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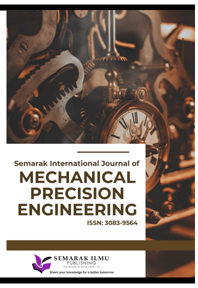

A Comprehensive Review of Heat Transfer Enhancement in Fins: A Comparative Analysis of Straight, Annular, and Perforated Geometries

Sandeep Kore[1,*], Pranav Gogawale[1], Soumitra Hulyalkar[1], Hardeep Singh Gaidhu[1]

[1] Department of Mechanical Engineering, Vishwakarma Institute of Information Technology, Pune-46, Maharashtra, India

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ABSTRACT

This paper presents a comprehensive review of heat transfer fin designs for effective thermal management, synthesizing findings from multiple studies on straight, annular, and perforated geometries. The analysis reveals two primary conclusions. First, for annular fins, a triangular profile is the most effective and economical design, providing superior heat transfer while generating the lowest thermal stresses. Perforated fins consistently outperform solid fins, with the size of the perforations proving to be a more critical optimization factor than their shape or pattern. Overall, the review highlights that advanced, optimized geometries are essential for maximizing thermal efficiency.

1. Introduction

This report presents a comprehensive overview of fins as essential engineering components, highlighting their dual roles in thermal management and fluid dynamic control. It integrates theoretical principles, design methods, material selection, and manufacturing techniques for both heat transfer fins (extended surfaces) and hydro/aerodynamic fins (foils). Key performance metrics, classifications, and applications—from electronics cooling and automotive radiators to aircraft stabilizers and marine keels—are examined in detail. The report also explores the convergence of these disciplines in complex systems and the emerging field of biomimicry, where natural designs drive technological innovation. Its goal is to provide an expert-level reference that bridges theory and practice for engineers and researchers in thermo-fluids.

* *Corresponding author.*
E-mail address: Sandeepkore@viit.ac.in

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2. Methodology
2.1 Fin Performance Metrics

To evaluate and compare the performance of different fin designs, several standardized metrics are used. These metrics provide a quantitative basis for assessing whether a fin is beneficial and how efficiently it performs its function.

The selection of an appropriate performance metric is not trivial and depends on the specific design constraints. For instance, a very long fin may be highly effective at increasing total heat transfer compared to the no-fin case, yet be very inefficient because the outer portions of the fin contribute little to the heat transfer due to their low temperature. This occurs because the ideal heat transfer rate (the denominator in the efficiency calculation) increases linearly with surface area, while the actual heat transfer rate grows at a diminishing rate as the fin lengthens and its tip temperature approaches that of the surrounding fluid. Conversely, a short, thick fin made of a highly conductive material will have a very high efficiency, as its temperature will be nearly uniform. However, if the convection coefficient is already high, the base area alone transfers heat effectively, and the addition of the fin may not provide a substantial improvement, resulting in low effectiveness. This demonstrates that fin design is not a simple maximization problem but a nuanced optimization task where the choice of metric efficiency or effectiveness is dictated by the engineering goal, whether it is maximizing performance for a given surface area or for a given mass or volume.

Table 1
Fin performance metrics

Metric	Definition	Formula	Physical Significance
Fin Effectiveness (ϵ_f)	The ratio of the heat transfer rate from the fin to the heat transfer rate that would occur from the base area if the fin were not present.	$\epsilon_f = \frac{Q_{fin}}{hA_{fin}(T_b - T_\infty)}$	Answers the question: "Is the fin worthwhile?" A value greater than 2 is typically required to justify the added cost and complexity.
Fin Efficiency (η_f)	The ratio of the actual heat transfer rate from the fin to the ideal heat transfer rate that would be achieved if the entire fin were at the base temperature.	$\eta_f = \frac{Q_{f\,in}}{hAfin\theta_b}$	Compares the actual fin to an ideal fin of the same dimensions. It is always less than 1 and quantifies the impact of the temperature drop along the fin.
Overall Surface Efficiency (η_o)	The weighted-average efficiency for a finned surface, accounting for both the finned area (A_f) and the un-finned primary surface area (A_b) between fins.	$\eta_o = \frac{A_b + \eta_f A_f}{A_b + A_f}$	Provides a comprehensive performance measure for an entire fin array, essential for the thermal analysis of heat exchangers.

2.2 Classification by Geometry
2.2.1 Straight fins

Straight fins also referred to as longitudinal fins, are extended surfaces that are attached perpendicular to a flat surface and typically run parallel to one another. This common fin type can be designed with various cross-sectional profiles, including rectangular, trapezoidal, or concave, to meet different operational requirements. Straight fins are utilized in a wide array of applications, such as in heat exchangers, automotive radiators, and for cooling electrical transformers and motors.

Baskaya *et al*., [5] "Experimental Investigation of Natural Convection Heat Transfer from Horizontal Fin Arrays," conducted an experimental study using aluminium fins of 3 mm thickness attached to a 250 mm x 250 mm horizontal base plate. They systematically investigated the effects of varying the fin spacing (from 6 mm to 28.7 mm), fin height (25 mm and 50 mm), and fin length (50 mm to 250 mm). The primary finding was the identification of an optimal fin spacing of approximately 8.1 mm, which maximised the heat transfer rate. Their results experimentally confirmed the critical trade-off in heat sink design: spacing below this optimum restricts airflow due to boundary layer interference, while larger spacing reduces the total heat transfer surface area. The study also concluded that increasing both fin height and length further enhanced thermal performance.[5] In the numerical study of Shaeri *et al*., [7) analysed a horizontal array of 10 rectangular aluminium fins, each 100 mm long and 20 mm high, using the standard k-ε turbulence model. The CFD analysis was conducted with a non-uniform structured mesh that was refined near the fin surfaces to ensure accuracy. Their investigation into the effect of the vertical position of rectangular perforations concluded that an optimal placement near the fin tip enhanced the heat transfer coefficient by up to 34.4% compared to a solid fin. This significant improvement is attributed to secondary buoyant plumes rising through the perforations, which disrupt the main thermal boundary layer and enhance fluid mixing [7].

The literature by MD. Safayet Hossain, Muhammad Ferdous Raiyan, Samantha Sayeed, J. U. Ahamed is used as reference for the present work. The following comparative results, including the analyses of temperature distribution and Heat Flux for Straight rectangular fin profile, is directly based on the finding reported in this study [1].

Fin was designed in such way, so that rectangular shaped geometry has been extended from a hollow cylinder. The inside of the cylinder was used as heating surface in this analysis. The outer diameter of this hollow cylinder is 25 mm and thickness is 1 mm. the height is 100 mm. total number of fin attached with the surface is twelve. Whereas their dimension is 25 × 2 × 100 mm3.

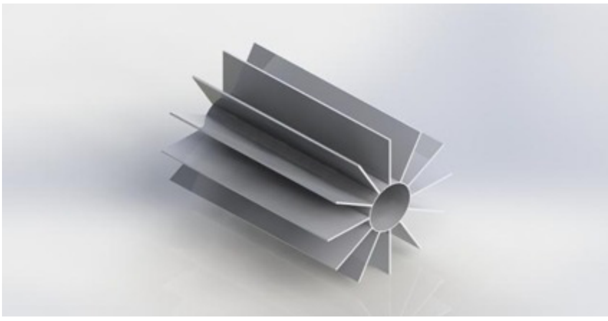


Fig. 1. Straight rectangular fin [1]

The analysis was based on the following common assumptions:

a) Steady-state heat flow
b) The materials are homogeneous and isotropic
c) There is no heat source
d) The convection heat transfer co-efficient is same all over the surface
e) The temperature of the surrounding fluid is uniform
f) The thermal conductivity of the material is constant

An analysis was carried out on a straight rectangular fin, as shown in Figure 1, to study its thermal performance. The investigation focused on determining the temperature distribution along the length of the fin and its heat dissipation characteristics. The results show clear variations in temperature distribution and heat transfer efficiency with the constant fin length. Additionally, thermal stress distribution along the fin length was evaluated to understand how temperature gradients influenced mechanical loading within the fin. The analysis revealed the magnitude and pattern of thermal stresses, providing insight for the optimal fin geometry for improved heat transfer efficiency. From Fig. 2, it can be seen that for 600 ℃ base temperature, the temperature at the outmost area of every fin was found 409.77 ℃ for selected fin geometry.

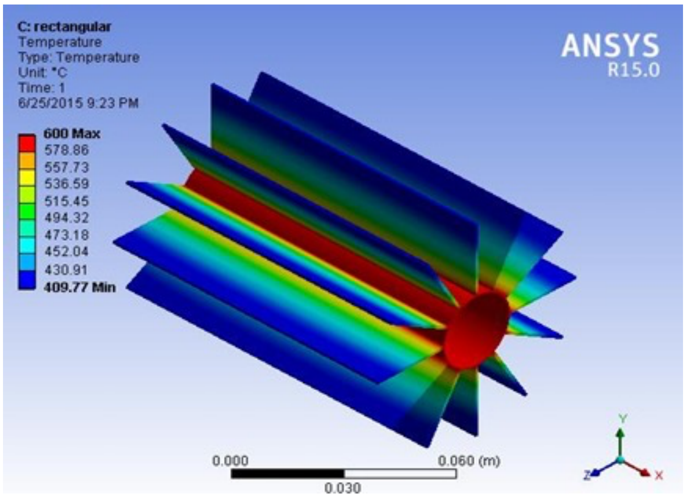


Fig. 2. Temperature distribution of straight rectangular fin [1]

The minimum and maximum heat flux were found 419.04 W/m2 and 8.9994e + 005 W/m2 respectively which occurred at different portions of the same geometry which can be observed from Fig. 3

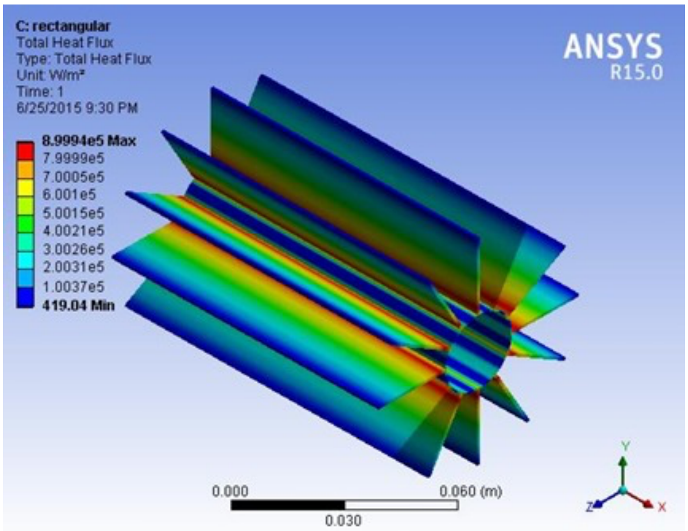


Fig. 3. Total heat flux of straight rectangular fin [1]

Fins are used to transfer excess amount of heat from a body to the surroundings. It is observed that due to convective heat transfer, the heat transfer from the base to fin tip is decreasing gradually. Base temperature is 600 ℃ and at the middle of fin, the temperature was found around 500 ℃ as depicted in Fig.2.Thus this experiment successfully satisfied the theoretical concept of fin.

Conclusion:

Heat transfer distribution through straight rectangular was observed. In addition to that, heat flux distribution was also analysed. The simulation was done by using finite element method-based solver. Besides, for the meshing process, in order to conclude numerical analysis, ANSYS meshing utility has been used. From the simulation the following decision can be considered; With the increase in thermal conductivity of fin material, temperature distribution is increased. The ratio of the perimeter to the cross-sectional area of the fin should be as high as possible to increase the heat transfer. It was observed that, different temperatures were obtained at different tips. For the longest profile, temperature was found 238.96 ℃ and for the shortest profile, temperature was found 342.19℃. The temperature at the outmost area of every fin was found 409.77 ℃ for rectangular fin geometry (Fig. 2 and Fig. 3).

2.2.2 Annular fin

The selection of a particular fin configuration in any heat transfer application depends on the space, weight, manufacturing technique and cost considerations as well as the thermal characteristics it exhibits. Radial or annular fins are one of the most popular choices for enhancing the heat transfer rate from the primary surface of cylindrical shape. Different profiles have profound influence on the thermal characteristics of annular fins.

In a analytical study, Kundu and Das [6] optimised the design of an annular fin featuring a single step change in its thickness. By solving the governing heat equations, they determined the ideal location for the step and the optimal thickness ratio to maximise heat dissipation for a fixed volume of material. Their analysis showed that a properly optimised step fin could outperform a standard uniform fin of the same volume by approximately 1.5% in a sample case, offering a strategy to improve thermal efficiency without increasing material costs [6]. In the numerical analysis, “Performance of Annular Fins with Different Profiles Subject to Variable Heat Transfer Coefficient,” Mokheimer [20] investigated how real-world conditions affect the performance of annular fins. The study analysed four different fin profiles (rectangular, triangular, trapezoidal, and parabolic) while considering a spatially variable heat transfer coefficient (h) that changes along the fin's radius. The crucial finding is that the common engineering assumption of a constant h can lead to significant predictive errors. For instance, if h actually decreases from base to tip, assuming it's constant can cause an underestimation of the fin's efficiency by more than 30%. Conversely, if h increases towards the tip, the constant h assumption leads to a significant overestimation. This work highlights the critical need to account for the variation in h for accurate thermal design [20].

The literature by Sudheer is used as reference for the present work. The following comparative results, including the analyses of temperature distribution and thermal stress for triangular, trapezoidal, and rectangular fin profiles, are directly based on the findings reported in this study [2].

The Research was conducted on the 3 different types of Annular Fins:

(a) annular fin with rectangular profile
(b) annular fin with trapezoidal profile
(c) annular fin with triangular profile.

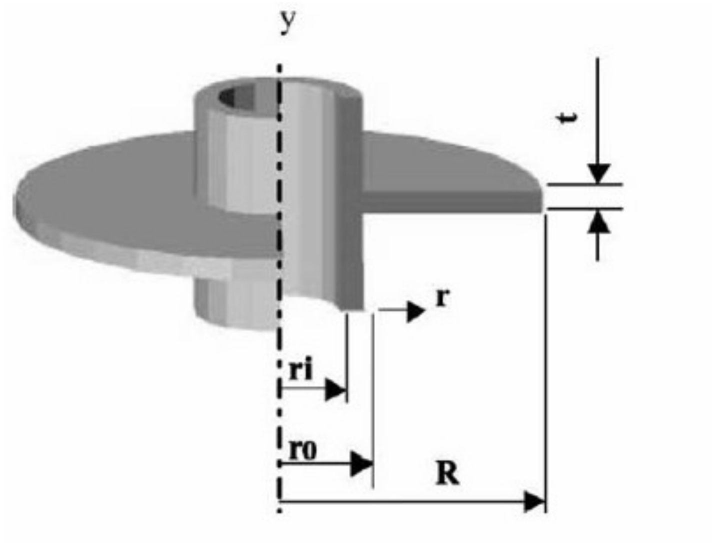


Fig. 4. (a) Represents annular fin with rectangular profile [2]

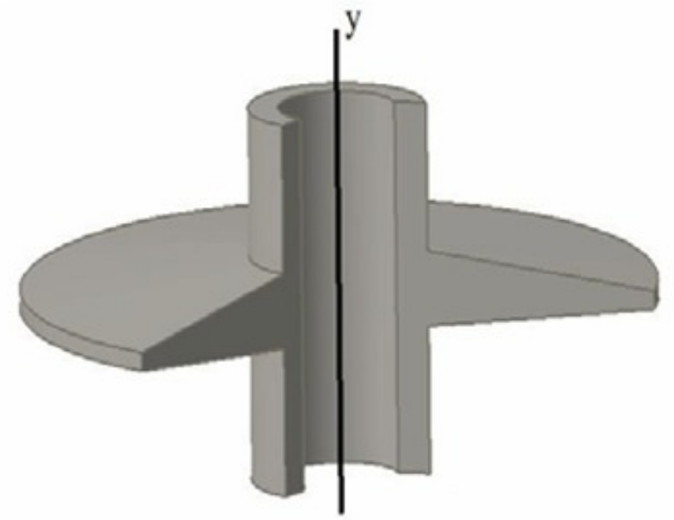


Fig. 4. (b) Represents annular fin with trapezoidal profile [2]

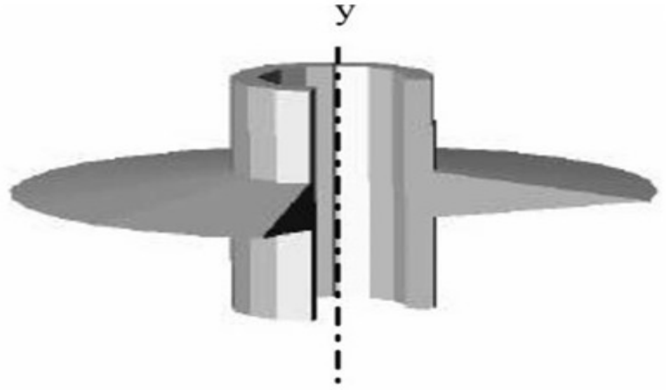


Fig. 4. (b) Represents annular fin with triangular profile [2]

The analysis was based on the following common assumptions:

g) Steady-state heat flow
h) The materials are homogeneous and isotropic
i) There is no heat source
j) The convection heat transfer co-efficient is same all over the surface
k) The temperature of the surrounding fluid is uniform
l) The thermal conductivity of the material is constant.

An analysis was carried out on different types of fins, as shown in Figure 4 (a)–(c), to study their thermal performance. The investigation focused on determining the temperature distribution along the length of the fin for various fin profiles, enabling comparison of their heat dissipation characteristics. The results show clear variations in temperature distribution and heat transfer efficiency due to changes in fin length and thickness. Additionally, thermal stress distribution along the fin length was evaluated to understand how temperature gradients influenced mechanical loading within the fin. The analysis revealed that changes in length and thickness significantly affect the magnitude and pattern of thermal stresses, providing insight into the optimal fin geometry for improved heat transfer efficiency.

Temperature distribution contours in case of radius ratio (height of fin) for the three different profiles are shown in Figure 5 (a)–(c), and the effect of different fin profiles on the temperature distribution for various radius ratios are represented in the Figure 3 (a)-(c).

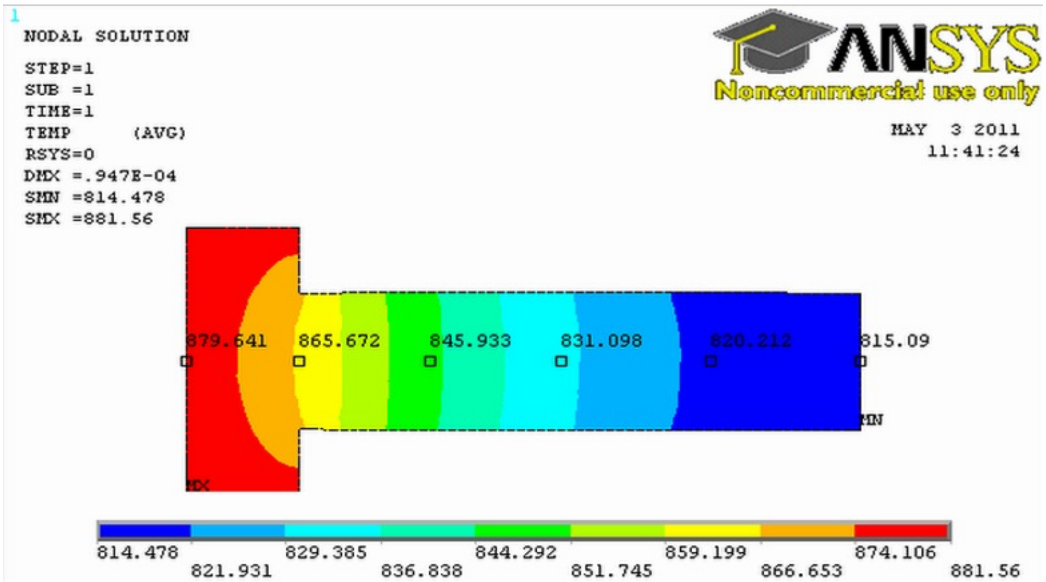


Fig. 5. (a) Represents temperature distribution along the centerline of fin with rectangular profile [2]

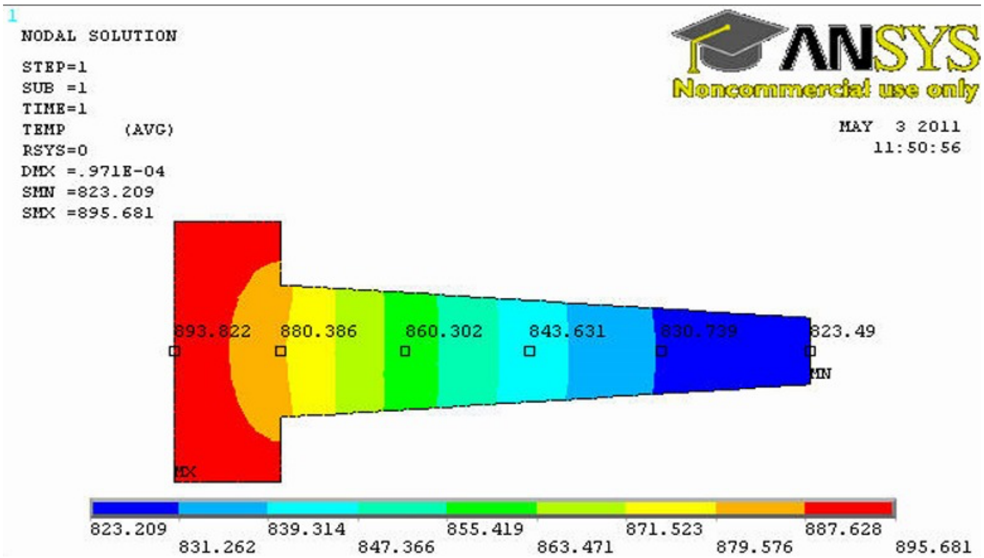


Fig. 5. (b) Represents temperature distribution along the centerline of fin with trapezoidal profile [2]

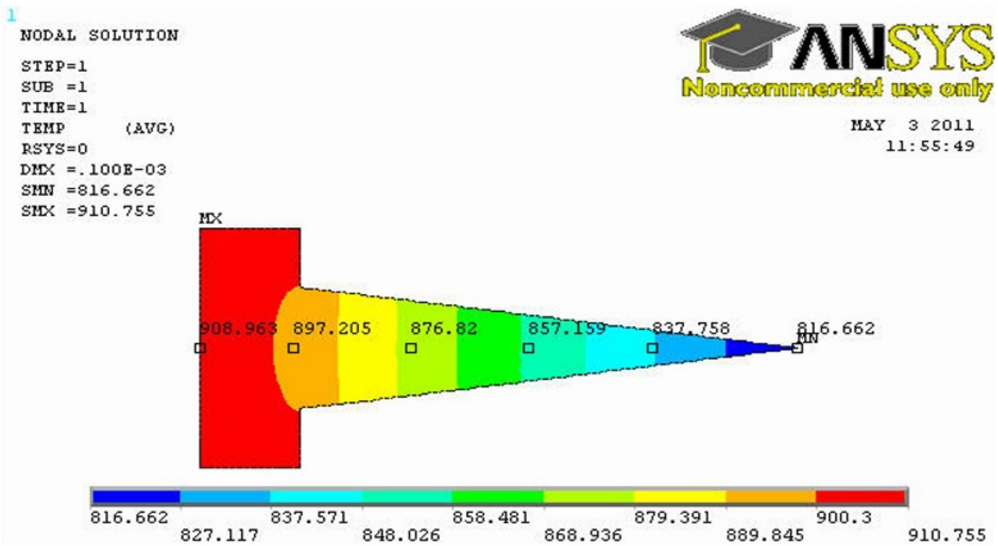
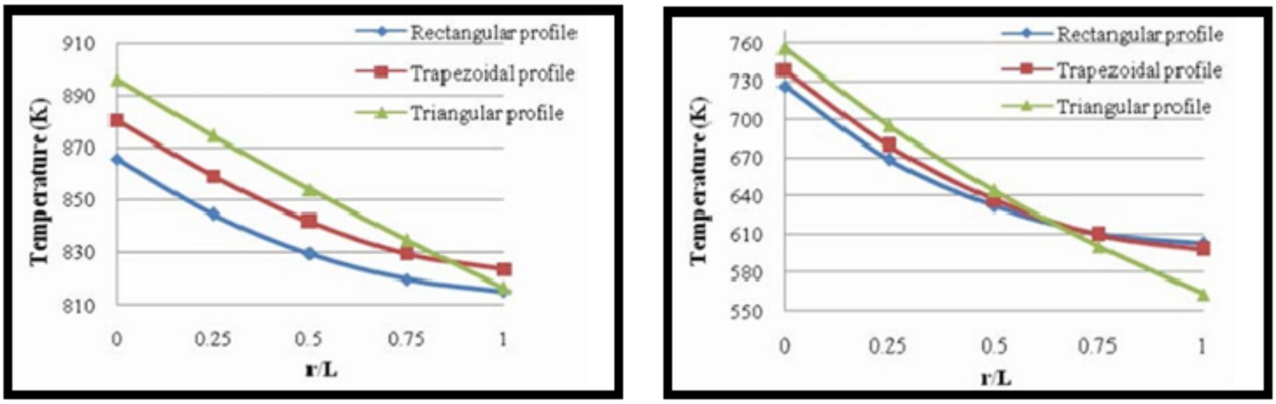


Fig. 5. (c) Represents temperature distribution along the centerline of fin with triangular profile [2]

From the Figure 6 (a)-(b), it is evident that there is a decrease in the temperature along the length of the fin for all the three profiles with various radius ratios. It is found that the base temperature is maximum in the case of triangular profile and minimum for rectangular profile, while that of the trapezoidal profile lies in between the triangular and rectangular profile. It is also seen that the temperature distribution along the length of the fin for all the three profiles decreases with an increase in the radius ratio. This is because large radius ratio value will lead to more heat being transferred to the surrounding and less heat stored in the fin material, hence resulting in low base temperature. This reduced temperature will induce smaller thermal stresses and the consequent distortion of the finned-tube.



(a) (b)

Fig. 6. (a) and (b) Represents graphical demonstration of variation in temperature distribution along the fin for change in length [2]

Thermal stress distribution contours in case of radius ratio for different profiles are shown in Figures 7 (a)-(c). In Figures 15-18, the effect of different fin profiles on the radial stress distribution for various radius ratios are shown.

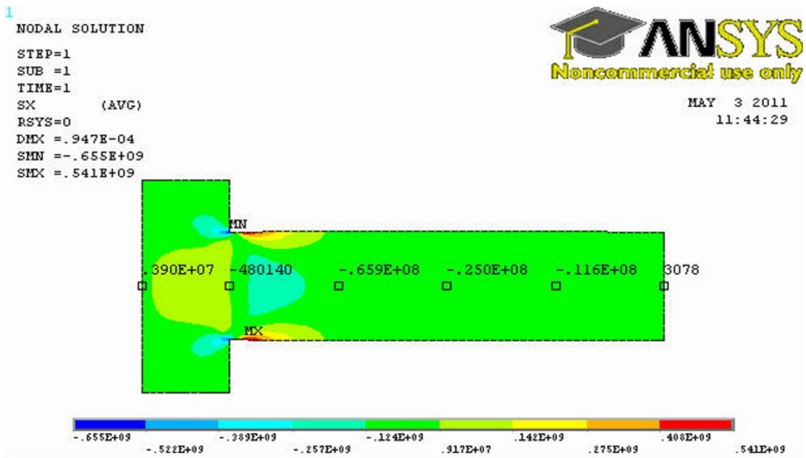


Fig. 7. (a)

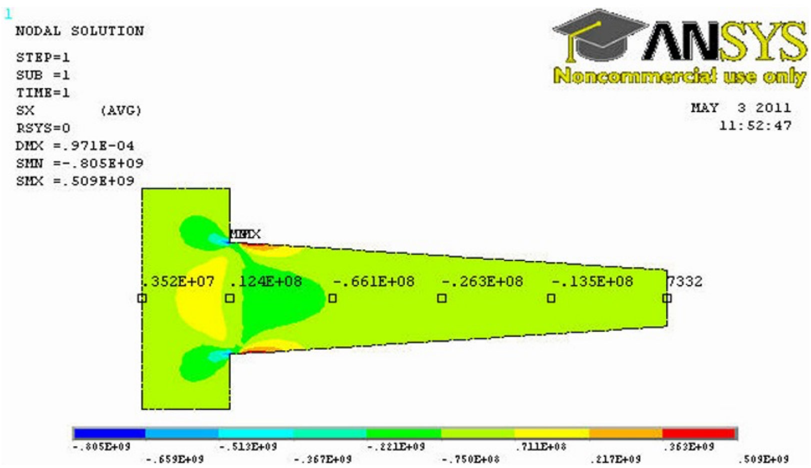


Fig. 7.(b)

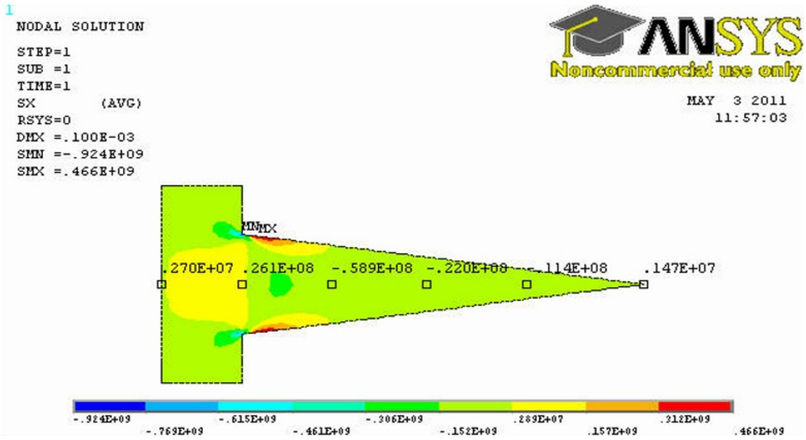


Fig. 7. (c)

Figure 7 (a)-(c) Represents thermal stress distribution along the centreline of fin [2]

From the Figure 8 (a) and (b), it can be seen that the nature of the radial stress is compressive near its base and reaches zero close to the tip of the fin for all the three profiles. It is also observed that the magnitude of the radial stress is maximum in the case of annular fin with rectangular profile and the least for triangular profile. It is found that the radial stress distribution decreases as the radius ratio of the annular fin increases. This is due to the fact that a large value will cause less temperature rise and thus less thermal stresses are induced. From stress contours presented for various radius ratios, it is found that lesser radius ratio, leads to higher stress contours.

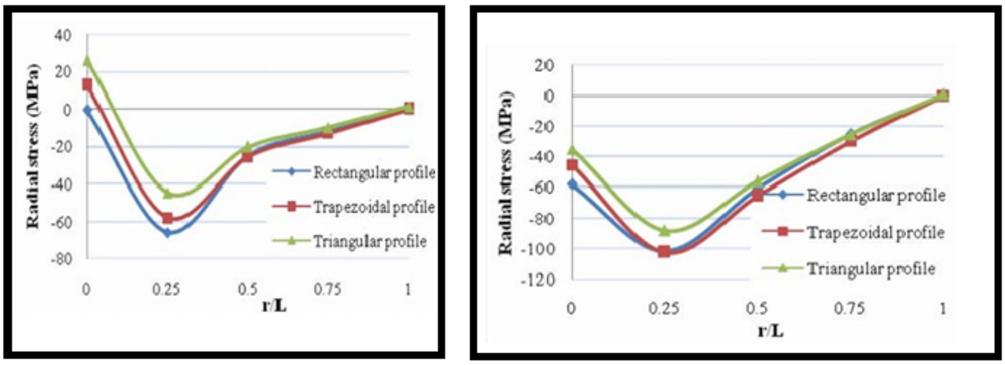


Fig. 8 (a) and (b)
Shows graphical representation of thermal stress distribution along the fins of different profile with change in radius ratio [2]

Conclusion:

Based on the analysis, the annular fin with a triangular profile is the most effective and economical design. It provides the best convective heat transfer and inherently generates the lowest thermal stresses compared to rectangular and trapezoidal shapes. Crucially, it achieves equivalent heat transfer with significantly less material volume, making it the most attractive option due to its lower material and construction costs, and superior thermal performance.

2.2.3 Perforated fin

In the realm of thermal management, perforated fins represent an innovative evolution of traditional cooling fins. These are extended surfaces, typically made of thermally conductive materials like aluminium or copper, that feature a series of holes or perforations through their structure. The primary purpose of these perforations is to enhance the rate of heat transfer from a surface to a surrounding fluid, such as air or a liquid coolant.

Al-Essa and Al-Badran [4] "Natural Convection Heat Transfer from a Horizontal Rectangular Fin with Rectangular Perforations," investigated a fin with a length of 100 mm, height of 50 mm, and thickness of 5 mm. Their analysis focused on varying the number of rectangular perforations, and they found that an optimal configuration of 9 perforations yielded a maximum heat transfer enhancement of approximately 19% compared to an equivalent solid fin. The key conclusion is that while perforations improve heat dissipation, performance peaks at an optimal number of holes. This indicates a critical trade-off between the enhanced fluid mixing and increased surface area provided by the perforations against the negative impact of reducing the fin's conductive cross-sectional area. In a highly analytical work, “Optimal Dimensions of Circular Fins with Variable Profile and Temperature-Dependent Thermal Conductivity,” Zubair *et al*., [8] developed a formal optimisation framework for circular fins. The study addresses two key real-world complexities: fins with variable profiles (such as rectangular or triangular) and materials whose thermal conductivity changes with temperature. Using advanced variational calculus, they determined the optimal dimensions that maximize the heat dissipation rate for a given fin volume. A crucial conclusion is that assuming constant thermal conductivity—a common simplification—can lead to significant errors in design; for instance, their analysis shows this can cause an overestimation of fin effectiveness by over 12% for certain materials. The study demonstrates that the optimal dimensions are strongly dependent on both the fin's geometric profile and its material-specific thermal properties [8].

The literature by M. Sudheer is used as reference for the present work. The following comparative results, including the analyses of temperature distribution and thermal stress for triangular, trapezoidal, and rectangular fin profiles, are directly based on the findings reported in this study [3].

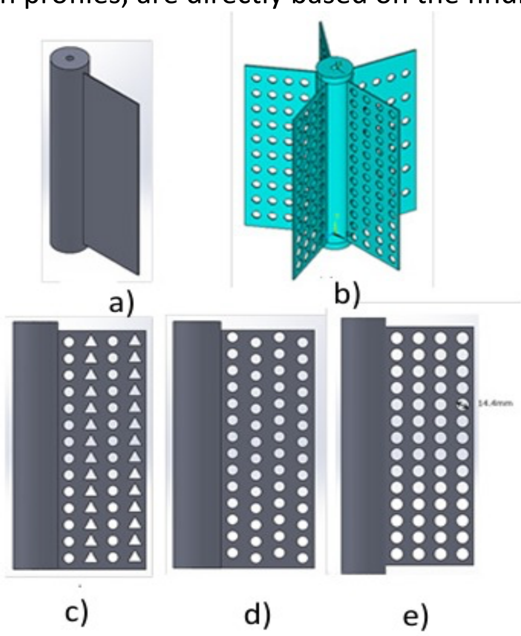


Fig. 9.
The fins were 100 mm long, 270 mm wide and 2 mm thick. These fins were divided into five groups (a). Solid fin (non-perforated), (b). Number of circular perforations, (c). Mixed

perforations (d). Triangular pitch design, (e). Increasing hole diameter [3]

Table2
Fin diameter and number of perforations

Sr. No	Perforated fin Diameter (in mm)	Number of Perforation (in mm)
1	12	24
2	12	32
3	12	40
4	12	48
5	12	56

Thermal contour results for a typical case of a plate with 56 perforations is presented in Figure 10, It is clear from the contour results that temperature drops from the fin base towards the tip.

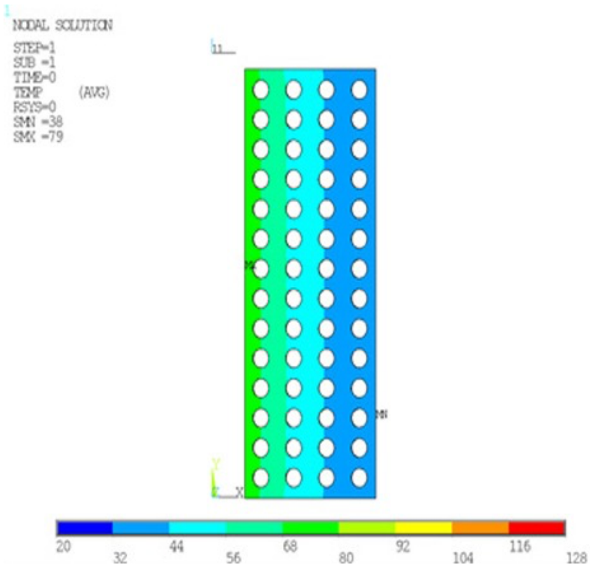


Fig. 10. Thermal contour in a plate of 56 holes [3]

Perforated fins have higher contact surface with the fluid in comparison with the solid fins. Thus the perforated fins are more effective than the solid fins in temperature reduction [8]. The maximum reduction observed is with the 56 number of perforations and is found to be 27% when compared to solid fin. The number of perforations, however, has shown only marginal effect on the temperature distribution as it is clear from the Figure 11.

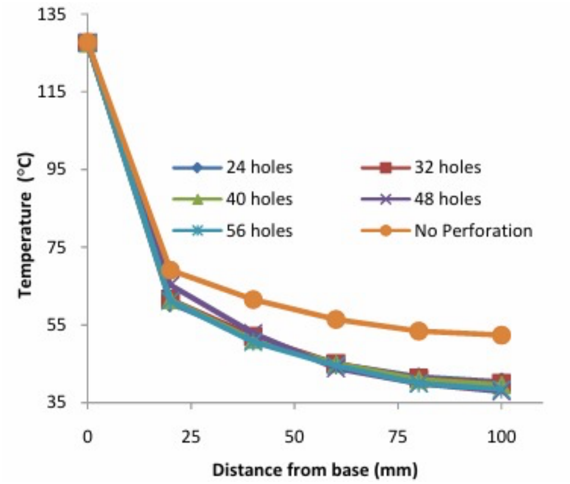


Fig. 11. Temperature distribution in non-perforated and perforated fins [3]

Figure 12 shows comparison of finite element temperatures between base line perforations and mixed perforations. In the present analysis, it is observed that temperatures of mixed perforations are less than the base line perforations by very small amount. As triangular and circular perforation has equal cross-sectional areas, there is no much change in the temperature observed.

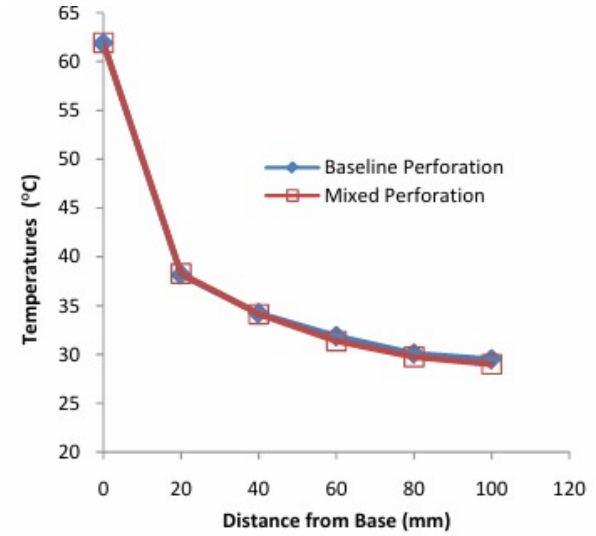


Fig. 12. Effect of mixed perforations on temperature distribution [3]

As indicated in Figure 13, the increase in the hole diameter has obviously resulted in temperature drop. This is because of increased cross-sectional area which in turn increases the influence of convection.

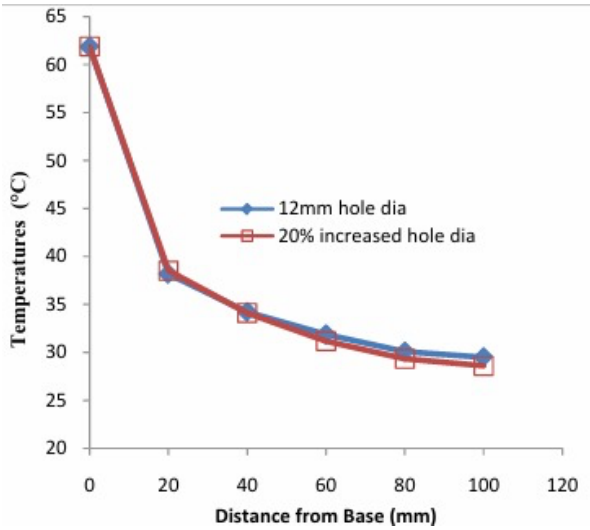


Fig. 13. Effect of increasing hole diameter on temperature distribution [3]

Conclusion:

The finite element analysis, confirms that perforated fins offer superior heat dissipation compared to solid fins. The study reveals that while the perforation pattern or shape does not significantly influence thermal performance, the size of the perforations is a critical factor. Increasing the diameter of circular perforations was found to be the most effective strategy for reducing fin temperatures and enhancing thermal performance. This indicates that optimizing perforation size, rather than pattern, is the key to improving the design of heat-dissipating fins.

Table 3
Summary of different types of fin geometry

Reference	Methodology	Fin Geometry	Key parts	Conclusion
Samantha Sayeed, Ahamed [1]	Finite Element Analysis	Straight Fin	Length Variation	Fins having the larger length (Cross-Sectional area) shows maximum heat dissipation
Sudheer Vignesh Shanbhag [2]	Analytical/ Finite Element Analysis	Annular Fin	Different Fin profile (Rectangular, Trapezoidal, Triangular)	Fins having Triangular profile have higher heat dissipation
Prashanth Kumar and Shashiraj Somayaji [3]	Analytical/ Finite Element Analysis	Perforated	With and without perforation	Fins with perforation have higher Heat dissipation
Al-Essa *et al.*, [4]	Numerical	Perforated horizontal rectangular fin.	Number and diameter of circular perforations.	Perforations improve heat dissipation, with performance peaking at an optimal number of holes
Shaeri *et al.*, [7]	Numerical (CFD)	Perforated horizontal rectangular fin.	Rectangular perforation dimensions and positions.	Perforations create buoyant plumes that enhance the heat transfer coefficient by up to 34%
Kundu and Das [6]	Analytical	Annular fin with a step change in thickness.	Fin geometry and profile.	A step-in fin thickness can be optimized to maximize heat transfer for a given fin volume
Baskaya *et al.*, [5]	Experimental	Horizontal	Fin spacing,	An optimal fin spacing exists

		straight fin array on a rectangular base	height, and length	that maximizes the total heat transfer from the array.
Zubair *et al*., [8]	Optimization Analysis	Circular fin with variable profile.	Temperature-dependent thermal conductivity	The optimal dimensions of a fin depend on its profile and the material's thermal properties.
Dhanawade *et al*., [12]	Experimental	Perforated straight fin array with staggered circular holes.	Perforation diameter and fin spacing.	Staggered perforations Provide better thermal performance than inline arrangements due to improved fluid mixing
Teamah *et al*., [13]	Experimental	Perforated annular fins on a horizontal tube.	Perforation diameter.	Perforating the fins of a horizontal finned tube enhanced its natural convection performance.
Alkam and Al-Nimr [10]	Analytical	Annular fin with porous inserts.	Porous medium properties.	Embedding porous inserts into a solid fin was shown to be an effective heat transfer enhancement technique.
Ali *et al*., [9]	Experimental	Vertical perforated straight fin array with honeycomb holes.	Perforation size.	Honeycomb perforations provided a good balance of heat transfer enhancement and material savings
Yildiz and Yüncü [15]	Experimental	Elliptical tube with fins.	Tube orientation and fin geometry.	For a given surface area, finned elliptical tubes can outperform circular ones in certain orientations.
Caliskan *et al*., [11]	Numerical	Perforated annular fins with NACA 4-digit profiles	Fin profile and perforation diameter.	Using aerodynamic profiles for fins with perforations can optimize flow and improve performance.
Yaghoubi, *et al*., [14]	Experimental	Straight fin array on an inclined surface	Angle of inclination, fin spacing.	The heat transfer rate from a fin array is highly dependent on its angle of inclination from horizontal.
Abdel-Gaied [16]	Numerical	Perforated vertical straight fin array	Perforation shape (circular vs. square).	Square perforations showed slightly better heat transfer enhancement than circular ones for the same open area.
Mehendale *et al*., [19]	Experimental	Shrouded vertical straight fin array	Shroud spacing and Rayleigh number.	A properly placed shroud creates a chimney effect, significantly increasing airflow and heat transfer.
Sahu and Singh [21]	Numerical	Annular fin with non-uniform root thickness.	Fin profile and material.	Tapering the fin root can optimize heat flow and improve overall fin efficiency.

Al-Mawed *et al*., [17]	Numerical	Perforated fin with porous-filled triangular holes.	Porosity, permeability, perforation size.	Filling perforations with a porous medium further enhances heat transfer compared to empty holes.
Taji *et al*., [22]	Numerical	Vertical perforated plate fin with diamond-shaped holes.	Perforation size and aspect ratio.	Diamond-shaped perforations were found to be more effective than circular ones for the same open area.
Mokheimer [20]	Analytical	Annular fin with different profiles.	Variable heat transfer coefficient along the fin.	The performance of an annular fin is strongly subject to how the heat transfer coefficient varies across its surface.
El-Shorbagy *et al*., [18]	Experimental	Perforated straight fin array with triangular holes.	Perforation pitch and size	Triangular perforations showed significant heat transfer augmentation compared to solid fins.
Yovanovich *et al*., [28]	Analytical/Correlations	Elliptical and circular pin fins.	Fin aspect ratio.	Developed correlations for heat transfer from isothermal elliptical fins under natural convection.
Singh *et al*., [26]	Numerical	Perforated rectangular fin with semi-circular holes.	Perforation diameter and location.	Semi-circular perforations along the fin edges effectively increase the heat transfer coefficient.
Joby and Paul [24]	Numerical	Perforated rectangular fin with leaf-shaped holes.	Perforation size and orientation	Bio-inspired leaf-shaped perforations showed superior performance over simple circular holes
Bar-Cohen and Rohsenow [23]	Analytical/Correlations	Vertical straight fin array.	Fin spacing and height.	A classic study that derived the relationship for optimal fin spacing to maximize natural convection.
Tari and Mehrtash [27]	Experimental	Straight fin array on horizontal and vertical cylinders	Cylinder orientation and fin parameters.	Orientation of the base cylinder (horizontal vs. vertical) drastically changes the flow patterns and heat transfer.
Zaidi *et al*., [29]	Numerical	Perforated rectangular fin with T-shaped holes.	Dimensions of the T-shaped profile.	T-shaped perforations were designed to promote better fluid flow and showed significant enhancement.
Senapati *et al*., [25]	Numerical	Perforated rectangular fins with circular vs. square holes	Aspect ratio of the fin and perforation shape.	For a given open area, square perforations were slightly more effective than circular ones.
Al-Sallami *et al*., [30]	Numerical	Perforated vertical annular fins.	Perforation diameter and number.	Perforating vertical annular fins enhanced heat transfer by allowing radial fluid flow.

Kim *et al*., [33]	Experimental	Straight array of pin-fins (in-line and staggered).	Fin spacing and Rayleigh number (Ra)	Staggered pin-fin arrays yield higher heat transfer rates than in-line arrays for a given base area.
Kang [32]	Numerical	Elliptical pin fin heat sinks.	Fin axis ratio and spacing.	An optimal axis ratio exists for elliptical pin fins that minimizes thermal resistance.
Zomrawi *et al*., [35]	Numerical	Perforated rectangular fin with Y-shaped internal cavities.	Cavity dimensions and angle.	Creating complex internal Y-shaped channels within the fin improves performance by increasing internal convection.
Starner and McManus [34]	Experimental	Straight fin array on a horizontal base.	Fin spacing, aspect ratio, temperature.	One of the foundational studies providing correlations for optimal spacing in fin arrays.
Yasar Islamoglu [31]	Numerical	Circular fin with different profiles in a ceramic tube	Fin profile (e.g., trapezoidal, curved).	The profile of a circular fin significantly influences the thermal characteristics of the equipment.

3. Conclusion

Perforated fins significantly outperform solid fins in heat dissipation. This enhancement is not merely due to the presence of perforations but is heavily influenced by their characteristics; factors such as the number, diameter, shape (e.g., circular, square, triangular), and arrangement (e.g., staggered, in-line) of the holes are critical design parameters that must be carefully optimized.

Furthermore, the research consistently demonstrates that fin profile geometry is a key determinant of efficiency. For instance, in annular fins, a triangular profile is repeatedly shown to be more thermally effective and economical than rectangular or trapezoidal profiles. The analysis also extends beyond the fin itself, emphasizing the crucial role of system-level factors like fin spacing and orientation, which profoundly affect airflow and convective performance. The collective findings point towards a clear trend: moving beyond simple solid designs to more intricate and optimized geometries is essential for maximizing thermal efficiency**.**

Continuous research is going on to improve the heat transfer performance of fins by optimizing its parameters. As on date, the literatures on finite element analysis of thermal performance of fins with perforations are limited. This paper focuses on enhancement of heat transfer in rectangular fins with circular perforations. For validation purpose, the analysis results are compared with already published experimental results available in literature.

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