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A review on enhancement of heat transfer rate in solar air heater using w-shaped roughness

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Abstract: Augmentation of convective heat transfer of a rectangular duct with the help of baffles/ribs has been a common practice in the past few years. This concept is widely applied in enhancing the thermo-hydrodynamic efficiency of various industrial applications such as thermal power plants, heat exchangers, air conditioning components, refrigerators, chemical processing plants, automobile radiators and solar air heaters. Solar air heater is a device used to augment the temperature of air with the help of heat extracted from solar energy. These are cheap, have simple design, require less maintenance and are eco-friendly. As a result, they have major applications in seasoning of timber, drying of agricultural products, space heating, curing of clay/concrete building components and curing of industrial products.

Index Terms **- Augmentation, convective heat transfer, rectangular duct**

I. INTRODUCTION

Fossil fuel sources are confined and so the present scenario of energy consumption and growth are not sustainable in the longer term [1]. The energy demand for different applications can be attained by pick up of the solar energy efficiently. Solar energy is the most promising source of energy and the simplest and efficient way of using solar energy is to convert it into thermal energy for heating applications such as space heating, drying of agricultural products and various industrial applications by using solar air heater. The solar air heater is not efficient due to low convective heat transfer coefficient between absorber plate and flowing air. The low rate of heat transfer coefficient is due to presence of a viscous sub-layer. Artificial roughness on the underside of the absorber plate breaks up the laminar sub-layer and increases heat transfer. Increased heat transfer makes the system more effective. Various investigators have investigated the effect of heat transfer and friction factor in various geometries of artificial rough- ness in a solar air heater duct. Solar air heaters are simple in design and construction. They are widely used as collection devices having applications such as space heating and crop drying. Efficiency of flat plate solar air heater is low because of low convective heat transfer coefficient between absorber plate and flowing air that increases absorber plate temperature, leading to higher heat losses to environment.

Low value of heat transfer coefficient is due to presence of laminar sub- layer that can be broken by providing artificial roughness on heat transferring surface [1]. Efforts for enhancing heat transfer have been directed toward artificially destroying or disturbing this laminar sub-layer. Artificial roughness in form of ribs and in various configurations has been used to create turbulence near wall or to break laminar sub-layer. Artificial roughness results in high frictional losses leading to more power requirement for fluid flow. Hence turbulence has to be created in region very close to heat-transferring surface for breaking viscous sub-layer. Core fluid flow should not be unduly disturbed to limit increase in pumping requirement. This is done by keeping height of roughness elements small in comparison to duct dimensions [2].

Solar energy is one of the most useful renewable energy resources without any adverse effects on the environment. Solar energy is widely used for generating electricity, heating and various industrial applications. Solar air heaters (SAHs) are simple in design and generally used as solar thermal collectors [1]. SAHs are inexpensive and the most widely used collection devices because of their inherent simplicity. SAHs form the foremost component of a solar energy utilization system [2]. Figure 1 shows various components of a solar air heater. These air heaters absorb the irradiance and exchange it into thermal energy at the absorbing surface and then transfer this energy to a fluid flowing through the collector. An absorber plate is usually a thin metal sheet coated with an absorbing substance such as black or selective coating to absorb solar radiations. The glazing provides a rigid, protective structure for the entire collector assembly. Insulation beneath the absorber and fluid flow passages inhibits downward heat loss. SAHs are found in several solar energy applications, especially for space heating, timber seasoning and agriculture drying [3].

Conventional SAH has poor thermal performance due to low convective heat transfer rate from the heated plate to the air. The use of rib roughness on the heated plate is one of the heat transfer augmentation methods employed in SAH systems. The idea of artificial roughness was initially applied to compact heat exchangers and cooling of gas turbine blades and electronic equipment [4]. Motivated by the improvements in thermal performance through the application of rib roughness in various configurations for gas turbine blade cooling, many researchers tried different roughness geometries to study their effect on the heat transfer of solar collectors and reported improvement in thermal performance [4–14]. Several experimental studies in SAH

performance had been conducted to optimize the roughness elements of shape, size, orientation relative to flow direction [5].

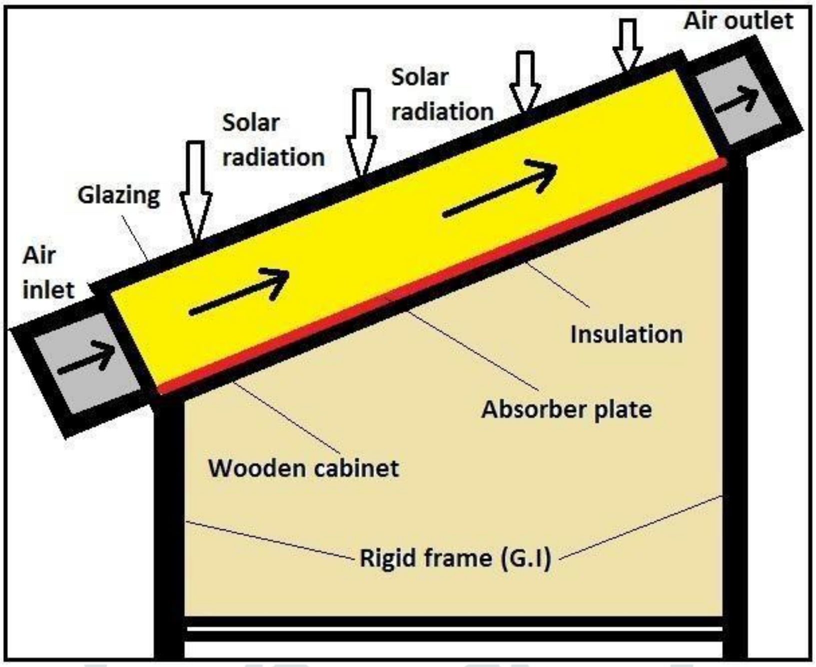

FIG. 1.1: SCHEMATIC OF A SIMPLE SOLAR AIR HEATER

This study presents CFD analysis on the thermal hydraulic characteristics of a three- dimensional SAH channel with square-sectioned discrete multi-V-pattern rib roughness. AverageNusselt number, friction factor and thermal hydraulic performance parameter were reported as functions of Reynolds numbers.

II. REVIEW OF PAST STUDIES

Agrawal et al. (2023) had done experimental examination of Nusselt number (Nu) and friction factor (f) characteristics of a Solar air heater using novel discrete double arc reverse form roughness bottom side of the absorber plate was carried out. The range for criterion, relative roughness pitch (p/e) of 6.67, relative roughness height (e/Dh) of 0.027, angle of arc (α) of 30°,45°, 60°, 75°, Reynolds number (Re) of 3000 to 14000, aspect ratio (W/H) of 8 were applied in between the laboratory test. It has been found that the performance of roughened solar air heater duct is better than the performance of a smooth duct for the range of roughness parameters investigated.

Fadala and Yousef (2023) Solar air heaters (SAHs) are the most widely used and inexpensive solar energy systems. As the absorbing plate collects solar radiation and transfers heat energy to the passing air, many effective experimental and analytical studies have been conducted on the SAH roughness solar heaters by a number of researchers.

Chaurasia et al. (2023) discussed the combination of two roughness geometries in the range of studied parameters and to obtain the optimum values for performance enhancement. The flow pattern of the combination of two roughness geometry has been studied. Hybrid roughness is categorized mainly into four basic sections i.e., rib roughness with staggered elements, a combination of two different rib geometries, rib roughness combined with a vortex generator and different types of rib arranged with grooves.

Saxena et al. (2023) provided a comprehensive overview of different types of roughness geometry that can be employed to produce artificial roughness in SAHs for improving their efficiency. The study reviews various rib shapes and their heat transfer qualities, and suggests that a combination of distinct rib forms can improve SAH's thermal performance.

Yadav et al. (2023) offered a holistic picture of the many forms of roughness geometry that may be utilized for the purpose of producing artificial roughness in SAHs in order to improve their effectiveness. In this article, the results of various experimental and computational works on SAHs that were roughened using various types of roughness geometry are presented. The influence that different rib parameters have on the processes of heat transmission and fluid movement are also covered in this article. The article presents the detailed reviews on heat transfer and flow friction analysis of a modified SAH system.

Singh et al. (2023) investigated solar air heaters (SAHs) with single-pass roughening with plastic net perforated multi-V and continuous multi-V ribs and compared for its effectiveness. Improvements in the Nusselt number ratio (Nu/Nus) and the friction factor ratio (f/fs) studied with the Reynolds number (Re) ranged from 2000–18000 for a relative roughness height (e/Dh) of 0.043, a relative roughness pitch (P/e) of 10, an aspect ratio (W/H) of 12, and an angle of attack (α) of 60°, maintaining a similar flow scenario. For a syntactically roughened channel with a perforated multi-V rib, the significant enhancement was recorded in thermo-hydraulic

performance with a slight decrease in pumping power. The study was extended to analyze the effect of perforation in a double pass parallel flow SAH.

Kumar and Layek (2023) established the effect of novel twisted V-shaped staggered ribs provided on the absorber plate of solar air heater on the Nusselt number, friction factor and thermo-hydraulic performance parameter. The liquid crystal thermography technique is employed to measure the distribution of Nusselt number over the absorber plate. Experimentations have been done for all configurations of varied roughness parameters termed as relative roughness pitch ranging from 7 to 11, relative roughness length in the range of 4.39–10.26 and Reynolds number varying from 3000 to 21,000. The Nusselt number and friction factor of the roughened plate are compared with the smooth absorber plate under similar flow conditions. The optimum roughness parameters based on thermo-hydraulic performance parameter index are as relative roughness pitch of 9 and relative roughness length of 6.15. The maximum thermo-hydraulic performance parameter index obtained is 2.59.

Arya et al. (2023) had done an experimental and simulation study using ANSYS (Fluent), a dimple with a V-miniature rib was fabricated on a plate (absorber) as a roughness element. By providing the angle of attack (α), relative long way (RLL) length (l/d), relative height (roughness) and relative wire lengths (w/Dh) ranging from 45 to 75°, 15–25, 0.024–0.036 and 0.14–0.21 respectively. The thermohydraulic performance (THP) factor of the proposed roughness was also investigated at Reynolds numbers (Re) ranging from 5000 to 20000. Results of average Nusselt number, turbulent kinetic energy (TKE), fluid flow characteristics and temperature are included to analyze the comparative merits of each dimple with miniature arrangements. The results revealed that among dimples with different miniatures, 90° transverse broken-miniature with dimple shows best thermohydraulic performance at Re below 10,000 while a dimple with V-miniature at an angle of attack (α) 45° shows the highest thermohydraulic performance at Re above 8750. It was found that THP achieved a maximum value of 1.63 at α = 45°, l/d = 20 and w/Dh = 0.18 at Reynolds number 12,500 for the dimple with a V-miniature rib.

Kumar and Layek (2022) provided researchers with a scientific perspective on the geometry, structure of ribs, flow directions, and laminar zone in order to maximize heat transfer and reduce friction. This review article discusses different roughness parameters, various artificial roughness

geometries, and thermohydraulic performance. Nusselt number and friction factor correlations have also been incorporated in this review article which is developed by various scientists based on their respective experimental results for various roughness parameters. The paper also provides a thorough analysis of current research, summarizes prior developments, and speculates on potential future routes for developing new heat transfer systems. Furthermore, this review paper will assist researchers and academics in developing a sound understanding of the effects of roughness on the absorber plate.

Singh et al. (2022) explained the development of solar air heater technique that makes a suitable designed model for increasing heat transfer without increasing the global warming in environment. The rectangular solar air heater model is designed by Ansys fluent software. The Ansys fluent software is generally used for investigating heat energy by using RNG k-e model method for the fluid (air or liquid) and also has perfect information about flowing fluid (3000 ⩽ Re ⩽ 18,000) and then gives the perfect physical information relevant to design model. The Rectangular channel is (1500 × 200 × 30 mm) a station for two Y- shaped ribs which are placed on top and bottom sides of surface of the channel and total length of each Y-shaped rib is 50 mm. Y-shaped ribs are constructed with variants of angles between upper two parts (θ and relative roughness pitch, P/e = 6, 8, 10, and 12. In the paper, Y- shaped ribs roughness is used to increase heat transfer rate of SAH and observed maximum Thermal hydraulic efficiency ηmax = 3.5992 at relative roughness pitch P/e = 10 mm, Re = 18000 and angle is taken θ = 90° between upper two parts of Y- shaped ribs.

III. Research Gap

Use of artificially roughened surfaces with different type of roughness geometries of different shapes, sizes and orientation is found to be the most effective technique to enhance the heat transfer rate with little penalty of friction. Roughness in the form of ribs and wire matrix weremainly suggested by different investigators to achieve better thermal performance. Among all, ribroughness was found the best performer as far as thermal performance is concerned.

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