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ANALYSIS OF NATURAL CONVECTION AROUND FINNED STRUCTURES

***[1]Md Zinnurain [2]Dr Parag Mishra [3]Deepak Patel**

[1]MTech Scholar, [2,3]Assistant Professor,

Department of ME, RITS, Bhopal, M.P. India.

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***Corresponding Author: Md Zinnurain**

MTech Scholar, Department of ME, RITS, Bhopal, M.P. India.

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ABSTRACT

In this review presents a comprehensive assessment of computational investigations on the coupled effects of natural convection and surface radiation in extended surfaces with various fin geometries, including annular, star, square, and triangular configurations. Emphasis is placed on three-dimensional numerical studies employing the finite volume method, commonly implemented using the ANSYS Fluent solver, to solve the governing conservation equations of mass, momentum, and energy. Buoyancy effects are typically modelled using the ideal gas assumption, and numerical results are validated against previously published data. The review synthesizes findings on the thermal behaviour and heat transfer performance of different fin geometries under a wide range of operating conditions. Key parameters such as Rayleigh number (10^3–10^6), fin spacing, surface emissivity, aspect ratio, fin orientation, and geometric modifications are systematically examined to elucidate their influence on coupled convective and radiative heat transfer mechanisms. Reported temperature distributions, flow structures, and heat transfer interactions are analysed to identify performance trends and governing transport phenomena. In addition, the review highlights the development of empirical and semi-empirical correlations linking the Nusselt number with Rayleigh number and geometric parameters for selected fin configurations. Overall, this work provides a critical and structured overview of recent numerical advances in convection–radiation heat transfer from complex fin geometries, offering valuable insights for the design and optimization of extended surfaces in heat exchangers and thermal management systems.

KEYWORDS: Natural convection, surface radiation, fin geometry, heat transfer, computational fluid dynamics, three-dimensional analysis.

1.INTRODUCTION

The study of heat transfer phenomena surrounding finned configurations represents a fundamental area of study in thermal engineering, which is critical for optimizing the efficiency and heat exchangers, cooling systems, and various thermal devices. Standard fin shapes such as straight or rectangular fins have been thoroughly studied. However, there is increasing interest in evaluating the thermal behaviour of intricate fin shapes such as annular, star, square, and triangular fins. These nonconventional geometries pose distinct challenges and possibilities because of their unique flow patterns and surface attributes, making them a fascinating subject for exploration. The motivation behind this investigation stems from the necessity to comprehend the interconnected impacts of natural convection and surface radiation on the heat transfer surrounding non-conventional fin configurations. Convective flow driven by temperature variation significantly influences the movement of the fluid and heat transfer in the vicinity of the fin surfaces. Surface radiation, which is dependent on the surface temperature and emissivity, introduces an additional layer of intricacy to the heat transfer, particularly in three-dimensional (3-D) scenarios. The interplay between natural convection and surface radiation becomes notably significant in complex fin geometries, where phenomena such as flow separation, recirculation regions, and variations in surface orientation markedly affect the heat transfer rates. Delving into these phenomena is imperative for advancing our understanding of thermal regulation in practical contexts, where unconventional fin shapes are utilized to augment heat dissipation. The specific aims of this study are as follows:

- Collective impacts of natural convection and surface radiation around annular, star, square, and triangular fin.
- Exploring the influence of geometric factors (e.g., fin shape, dimensions, and spacing) and thermal boundary conditions on heat transfer efficiency.

To address these objectives, sophisticated computational fluid dynamics (CFD) simulations integrated with thermal radiation modelling were employed. This methodology will facilitate an exhaustive examination of the 3-D flow and temperature distributions surrounding intricate fin configurations, considering both convective and radiative heat transfer mechanisms. The results of this study will enrich the existing knowledge base on interconnected heat transfer phenomena in finned structures, providing valuable insights for the design and enhancement of thermal systems in engineering applications. By elucidating the interplay between natural convection and surface radiation around unconventional fin shapes, this study endeavours to support the development of more effective and dependable heat-transfer solutions across various industrial and technological sectors.

2.Literature Review

Adam et al. (2020) In this research paper focused on fin-and-tube heat exchangers, investigating heat transfer enhancement and pressure drop reduction. His work showed that increased fluid velocity consistently improved heat transfer and pressure drop, regardless of tube shape or configuration.

Sebastian et al. (2020) In this research paper conducted a comprehensive investigation into the heat transfer characteristics of finned heat exchanger configurations. His research included innovative designs featuring integrated pin fins, designed to enhance both conduction and air-side heat transfer.

Anjali et al. (2021) In this research paper investigates natural convection heat transfer in vertical plate fin arrays using computational studies, comparing different fin shapes and configurations. Seven combinations of fin arrays are analysed, including plain rectangular, notched, inverted notched, and hybrid notched fins. The highest average heat transfer coefficient is found for the inverted hybrid square-semi-circular notched fin array**.**

Krishnayatra et al. (2022) In this research paper conducted in this study utilizes Ansys Fluent software for a comprehensive numerical analysis aimed at examining the influence of fin length, fin thickness, number of fins, and fin material on the heat transfer rate and effectiveness of the system. The results underscore the critical significance of optimizing these parameters to achieve peak efficiency in heat transfer processes.

Dogmas et al. (2022) In this research paper Conducted an experimental study on functionally graded (FG) and aluminium annular fins' thermal performance under natural convection. They used numerical analyses to determine the ideal FG fin volume distribution and observed that FG fins outperformed aluminium fins significantly. The Nusselt number for FG fins was 40% higher, and FG fins enhanced net heat transfer by 59% on average.

Attouchi et al. (2022) In this research paper focused on natural convection heat transfer in square cavities with finned surfaces and periodic wall temperature. The study also highlighted the effectiveness of three fins on the hot sidewall and consistent Nusselt numbers on the cold sidewall.

Wang et al. (2022) In this research paper conducted a numerical study on transient combined natural convection and surface radiation in a cylindrical cavity, highlighting the significant impact of surface emissivity on radiative heat transfer.

Amine et al. (2022) In this research paper focuses on studying the interaction of natural convection with thermal radiation in a cylindrical enclosure filled with air, emphasizing the impact of surface radiation on temperature distribution and flow patterns at higher Rayleigh numbers. The authors introduce dimensionless parameters to characterize the system and provide boundary conditions for the numerical simulations, enabling a comprehensive analysis of the heat transfer processes in the enclosure. The study also highlights the importance of accurately predicting the total average Nusselt number to ensure a comfortable thermal environment in buildings, underscoring the practical implications of the research findings.

Subhasisa et al. (2022) In this research paper conducted a comprehensive study on heat dissipation from heat-generating electronic devices using natural convection. The research focused on the thermal performance of radial heat sinks with longitudinal wavy fins and included three-dimensional numerical computations.

Attouchi et al. (2023) In this research paper conducted a numerical investigation of natural convection in a rectangular cavity equipped with a finned surface, where the bottom wall temperature varies linearly. The study focused on laminar, steady-state flow conditions to analysed the coupled thermal and hydrodynamic behaviour of the internal fluid. Vertical walls were considered thermally insulated, while the top wall was maintained at a constant cold temperature and the bottom wall at a linearly varying hot temperature. The governing equations of fluid flow and heat transfer were solved using a finite volume method implemented in a Fortran 90 code. Simulations were carried out for Rayleigh numbers ranging from to with a fixed Prandtl number of 0.71, representing air. The results demonstrated significant effects of Rayleigh number and fin-induced flow modification on temperature distribution, streamlines, velocity fields, and mean Nusselt number, highlighting the role of finned surfaces and non-uniform heating in enhancing natural convection heat transfer within enclosed cavities.

Kim and Kim et al. (2024) In this research paper conducted the first systematic experimental study on curved finned horizontal cylinders under natural convection. The effects of cylinder temperature, fin number, and fin height on heat transfer performance were experimentally investigated. A new Nusselt number correlation was proposed for Rayleigh numbers between 20 and 50,000, predicting the convective heat transfer coefficient within

±10% error. The proposed correlation showed significantly better accuracy than existing correlations. The study also identified optimal fin number and fin thickness, demonstrating that curved finned cylinders provide approximately 20% higher thermal performance compared to conventional finned cylinders. Complementing experimental studies,

Le et al. (2024) In this research paper numerically investigated natural convection in a differentially heated cubical cavity with solid fins. Using a finite-difference method with velocity–vorticity formulation, they analysed the effects of Rayleigh number, fin length, fin location, and fin number. The study revealed that properly placed solid fins enhance heat transfer, while excessive fin length at high Rayleigh numbers can reduce the average Nusselt number. Optimal fin configuration was shown to be crucial for maximizing thermal performance.

Sultan et al. (2024) In this research paper conducted a 3D numerical study on a horizontal heat sink with rectangular fin arrays under natural convection. Using the finite volume method, they demonstrated that increasing heat flux intensifies natural convection, leading to substantial increases in the average heat transfer coefficient and Nusselt number. The numerical results showed good agreement with experimental data, confirming the reliability of the model.

Matuszczak et al. (2024) In this research paper experimentally studied finned tube heat exchangers operating under natural convection conditions. The authors demonstrated that a novel wavy-fin geometry significantly improved heat rejection compared to conventional designs, with heat flux density enhancements ranging from 12% to 24% as fin spacing increased. The study further highlighted the strong influence of fin spacing, exchanger orientation, and casing height on thermal efficiency, showing that wider fin spacing and higher casing heights markedly enhance natural convection heat transfer.

Bawazeer (2025) In this research paper convection a finite element-based numerical study on laminar natural convection in a square cavity with a horizontal fin attached to the heated wall. The study highlighted the critical role of fin position, geometry, and thermal conductivity in controlling flow structure and heat transfer, particularly at higher Rayleigh and Prandtl numbers. Optimal fin placement at mid-height enhanced thermal mixing and symmetry, while thicker fins improved conductive heat transfer. A normalized Nusselt ratio was introduced to assess fin effectiveness beyond surface area effects, offering practical insights for passive thermal management in enclosed system.

Zhang et al. (2025) In this research paper the role of fins in phase change material (PCM) melting, highlighting that fins do not always enhance melting performance due to their potential to suppress natural convection. To address this limitation, the authors proposed the use of non-contact fins and numerically examined their influence on convection-driven melting. The results showed that melting time could either decrease by up to 10.1% or increase by 11%, depending on the fin mounting configuration. The study revealed that narrow fin spacing weakens local convection and increases momentum loss as liquid PCM interacts with fin surfaces, thereby hindering heat transfer. Additionally, the authors identified the velocity within the mushy zone and the normal velocity at the solid–liquid interface as more reliable indicators for evaluating fin effectiveness during the melting process.

Ali et al. (2025) In this research paper numerically investigated natural convection heat transfer from a vertical cylinder equipped with perforated annular fins. Using a conjugate heat transfer model in the laminar regime, the study analysed the effects of Rayleigh number and fin pitch-to-diameter ratio on thermal performance. The results showed that perforated fins significantly enhance heat transfer compared to solid fins, with Nusselt number improvements of up to 49% at higher Rayleigh numbers and smaller fin spacing. The enhanced performance was attributed to improved fluid circulation through the perforations, which strengthened buoyancy-driven flow.

Mora et al. (2025) In this research paper performed CFD simulations to analyse natural convection heat dissipation from a finned MMRTG operating under low-density CO_2 Martian atmospheric conditions. Their results showed laminar buoyancy-driven plume formation, with fin-induced thermal plumes merging at higher elevations. The evaluated dimensionless numbers confirmed laminar natural convection, providing valuable insights for passive thermal management and finned heat-dissipating systems in space applications.

Dogmaz et al. (2025) In this research paper examined the thermal performance of functionally graded annular fins mounted on a horizontal cylinder under natural convection. The results showed that functionally graded fins substantially outperform conventional aluminium fins, achieving up to 59% higher heat transfer rates and a 40% increase in convective heat transfer coefficient, highlighting the importance of material gradation and fin spacing in natural convection enhancement.

Peng Ding et al. (2025) In this research paper numerically investigated a novel twisted fin configuration to enhance natural convection–driven melting of phase change material (PCM) in a shell-and-tube latent heat storage system. Using the enthalpy–porosity method, the study examined the effects of fin twist angle and system orientation (vertical and horizontal) on thermal performance. Results showed that twisted fins significantly mitigate natural convection suppression compared to conventional annular fins, leading to faster PCM melting. A twist angle of 35° provided the best performance, increasing the average heat storage rate by 10.7% in vertical and 14.8% in horizontal orientations. Enhanced convection patterns were clearly demonstrated through streamline visualization, confirming the effectiveness of the proposed fin design.

3.Research Objective

The enhancement of heat transfer using various geometries of fin. Below is the outcome of the research:

- Analysis of Finned Surfaces: Study the geometry, structure, and characteristics of Finned Surfaces and their impact on natural convection.
- Heat Transfer Analysis and Weight Reduction: Analyze the heat transfer mechanisms and rates involved in the natural convection process, focusing on temperature gradients and flow patterns.
- Effect of Fin Parameters: Investigate how varying parameters such as fin height, thickness, spacing, and arrangement influence natural convection and subsequent heat transfer.
- Simulation and Modeling: Utilize computational tools to simulate and model the natural convection phenomenon around finned surfaces with air as the fluid material.

4.Research Gap

- According to the aforementioned literature survey, the majority of research projects focus on fluid flow analysis near finned surfaces, but
- There is no 3D geometry with different fin shapes.
- Surface radiation not included.
- Fin was long
- There is no 3D simulation available.
- That's why I made the decision to embark on a simulation based Natural convection study in 3D geometry.

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