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A Review On Cfd Analysis Of Flat Plate Solar Collecter

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Abstract- Fossil fuel sources are confined and so the present scenario of energy consumption and growth are not sustainable in the longer term. 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. Turbulence element on 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 roughness in a solar air heater duct.

Keywords- Solar flat plate collector, energy consumption, absorber plate, performance

I. INTRODUCTION

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 fromthe heated plate to the air. The use of rib roughness on the heated plate is one of the heat transferaugmentation methods employed in SAH systems. The idea of artificial roughness was initiallyapplied to compact heat exchangers and cooling of gas turbine blades and electronic equipment [4].

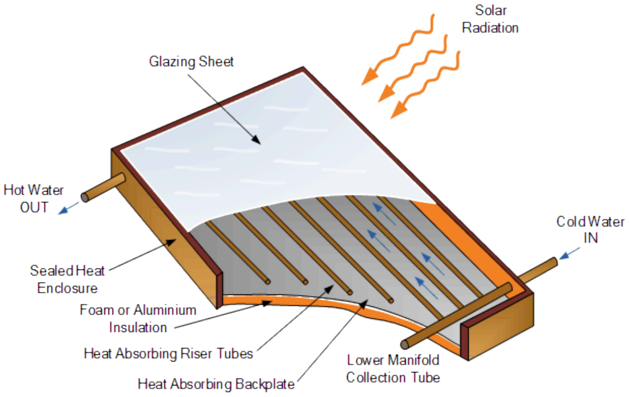

Fig. 1: Schematic of a simple solar air heater

Motivated by the improvements in thermal performance through the application of rib roughnessin various configurations for gas turbine blade cooling, many researchers tried different roughnessgeometries to study their effect on the heat transfer of solar collectors and reported improvement inthermal performance [4–14]. Several experimental studies in SAH performance had been conducted tooptimize the roughness elements of shape, size, orientation relative to flow direction [5].

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. Average Nusseltnumber, friction factor and thermal hydraulic performance parameter were reported as functions ofReynolds numbers.

II. SOLAR AIR HEATER

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 [1].

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 [2, 3]. The shape of a solar air heater of conventional application is that of rectangular duct encapsulating an absorber plate at the top, a rear plate, insulated wall under the rear plate, a glass cover over the sun-radiation exposed surface, and a passage between the bottom plate and absorber for air to flow in [4, 5].

The detailed constructional details of a solar air heater are shown in fig. 1. Solar air heaters have higher thermal efficiency when the Reynolds number of air flow through their passage is 3000-21000 [3]. In this range, the duct flow is generally turbulent. Hence, all the research work pertaining to the design of an effective solar air heater involves turbulent flow. Conventional solar air heaters with all the internal walls being smooth usually have low efficiency. The solar air heater's internal surface can be artificially roughened by mounting certain ribs/obstacles of different shapes such as circular wires, thin rectangular bars, etc. periodically on the lower side of collector plate. This results in a considerable augmentation in the heat transfer rate, but at the same time leads to increase in friction factor thereby enhancing the pumping power requirements.

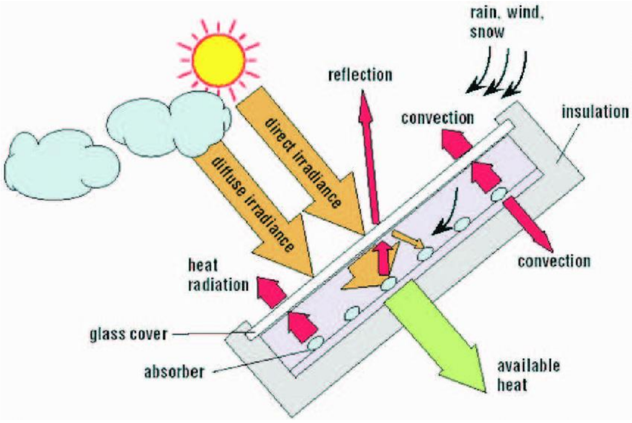

Fig. 2: Solar air heater constructional details

It is a well-known fact that the friction factor and convective heat transfer coefficient of turbulent flow are highly dependent on the surface roughness of the duct through which they pass [6]. Hence, artificially roughened solar air heaters must be designed in such a manner that their performance yields higher convective heat transfer rates from absorber plate to air low roughness to air flow. Extensive research is being conducted in this field by many authors, whose work generally involves performing experiments or carrying out numerical simulations with different types, sizes and patterns of ribs/ baffles and finding the right parameters at which the heater gives optimal performance (minimum friction loss and maximum heat transfer).

Some scientists, after performing research work on solar air heaters, develop a set of correlations for calculating Darcy's friction factor and Nusselt number in terms of operating and roughness parameters. The mechanism by which heat transfer, between air and roughened absorber plate, increases is breakage of laminar sub-layer. The introduction of ribs leads to local wall turbulence andbreakage of laminar sub-layers leading to periodic flow reattachment and separation. Vortices are formed near these baffles, which leads to a significant rise in Nusselt number. As compared to experimental activities being carried on solar air heaters, very less numerical work has been done in this field. Numerical study of solar air heaters using CFD software is an excellent method to understand in detail how flow behaves under the presence of obstacles in solar air heaters. CFD results are more accurate as compared to experimental results. Other benefits of using CFD software's are saving of time and less costs required to complete the work. Some commercially available CFD software packages are FLUENT, FLOVENT, CFX, STAR- CD and PHOENICS.

III.MECHANISM OF AUGMENTATION OF CONVECTIVE HEAT TRANSFER

A solar water heater is an important device that uses solar energy to heat water for domestic or commercial use. It consists of a solar collector, which absorbs the sun's energy, and a storage tank for hot water. The solar collector can be flat plate or evacuated tube and is typically mounted on a roof or a wall facing the sun. The storage tank is typically located near the collector and is insulated to reduce heat loss. The hot water produced by the solar collector is transferred to the storage tank, where it can be used as needed. Solar water heaters are an environmentally friendly and cost-effective alternative to traditional water heating systems that rely on fossil fuels.

Heat transfer enhancement for a solar water heater refers to methods used to improve the heat transfer rate from the solar collector to the water in the storage tank. This can be achieved by increasing the heat transfer area, the heat transfer coefficient, or the temperature difference between the two fluids. The common method for heat transfer enhancement is to improve the design of the solar collector by incorporating fins or other structures to increase the heat transfer area and, at the same time, use more thermally conductive fluids, such as water, with a high thermal conductivity, which can be used to transfer heat more efficiently.

Implementing these heat transfer enhancement methods can lead to an improved performance and increased efficiency of a solar water heater. Generally, the technique of heat transfer enhancement (HTE) is divided into three categories: active techniques [1]; passive techniques [2,3]; and combined or combinational techniques [4,5]. Conventional heat exchangers (HEs) are incapable of satisfying the demand of heating and cooling in modern industries with their limited capacity. Modifications are being applied to the heat exchangers to enhance their thermal and flow performance. This includes use of ribs, turbulators, ultrasound, vibrations, magnetic field, electric field, advance heat transfer fluids, etc. [6]. The objective is to increase the thermohydraulic performance of a thermal device, whether by increasing the surface area for fluid interaction, by increasing the swirling motion of the fluid, or by increasing the thermal conductivity of the fluid. The thermohydraulic performance of a heat exchanger refers to its ability to transfer heat from one fluid to another. This performance is influenced by various factors, such as the temperature difference between the two fluids, the flow rate of the fluids, the heat transfer area, and the heat transfer coefficient. The overall thermohydraulic performance can be evaluated by calculating the heat transfer rate, the thermal efficiency, and the pressure drop across the heat exchanger. Improving the thermohydraulic performance of a heat exchanger can be achieved by optimizing these factors and increasing the heat transfer area and the heat transfer coefficient.Among the various techniques of HTE in SWHs, ribs are the simplest, and the enhancement is appreciable when compared with other methods [7,8,9,10].The insertion of the novel-shaped ribs will increase the Nusselt number in heat transfer situations by creating turbulence in the fluid flow and enhancing the convective heat transfer. This will lead to an increase in the overall heat transfer coefficient and result in an increased Nusselt number.

IV. 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. Enhancement of heat transfer coefficient (h) was noticed 266% more than a smooth channel.

Increments of Nusselt number (Nu) and friction factor (f) were found at 268% and 221% more than smooth channel respectively. Maximum thermal efficiency was found 137% more than a smooth channel. Thermo-hydraulic concepts have been used to identify the ideal design and operating conditions. Depending on the insolation, it has been discovered that systems running within a certain Reynolds number range operate better thermo-hydraulically. The range of Thermo-hydraulic performance (THP) improved along with the increment of the Reynolds number. At a relative roughness pitch (p/e) of 6.67, a relative roughness height of 0.027, along the angle of arc (α) of 60°, the highest improvement of Thermo-hydraulic performance (THP) was noticed 2.22.

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. The artificial roughness elements that break down the laminar sub-layer at the surface of the absorber plate are detailed in this work in order to optimize heat transfer absorption in the solar air heater duct. in this paper. In this example, we'll look at how different forms of synthetic roughness affect performance and heat transfer. The experiments on this page show how the shape and type of synthetic roughness and its many properties can improve the performance of solar air heaters.

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. This study focuses on analyzing the parameters responsible for the maximum heat transfer and thermal performance. An attempt has been made to highlight the numerous earlier research work done by the various researchers by considering single roughness geometries implemented over the absorber plate for the augmentation of heat transfer.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 utilised 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 andLayek (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 analyse 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.

V.CONCLUSION

In recent years, attention to the issue of improving heat transfer in the engineering sciences and industry has been growing at anincreasing rate, so it has become a very important part of experimental and theoretical research. Electricity demand in the world willincrease by 2.1% every year until 2040. Due to the disadvantages of fossil fuels for the environment and the depletion, countries areinvesting heavily in renewable energy. The foremost imperative renewable energy sources are biomass, solar, geothermal, and wind[1,2]. Sun-based energy has attracted more attention than other renewable energy sources due to its availability in all parts of the globeand the need for less initial investment. Solar collectors are a type of heat exchanger, and a set of Flat plate solar collectors (FPSCs) cansupply the needed energy for houses, power plants, solar cars, and so on [3–6]. Other advantages of solar energy include non-pollutionand using it even in the most remote parts of the earth. FPSCs are the most widely used solar collector and have an ideal operatingrange for water heating. About 6% of energy consumption worldwide is used for heating water for domestic purposes, and solarcollectors can change over sun energy into heat energy. One of the primary reasons for the vast utilization of flat plate solar collectorscompared to other collectors is the cheapness and easy construction of this type of collector.

There are two methods to raise theefficiency of heat exchangers: passive and active methods. Changing the thermo-physical properties of the working fluid by adding nanoparticles and applying changes in the geometry are passive methods that do not need extrinsic energy [7–10]. Conventional heat transfer fluids such as ethylene glycol, water, and engine oil have lower conductivity than metals and metal oxides. One way to achieve a high conductivity fluid is to add metal or non-metallic particles with high thermal properties such as copper oxide, titanium oxide, and aluminum oxide to the typical base fluid. Further progress in nanofluids led to hybrid nano materials, which resulted in superior thermophysical properties and heat transfer enhancement.

The hybrid nanofluid comprises two or more nanoscale materials, and its purpose is to obtain more heat transfer by rising the thermal conductivity (k) of base fluids. Nanofluids are used in various fields, and many numerical and experimental studies have been performed to identify most of their properties [11–24]. Yet limited studies are available on turbulence inducing elements. Therefore, this study closes this gap.

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