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A Comprehensive Review on Methodologies to Improve Solar Air Heater Efficiency

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Abstract: *Solar air heaters (SAHs) have evolved from their historical role of preserving food by drying it in the sun to become versatile devices used for heating air, water, cooking, and space conditioning. The primary objective of SAHs is to harness solar radiation and convert it into thermal energy to heat the air flowing through them. SAHs are cost-effective and widely used for collecting solar energy due to their simple design. These devices find applications in space heating, timber seasoning, and industrial product curing, including concrete and clay building component drying. As the cost of conventional energy sources continues to rise, solar energy is emerging as a sustainable alternative. This study explores the use of combined roughness, involving fan and arc-shaped elements, in rectangular solar air heaters to maximize energy collection. Experimental data and analysis of multiple SAH devices are presented, offering insights into solar energy utilization.*

Keywords: *Solar air heater, solar energy, thermal efficiency, combined roughness, renewable energy, sustainable heating.*

I. INTRODUCTION

In the past, solar energy was mainly used to sun-dry food in order to preserve it. Today, however, its uses are much more varied and include things like heating air, warming water, cooking food, regulating climate, particularly in the winter, and serving a variety of commercial heating needs. A solar air heater's main objective is to collect solar radiation and use it to heat the air flowing through a duct [1]. The basic tools for transforming solar energy into thermal energy are solar air heaters. They are widely used as solar energy collection devices because of their low cost and simple design. Solar air heaters are frequently used for space heating, wood seasoning, industrial product curing, as well as for drying and curing of concrete and clay building components [2]. The development of science has been greatly aided by solar energy, which spans generations and holds out hope for the future. Solar energy stands out as a major contributor, reducing the rising cost of accessible energy resources in a world where alternative energy sources like fuel, electricity, and nuclear power are becoming more and more expensive. The solar air heater, which uses sunlight for useful purposes, is one efficient solar energy application.

Researchers use a combined roughness approach and fan and arc-shaped elements inside rectangular solar air heaters to optimize solar energy absorption with no loss. These solar air heater configurations are tested, and the outcomes are carefully examined to determine how well they capture solar energy [3].

There are several different types of energy, such as kinetic energy, which is produced when particles move in a particular direction, and potential energy, which is kept in a specific place. The use of energy produced from fossil fuels has contributed to rising greenhouse gas emissions and geopolitical tensions. With negative effects on the environment, human health, and global air quality, this reliance on fossil fuel energy is becoming more and more harmful to society. When the switch to a sustainable energy system will happen is a crucial question that is of utmost importance [4]. Energy is a necessary part of daily life and has an impact on many facets of life. There is a growing shift toward renewable energy sources as conventional energy sources run out and global climate concerns intensify. A clean and sustainable method of supplying energy to a variety of applications is solar thermal energy. For low to medium temperature applications, solar air heaters (SAHs) are used to capture this energy.

A black surface known as the absorber, which serves as a heat source in a SAH system, absorbs solar irradiance that passes through glass in the system. After that, the heat is transferred from the absorber to the fluid that is passing over it. However, because air has a relatively low thermal conductivity, there is less convective heat transfer between the air and the absorber, resulting in a significant reduction in the efficiency of the SAH.

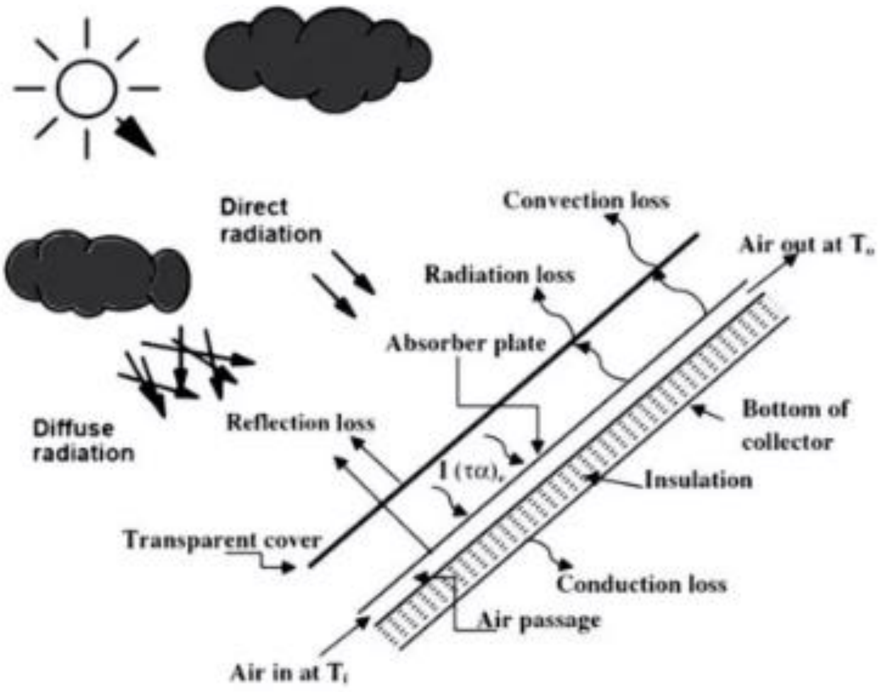

Figure 1 Conventional of a solar air heater

A conventional solar air heater is a simple and cost-effective device that uses sunlight to heat air. It consists of an absorber plate, a transparent cover, and insulation, housed in a metal box. This design is widely used for various heating applications, relying on natural convection for heat transfer.

There are several types of solar air heaters designed to harness solar energy for various heating applications. The choice of a specific type depends on factors such as intended use, efficiency requirements, and available space. Here are some common types of solar air heaters [5].

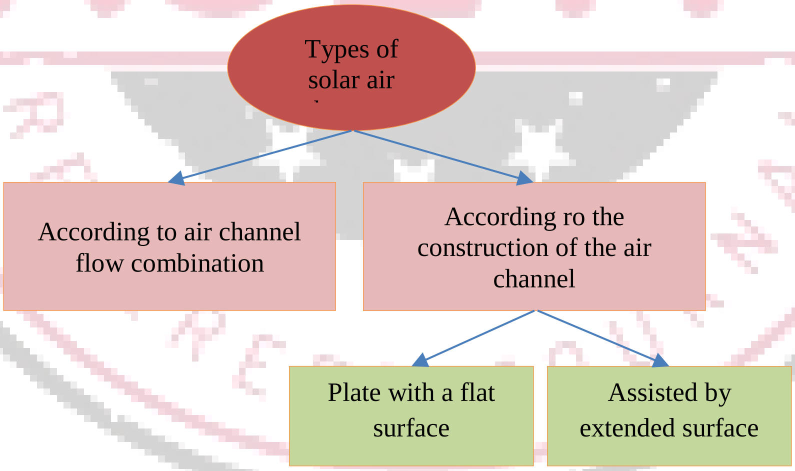

Figure 2 Types of Solar air heaters

II. LITERATURE REVIEW

Arunkumar, et. al. [6] Both residential and commercial applications make extensive use of solar air heaters. In order to improve these heaters' previously low thermal efficiency, researchers are now concentrating on introducing artificial flow modification techniques within the airflow. The laminar sublayer beneath the absorber plate is broken up by this technique, which increases air turbulence and, as a result, the rate of heat transfer from the absorber plate. The impact of variously shaped turbulators used by various researchers to improve the thermal efficiency of air heaters is explored in depth in this paper. It thoroughly analyzes design factors, applied geometries, flow conditions, and their respective impacts on turbulence intensity, heat transfer rates, absorber temperatures, and thermo-hydraulic enhancement factors. Their study concludes with some closing thoughts and suggests future directions for enhancing the efficiency of solar air heaters.

Yadav, A. S., et. al. [7] To increase the heat-transfer coefficient, rib structures were tested on the smooth plates of a solar air heater (SAH) using a numerical investigation using a two-dimensional approach. In order to examine the turbulent airflow in this study, semi-circular ribs were purposefully added and looked at using ANSYS Fluent 16. In order to quantify the improvements in the Nusselt number over a Reynolds number range spanning from 3800 to 18000, various rib arrangements were investigated, and the results were compared against a smooth duct. To simulate the suggested geometric configuration with different pitch distances (P) of 10, 15, 20, and 25 mm, the renormalization k-model was used. The findings show that the semi-circular rib configuration with a pitch distance of P = 15 mm yields the most favorable Nusselt number enhancement, accompanied by a gradual reduction in the friction factor.

Nidhul, K., et. al. [8] Both computational fluid dynamics (CFD) and exergy analysis were used to evaluate the impact of secondary flow caused by V-ribs on the overall performance of a triangular solar air heater (SAH) duct. In this study, the effect of rib inclination (α) was examined for a range of Reynolds numbers ($5000 \leq Re \leq 20000$) using the CFD technique. The relative rib pitch (Rp = 10) and relative rib height (Rh = 0.05) were held constant. Empirical correlations were created using the results of the CFD simulations, allowing Nu and f to be predicted with minimal absolute variances of 8.7% and 4.7%, respectively. The analysis of energetic performance was then done using these correlations. At α = 45° and Re = 7500, the highest effectiveness parameter (ε) of 2.01 was found. The exergetic analysis revealed that the ribbed triangular duct generates less entropy than the smooth duct, leading to an increase in exergetic efficiency (ηex) of up to 23% for α = 45°. The rectangular duct is included in the study's scope in order to compare its performance to that of the ribbed triangular duct SAH (α = 45°). The findings demonstrate the superiority of the ribbed triangular duct SAH (α = 45°) over various ribbed rectangular duct SAH configurations, especially at higher mass flow rates.

Anil Singh Yadav & Manish Kumar Thapak [9] Over the past three decades, research has focused on studying solar air heaters that have been artificially roughened. These heaters' heat transfer and fluid flow processes can be understood using three different approaches: theoretical analysis, experimental research, and computational fluid dynamics (CFD). The research on studies into artificially roughened solar air heaters is reviewed in-depth in their article. In order to improve heat transfer in solar air heaters, various roughness geometries are used. In this article, we aim to provide a comprehensive view of these different roughness geometries. This comprehensive review highlights a large body of work focused on designing artificially roughened solar air heaters through experimental means, with comparatively fewer studies carried out using theoretical and CFD approaches. The thermo-hydraulic performance of 21 different artificial roughness geometries connected to the absorber plate of solar air heaters are then compared using this article's comparative analysis, which is based on thermo-hydraulic performance parameters. The article also compiles heat transfer and friction factor correlations created by different researchers for various types of artificially roughened solar air heaters.

Yadav et. al. [10] By adding ribs to the surface of the duct, it is possible to significantly increase the efficiency of a solar air heater (SAH). In this article, the numerical analysis of a SAH with circular and semicircular rib configurations is the main topic. The RNG k-ε turbulence model is used in the study, which is carried out using ANSYS Fluent v16. A second-order upwind scheme is used for the momentum and energy equations. The SIMPLE algorithm is used to combine pressure and velocity. A strict convergence criterion is adopted for all residuals in order to guarantee accurate predictions of various parameters.

Within the turbulent flow regime, the investigation covers various e/D ratios and Reynolds numbers ranging from 3800 to 18,000. The semi-circular rib configuration, according to the results, produces the highest Thermal Enhancement Factor (TEF). At a Reynolds number of 15,000, the TEF reaches its highest value of 1.76.

Nagaraj, et. al. [11] Researchers are committed to improving heat extraction from the airflow from the Solar Air Heater (SAH), which is a promising device for utilizing solar radiation. To increase the effectiveness of such collectors, numerous innovative approaches have been investigated. The goal of this study is to increase thermal performance by numerically analyzing a single-flow, double-pass solar air heater that uses two different configurations of aerofoil fins. The study examines the impact of aerofoil fin height and configurations on thermal and thermohydraulic efficiencies. While maintaining a constant axial pitch for the fin, the fin height is systematically varied over a range of Reynolds numbers, ranging from 3000 to 24,000. The results show that thermal efficiency rises with increasing fin height, which is attributed to increased flow turbulence, which allows the working fluid to absorb more heat. However, it has been found that above a certain fin height, thermal efficiency decreases as a result of anticipated primary stream flow obstruction.

Efficiency of the thermohydraulic system increases as fin height is reduced. The optimal aerofoil fin arrangement shows a remarkable improvement over the single-pass solar air heater (base model), with a roughly 23.24% higher thermal efficiency, according to the results of Computational Fluid Dynamics (CFD). Additionally, in the case of the optimum aerofoil fin configuration, the thermohydraulic efficiency is approximately 20.94% higher than that of the base model.

III. NEED FOR EFFICIENCY ENHANCEMENT

People from every walk of life are embracing clean and sustainable energy sources as a means of reducing rising environmental pollution as a result of growing awareness of the negative effects of changing climate conditions on a global, regional, and local scale. Solar photovoltaic, wind, geothermal, solar thermal, biomass, small and large hydro, and municipal waste are just a few of the renewable energy sources that are currently being promoted. Due to the rapid advancements in technology and the accessibility of wind turbines in a range of sizes, which can be used for a variety of purposes ranging from residential to large-scale grid-connected utilities, wind power has emerged as a dominant global energy source. Cleanliness, recyclability, and constant availability are benefits of wind power, despite its irregular fluctuations. However, it continues to be a meteorological parameter with significant variability, subject to change depending on things like location, time of day, day of the month, month of the year, and even from one year to the next [10].

The need for efficiency enhancement in solar air heaters (SAHs) is paramount in today's quest for sustainable and renewable energy sources. SAHs are designed to harness solar energy and convert it into heat, making them a valuable tool for reducing energy costs and minimizing environmental impact. However, to fully realize their potential, it is imperative to enhance their efficiency. The primary driver behind this necessity is the ever-increasing demand for cleaner and more sustainable energy solutions. Improved SAH efficiency not only maximizes the utilization of freely available solar energy but also reduces the reliance on fossil fuels for heating applications. Furthermore, higher efficiency translates into significant energy savings, making SAHs a practical choice for residential, commercial, and industrial heating needs. By enhancing SAH efficiency, we can take a substantial step towards achieving energy sustainability and mitigating the adverse effects of climate change.

Environmental Sustainability: Enhancing SAH efficiency contributes to a greener and more sustainable future by reducing greenhouse gas emissions associated with conventional heating methods.

Energy Savings: Improved SAH efficiency results in lower energy consumption, leading to cost savings for users and reduced strain on energy resources.

Renewable Energy Utilization: SAHs are a prime example of harnessing renewable energy, and maximizing their efficiency aligns with global efforts to transition to cleaner energy sources.

Reduced Carbon Footprint: Higher SAH efficiency reduces the carbon footprint of heating processes, making them eco-friendly alternatives.

Energy Security: By relying more on solar energy, we enhance energy security by decreasing dependence on fossil fuels, which are subject to price volatility and supply limitations.

VI. CONCLUSION

The diverse applications of solar energy and the simplicity of SAH designs have made them indispensable tools for transitioning to renewable and sustainable energy sources. The need to enhance SAH efficiency is driven by the growing demand for cleaner energy solutions in the face of environmental challenges. Enhanced SAH efficiency not only optimizes the utilization of abundant solar energy but also reduces dependence on fossil fuels for heating needs, leading to significant energy savings. This pursuit of efficiency aligns with global efforts to reduce greenhouse gas emissions and minimize environmental impact, ultimately contributing to a greener and more sustainable future. By embracing solar energy and striving for efficiency enhancement in SAHs, we take significant steps toward achieving energy sustainability and mitigating the adverse effects of climate change while reducing our carbon footprint and enhancing energy security.

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