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REVIEW ON CFD ANALYSIS OF I-TYPE SHAPE VERTICAL FIN SOLAR HEATER

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ABSTRACT

In this paper explores the Computational Fluid Dynamics (CFD) analysis of vertical fin-type solar heaters, focusing on their thermal performance and efficiency enhancements. Solar heaters are critical in harnessing renewable energy, and the integration of vertical fins is a promising approach to improve heat transfer rates. The paper provides a comprehensive overview of the latest CFD studies conducted on vertical fin-type solar heaters, examining various parameters such as fin geometry, material properties, and fluid flow characteristics. Key findings highlight how different fin configurations influence thermal efficiency and fluid dynamics. Additionally, the review discusses the role of CFD as a powerful tool for optimizing design and predicting performance under diverse environmental conditions. The paper concludes by identifying current challenges and potential areas for future research in the development of more efficient solar heating systems using vertical fins.

Keywords:
CFD analysis, Vertical fin solar heater, thermal performance, heat transfer enhancement, renewable energy, solar heating systems.

I. Introduction

The increasing demand for sustainable energy solutions has propelled research into efficient solar energy utilization technologies. Solar heaters play a pivotal role in converting solar energy into thermal energy, which can be used for various domestic and industrial applications.
Traditional solar heaters face limitations in efficiency due to suboptimal heat transfer mechanisms.

1.1 Incorporation of Vertical Fins for Enhanced Efficiency

To address these challenges, the incorporation of vertical fins has emerged as a promising approach to enhance the thermal performance of solar heaters.
Vertical fins are designed to increase the surface area available for heat exchange, thereby improving the overall heat transfer rate and boosting the efficiency of solar heaters under varying environmental conditions.

1.2 Role of Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) has become an essential tool in analyzing and optimizing the performance of these systems. CFD allows for detailed simulation of fluid flow and heat transfer, providing insights that are difficult to obtain through experimental methods alone.
This review paper aims to provide a comprehensive analysis of CFD studies conducted on vertical fin-type solar heaters. It will discuss various design parameters, such as fin geometry, material selection, and fluid flow characteristics, that influence thermal performance.
The paper highlights the advantages of using CFD in predicting system behavior, optimizing designs, and evaluating performance under different operating conditions.
By synthesizing the latest research findings, this paper seeks to identify current trends, challenges, and future directions in the development of more efficient solar heating systems.

II. Literature Review

This work explores the use of vertical fins to enhance the thermal performance of solar heaters, a key solution for improving solar energy efficiency. It reviews the application of Computational Fluid Dynamics (CFD) in optimizing solar heater designs, focusing on the effects of fin geometry, material

selection, and fluid dynamics. By synthesizing recent research, this paper identifies current trends, challenges, and future directions for more efficient solar heating systems.
Singh et al. (2024) In this paper the impact of diverse fin patterns on the thermal performance of FPSCs. The study involves the development of a 3D-CFD model for FPSC using the computational fluid dynamics (CFD) software ANSYS FLUENT. The analysis is conducted for variable mass flow rates (mf) ranging from 0.01 to 0.05 kg/s with an interval of 0.02 kg/s. Each flow rate is assessed for three distinct fin patterns: straight plate fins, V-shaped fins and wavy fins.
Du Juan et al. (2024) They represented a strategy by employing multiple spiral fins (SFs) for enhancing the low heat transfer rate of traditional smooth solar air heaters (SAHs). A numerical study involving the effects of the pitch ratio (P/Dh), quantity (N), and arrangement of SFs on fluid flow, heat transfer, and thermodynamic characteristics of the SAHs was conducted. The research findings indicated that the flow field was homogenized and the thermal boundary layer was weakened by inserting multiple SFs into the smooth SAH.
Alrashidi et al. (2024) In this research a flat absorber plate of a solar air heater (SAH) with innovative straight interrupted fins arranged in a V-shaped pattern is analyzed using energy and exergy approaches, as the literature clearly shows that the low rate of heat transfer of flat plate SAH remains a source of concern for energy experts.
Mund et al. (2024) In this research they represented a solar air heater (SAH) that utilizes solar energy to provide medium temperature air output. The main disadvantage of SAH is its low efficiency. So, researchers have used different ways to improve its efficiency. This paper looks into the numerical methods and new techniques implemented by investigators to numerically model a SAH while organizing their results in a tabular form. Subsequently, the study analyses the thermal performance of SAH in terms of thermohydraulic performance parameter (THPP) and organizes their results in tabular form.
Balakrishnan et al. (2024) In this experimental investigation examines the thermal efficiency of a forced convection solar air heater (SAH) using rectangular fins and paraffin wax as a phase change material (PCM). The strategic placement of vertical rectangular fins on the absorber surface is intended to increase the absorber area and air distribution. The modified SAH, equipped with finned PCM, attains a peak air outlet temperature of 47.8 °C using hollow rectangular fins with dimensions of 0.09 m in height and 0.025 m in width.
Hasan et al. (2024) In this detailed computational analysis of air-cooled heat sinks with varying fin configurations to enhance the thermal regulation of PV panels. Using computational fluid dynamics simulations, this work evaluates the influence of fin number and spacing on airflow dynamics and heat dissipation efficiency. Key findings from ANSYS Postprocessor simulations indicate that heat sinks with a higher number of fins improve heat dissipation, with the 11-fin configuration.
Chamarthi et al. (2024) They presented computational modelling and simulation technique, firstly to analyse the effect of baffle design and geometrical parameters on fluid dynamics, heat transfer and the system's thermohydraulic efficiency. Secondly the combined effect of baffles and fins on the thermohydraulic efficiency is analysed.
Abrofarakh et al. (2024) In this paper the impact of metal foam embedding into evacuated tube collector solar air heaters with inserted baffle (IBMF-ETC- SAH) on the device thermal performance using a computational fluid dynamics (CFD) approach. A three-dimensional model is employed to analyze the system under steady-state conditions. The key finding of this study is that the utilization of metal foam leads to a substantial increase in thermal performance, with an average improvement of approximately 300 %.
Marzouk et al. (2024) They represented the effects of various absorber configurations of a tubular solar air heater are investigated. The models such as direct flow with a standard absorber (DF-SA), swirl flow with a standard absorber (SF-SA), swirl flow with perforated longitudinal fins (SF-PLF), swirl flow with radial fins (SF-RF), swirl flow with perforated radial fins (SF-PRF) are studied. Elakrout et al. (2024) In this thorough investigation into the thermal performance of the double

pass solar air collector, with a specific focus on the effects of three distinct fin configurations: parallel, vertical, and opposed. It is significant as it delves into the realm of solar air heating efficiency, a critical component in the broader application of solar energy technologies.

Roughness plays a crucial role in thermal energy transfer in a solar air-heater. Several investigators have worked over different types of roughness geometry to improve the performance of SAH.

Patel and Lanjewar(2021) Investigated the performance of solar airheater roughened using V-ribs having symmetrical gap and staggered element. The maximum increment achieved in the value of Nusselt number and friction factor was 2.51 and 2.7 times that of conventional SAH for the ration of gap width to rib height of 1.

Saravanan et al. (2021) Used the staggered multiple C shaped perforated and non- perforated fins as roughness over absorber surface. The thermal performance of perforated C shaped ribs was found to be slightly higher than that of nonperforated C- shaped ribs for relative height ratio of 0.6 and relative pitch to gap ratio of 3.8.

Mahanand and Senapati (2020) Conducted the fluid flow and heat transfer analysis over a transverse inverted T-shaped ribbed absorber plate in a solar air-heater. In their study, they adopted RNG k- turbulence model for simulation and observed increment in thermal enhancement factor by 1.87 times of conventional SAH.

Ghritlahre et al. (2020) Investigated the heat transfer rate in a solar air-heater roughened using arc-shaped ribs for the apex- up and apex down air flow arrangement. The apex-up configuration was found to be more efficient than the apex-down air flow configuration for mass flow rate varying from 0.007 to 0.022 kg/s.

Wang et al. (2020) Evaluated the thermal performance of solar air-heater roughened with S-shaped ribs having gap. The maximum thermal efficiency achieved using this roughness was 48%.

Komolafe et al. (2019) Used rectangular ribs as artificial roughness over as absorber plate to enhance its efficacy. The maximum thermal efficiency obtained using this roughness geometry was 56.5% under the outdoor conditions.

Both computational analysis and liquid crystal thermography (LCT) technique were adopted by Kumar and Layek (2019) For analyzing the heat transfer distribution of transverse circular ribs in a SAH. The performance was tested for different Reynolds number ranging from 8551 to 11149 and for constant roughness pitch ratio of 10.

Kumar et al. (2017) Conducted experiment to test the performance of SAH for an arc- shaped wire rib arranged in S-shape over the surface of absorber plate. The maximum increment in Nusselt number and friction factor was observed at p/e of 8, e/Dh of 0.043 and arc angle of 60˚.

Yadav and Bhagoria (2014) Used RNG k- turbulence model to investigate the performance of twelve different configuration of square sectioned transverse ribs in a SAH. It was reported that the maximum thermo-hydraulic performance using this roughness was found at e/D of 0.042 and P/e of 10.71.

III. Objectives of The Study

1. To explore the role of vertical fins in enhancing the thermal performance of solar air heaters by increasing heat transfer surface area and improving air flow dynamics.
2. To review and analyze recent CFD-based studies that focus on various fin geometries, materials, and configurations used in vertical fin-type solar heaters.
3. To evaluate the influence of design parameters such as fin height, spacing, shape, material properties, and placement on heat transfer rate and thermal efficiency.
4. To assess the effectiveness of CFD simulations (particularly using tools like ANSYS FLUENT) in predicting system behavior and optimizing finned absorber designs for solar heaters.
5. To identify and summarize key findings from the literature on performance enhancements achieved through the integration of vertical fins in solar air heaters.
6. To outline design optimization strategies and best practices derived from computational studies for developing more efficient solar heating systems.

IV. Research Gap

- Limited focus on vertical fins: While many studies explore artificial roughness and various fin shapes (V-shaped, wavy, arc-shaped, spiral, etc.), very few focus exclusively on vertical fin configurations and their comparative performance.
- Insufficient comparative data on fin orientation: The literature presents multiple fin geometries but lacks direct comparisons between vertical and other fin types (like inclined, spiral, or transverse) under similar operating conditions.
- Lack of standardization in design parameters: Studies differ in terms of flow rates, fin dimensions, and material properties, making it difficult to draw generalizable conclusions or define optimal configurations for vertical fins.
- Limited experimental validation: Many CFD studies do not include experimental correlation, which restricts the practical validation of simulated results for vertical fin-enhanced SAHs.
- Neglected environmental variability: Few studies simulate or evaluate system performance under realistic and changing environmental conditions such as variable solar radiation, wind effects, or ambient temperature changes.
- Integration challenges with PCMs and advanced materials: Although some research includes phase change materials (PCMs), integration with vertical fins is still underexplored, especially in CFD simulations aimed at enhancing energy storage and delayed heat release.
- Gap in combined effects analysis: The combined influence of baffles, vertical fins, and thermal storage media has not been thoroughly studied, especially from a thermohydraulic performance standpoint using CFD tools.

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