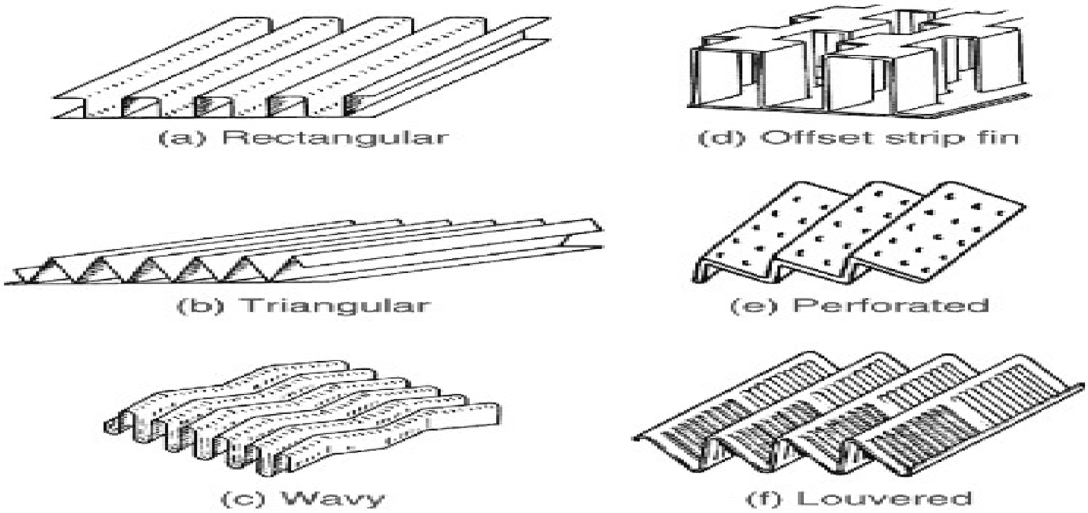


Figure No.12 Plate-fin exchanger surface geometries (Webb and Kim, 2005): (a) plain rectangular fins; (b) plain triangular; (c) wavy; (d) offset strip; (e) perforated; (f) louvered

This rectangles and triangle fins are straightforward conventional fin geometries whose small hydraulic radius enhances heat transfer. A portion of the heat transmission is increased when perforations or holes are incorporated into the surface of the fin due to the wake interacting that taking place in the regions of the holes. The secondary flows created by the moving channel result in enhanced heat transmission facilitated by the moving fins.

Comparing The Coefficient of Heat Transfer of Three Distinct Fin Geometries

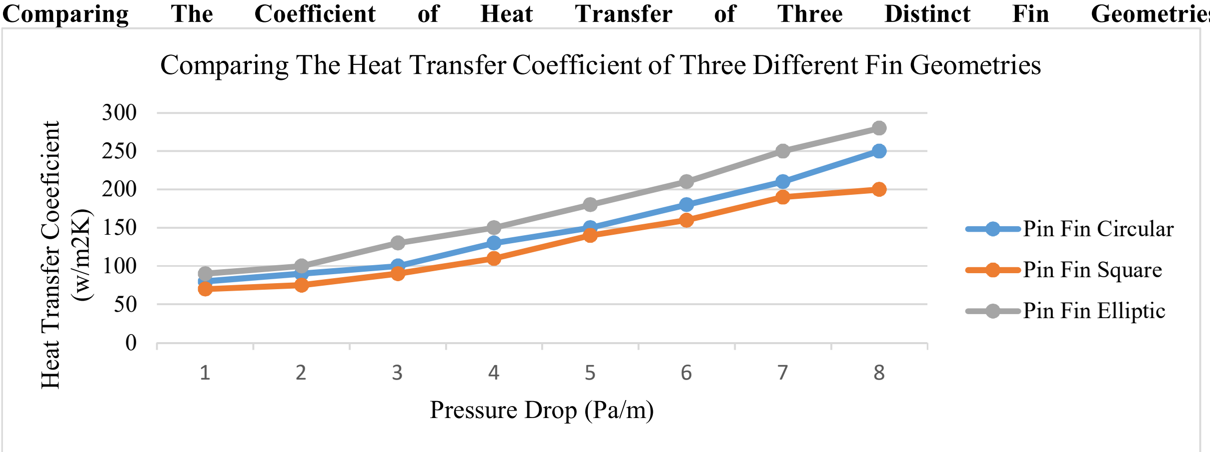


Figure No.13 Comparing The Coefficient of Heat Transfer of Three Distinct Fin Geometries

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.

Research Gap

The research that has been presented emphasises a significant knowledge deficit regarding the examination of thermal management techniques for electronic devices, specifically with regard to microchannel heat sinks (MCHS). The studies that were reviewed, including those by Prabhakar Bhandari, Hussam Siddique, Hamdi E. Ahmed, Yoav Peles, Jie Gao, and Hamza Babar, have provided significant insights into different facets of MCHS and heat transfer enhancement techniques. However, further extensive research is clearly required to tackle the issues of uneven heating and overheating that are prevalent in contemporary electronics. A considerable segment of the literature being examined is dedicated to particular aspects of heat transfer improvement and microchannel heat sink (MCHS) design. These include changes to the microfins fin designs, secondary flow optimizing for thermal enhancement, forced heat transmission via pinned fin micro cooling systems, and the use of micro channels to symbolize the transfer of heat and movement of fluid in heat sinks. While these studies provide useful information into particular elements of thermal management, the study of the more extensive issue of irregular heating caused by the presence of various heat sources, which is common in modern electronics, is clearly absent. Additionally, the paper identifies a lack of scholarly works that examine the issue of irregular heating in comparison to situations involving uniform or single-peak heating. Despite the investigation of numerous design and optimisation techniques, the conclusion's critical analysis emphasises the necessity for further research to address the problem of irregular heating. The technological potential of topology optimisation is underscored as it possesses the greatest degree of longitude to effectively tackle this particular thermal management challenges.

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.

Future Scope

The future of heat sink design holds promising avenues for innovation and efficiency improvement. Integrating Thermal Performance Monitoring Systems (TPMS) offers real-time insights into the thermal behavior of heat sinks, enabling dynamic adjustments and proactive heat management. Exploring bionic structures, inspired by natural designs, presents an intriguing path for enhanced cooling effects. The application of topology optimization techniques allows for the systematic refinement of heat sink geometries, maximizing performance while minimizing material usage. Further research into advanced materials, including Nano fluids, can revolutionize heat sink technology by improving heat conductivity and overall efficiency. Additionally, the exploration of flexible manufacturing processes, adaptive to varying production scales and prototyping needs, will be crucial for addressing the dynamic demands of diverse industries. As the electronic and mechanical landscapes evolve, ongoing studies in heat sink design will likely focus on holistic solutions, encompassing both thermal performance and practical manufacturing considerations, ensuring sustainable advancements in this critical field.

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