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A Review on Influence of Various Artificially Roughness Ribs on Solar Air Heater to Increase the Thermal Performance

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ABSTRACT

The heat transfer coefficient between the absorber surface of the collector and the fluid i.e. air can be improved by providing artificial roughness on the absorber surface. In this way, the thermal efficiency is increased. The pumping power of the solar collector increases due to friction losses in the duct due to the roughness geometry. Therefore, it is necessary to take into account the size, shape and flow pattern of various roughness elements in order to maximize efficiency with minimum friction loss. Various artificial roughness geometries have been reported in the literature by investigators to determine the effect of different roughness geometries on the heat transfer enhancement and friction characteristics in the rough ducts of solar air heaters. A review of various studies is presented in this study.

Keywords: Solar Air Heater, Artificial Roughness, Ribs, Thermal Performance.

1. Introduction

Improved heat transfer rates are urgently needed in numerous thermal systems to reduce power usage. This is especially important for applications involving elevated temperatures in engineering. Technically speaking, several improvement methods for enhancing heat transfer have been divided into four categories: expanded surfaces, twisted tapes, and wire coiled tube inserts. By taking into account the degree of enhancement, available pressure drops, complexity, and cost, the proper sort of heat transfer enhancement technology can be chosen. The majority of heat transfer augmentations enlarge the heat transfer surface area, prevent the formation of boundary layers, and increase turbulence. These frequently lead to increased flow resistance and pressure decrease, necessitating the use of more pumping power. Finding a new roughness geometry that can improve heat transfer with a little increase in flow friction is therefore a serious problem for researchers. In order to improve the thermal performance of compact heat exchangers, gas turbine blade cooling systems, fuel elements for advanced gas-cooled nuclear reactors, cooling systems for electronic equipment, cooling of scram-jet engine inlets, and electric utility devices, artificially roughened surfaces have been used for many years. The primary goal of the heat transfer enhancement is to produce a secondary flow pattern in addition to disrupting the velocity and temperature profiles near to the walls. Due to the created vortices, this secondary flow pattern enhances the fluid mixing qualities, which in turn boosts the local heat transfer coefficient. The degree of local heat and momentum transmission to the fluid depends on how the roughened surface impacts boundary layer growth. Boundary surface roughness affects the rate of diffusion of characteristics via the neighbouring fluid. Stakeholders, represented by ribs, have expressed interest in various enhancements with various geometries and orientations. Due to the presence of ribs, heat transport is improved by two different ways. The wall sub layer is first disturbed, causing flow turbulence, separation, and reattachment that raises the heat transfer coefficient. Second, the presence of the ribs increases the surface area available for heat transfer. For the aim of intentionally improving heat transmission, it is crucial to understand the hydrodynamic and thermal flow characteristics in the boundary layer next to the heated walls.

2. Literature Review

Noot and Matteij (2000) studied if adding ribs, or "turbulators," to the cooling ducts would improve the cooling of turbine blades. It is looked into how these ribs affect how much heat the cooling air on the blade’s transfers. To examine this issue, a model is provided that is conducive to a numerical strategy. The issue at hand is covered in great detail. It is demonstrated how the concepts are put into use in a numerical code. The simulation results are evaluated and a useful method for evaluating the performance of these cooling ducts is presented.

Velocity fields across the rib-roughened wall of an orthogonally rotating channel were explored by Coletti and Arts (2011) and derived using two-dimensional PIV. With a bulk Reynolds number of 1.5 104 and a rotation number of 0.3, the flow is outward. At mid-span, the measurements are taken along the wall-normal/stream-wise plane. The PIV system spins with the channel, enabling direct, high-resolution collection of the relative velocity field. The flow demonstrates to be periodic in the current range of rotation number. The stability of the boundary layer and the free shear layer are both impacted by Coriolis forces under rotation; as a result, both shear layers towards the cyclonic (anti-cyclonic) side have positive (negative) values of the rotating Richardson number (augments)

Deniz et al. (2010) Solar heater energy and allergen output are rated according to different airflows (25, 50 and 100 m3/m2 h), tilt angle (0°C, 15°C and 30°C) and temperature conditions by the time. Based on energy production and allergy rates, the double-glazed lid and finned heater (Type II) are said to be more efficient and the difference between inlet and outlet air temperatures is higher than those of other types.

The performance of solar air heaters with 60° v-down discrete rectangular cross-section repeating rib roughness on the air flow side of the absorber plate was examined, and the findings were given by Karwa and Chauhan (2010). The study demonstrated that roughened duct solar air heaters had a considerable performance advantage over the smooth duct air heater at air mass flow rates smaller than approximately 0.04 ks/s of the absorber plate. The effective efficiencies of the smooth and rough duct solar air heaters were nearly identical at a mass flow rate of 0.045 kg/s.

The study of fluid flow and heat transmission in a SAH was presented by Karmare and Tikekar (2010) using computational fluid dynamics (CFD), which saves time and money. Metal ribs with circular, square, and triangular cross sections with 60° inclinations to the air flow are used to roughen the lower surface of the collection plate. To create a defined grid, the grit rib components are glued to the surface in an uneven pattern.

Siddique et al. (2012) investigated how a gas turbine's high input temperatures increased its thermal efficiency. As a result, cooling of gas turbine blades and vanes is necessary. One of the best ways to lower metal temperatures is through internal cooling of the gas turbine blades or vanes using two-pass channels. A turbine vane's trailing edge, in particular, is a crucial section that requires efficient cooling.

In a two-dimensional duct of a solar air heater with a tiny diameter of transverse wire rib on the absorber plate, Yadav and Bhagoria (2013) conducted numerical research of turbulent forced-convection. While the lower wall is insulated, the upper wall has a constant heat flux. The absorber plate has ribs on the underside, but the other sides of the duct are smooth. The outcomes of the current CFD analysis have been contrasted with the results of accessible experiments.

Xie et al. (2013) investigated the flow structure and heat transfer enhancement in a square ribbed channel with different positioned deflectors and discovered that in all cases, Case D, in which the deflectors are positioned above and close to the ribs and the distance from the bottom wall is 20 mm, has the most prominent effect on the heat transfer enhancement and thermal enhancement factor. In this investigation, the channel inlet Reynolds number spans from 8,000 to 24,000.

In an intentionally roughened solar air heater with square-sectioned rib roughness on the absorber plate, Yadav and Bhagoria (2014) provided a CFD model for estimating the heat transfer and flow friction phenomena. The current study is unusual in that it is the first of its kind to use a CFD technique to examine solar air heaters that have been roughened using square-sectioned transverse ribs. In the current work, turbulent forced-convection is investigated using computational fluid dynamics (CFD) in a two-dimensional duct of a solar air heater that has square-sectioned transverse ribs on the bottom of the absorber plate.

Few research on the CFD analysis of artificially roughened solar air heaters have been conducted, according to Yadav and Bhagoria (2014), in order to determine the ideal rib form and arrangement that may improve convective heat transfer while utilising the least amount of pumping power. Additionally, a thorough literature search reveals that there is a dearth of information on the heat transfer and flow friction properties of solar air heaters that have been roughened using equilateral triangle sectioned rib roughness.

In order to improve the heat transfer by air moving through the internal ribbed passages, Xie et al. (2014) researched the repeated ribs in the middle of the internal cooling passageways of turbine blades. Despite the fact that study on flow structure and enhanced heat transfer inside various ribbed channels has been thoroughly done, earlier works generally paid little attention to the influence of rib topology (height-to-pitch, blockage ratio, skew angle, rib shape).

In a two-pass smooth square duct, turbulent flow and heat transfer were explored experimentally and computationally by Erelli et al (2015). In this study, four distinct turn configurations (cases 1, 2, 3, and 4) with varying divider and outer turn geometries were taken into consideration. A thin stainless-steel foil is utilised as the heater, and the local temperature distribution on the heated surface has been measured using the infrared thermography (IR) technique for three distinct Reynolds numbers, namely, 25,000, 35,000, and 45,000.

Gawande et al. (2016) the inverted L-shaped rib roughness on the absorber plate of a solar air heater that has been intentionally roughened has been analysed experimentally and in two dimensions using two-dimensional computational fluid dynamics (CFD) in the current research. Relative roughness pitch and Reynolds number have an impact on flow friction and heat transfer enhancement.

Srinivasan and Kumar (2016) investigated the effects of steam and air cooling on a rectangular channel with parallel ribs. On steam and air convective heat transfer, the effects of Reynolds numbers (Re), rib spacing ratios (P/e), and rib angles () were discovered. For rib spacing ratios (P/e) of 8, 10, and 12 as well as rib angles between 900 and 450, heat transfer distribution is performed. Both air and steam improve heat transmission.

In a rectangular duct with its bottom wall artificially roughened by ribs of various shapes, Alfarawi (2017) evaluated experimentally the heat transfer and flow friction of turbulent flow (rectangle, semi-circle and hybrid ribs). Additionally, the goal of this work is to create new connections between the Nusselt number enhancement ratio, Darcy friction factor ratio, and efficiency index in terms of Reynolds number and rib pitch to height ratio.

In wavy wall channels with three distinct corrugation profiles, flow and heat transfer were examined numerically using the finite volume approach for Reynolds numbers between 400 and 1400, according to Akbarzadeh (2017). The sinusoidal, trapezoidal, and triangular forms of corrugation profiles were used. Comprehensive research has been done on the impact of Reynolds number and corrugation profiles on the formation of thermal and viscous entropy as well as the thermo-hydraulic performance of channels.

Ravi et al. (2017) a two-pass stationary channel, the heat transfer and friction properties of four distinct rib geometries—45°-shaped, V-shaped, W-shaped, and M-shaped ribs—have been explored numerically. The cooling channel's aspect ratio (Height to Width) was 1:1. (square). The Reynolds number might be anything between 20,000 and 70,000. The realisable version of the k-e (RKE) model was employed to solve the Reynolds averaged Navier-Stokes (RANS) equations for the calculations.

The flow and heat transmission properties of a spinning serpentine channel with ribbed walls were investigated by Kaewchoothong et al. (2018). The rib height-to-hydraulic diameter ratio (e/Dh), rib angle of attack (p/e), rib pitch-to-height (p/e) ratio, and aspect ratio (AR) of the revolving serpentine route were fixed at 11.33, 0.13, 90°, 10 and 1, respectively. The Reynolds number used for the numerical calculations was Re = 10,000.

Singh et al. (2019) carried-out the an experimental as well as CFD for two novel ribs arrangement namely square wave shaped ribs and multiple broken transverse ribs for performance enhancement in SAH. The thermal and fluid flow characteristics of both rib arrangements were studied using experimental as well as CFD approach. The obtained experimental results were depicted by the pressure, temperature and Nusselt number contours.

According to Qader et al. (2019), THPP outperformed earlier studies that were conducted at varied roughness geometries. This anticipated result shows that the inclined fins on the absorber plate's underside are realistic for real-world uses. The earlier investigations clearly identified the methods for improving thermal performance, primarily through the use of artificial roughness. However, the pressure drop's rise causes the pumping power to climb.

The usage of spherical dimple roughness in the airflow side of the absorber plate of a SAH with dimple roughness is developed, produced, and studied by Parwez and Kumar (2019). Following the studies, the thermal performance of SAH using dimple roughness is compared to that of FPSAH. This investigation presents the comparison of factors like ‘Nu’, ‘Re’, and thermal efficiency. The heat transfer aug- mentation produced by the SAH by employing dimple roughness can be utilized in crop drying and space heating. This inquiry compares variables such as "Nu," "Re," and thermal efficiency. Crop drying and space heating can benefit from the SAH's enhanced heat transmission provided by the use of dimple roughness.

Kumar et al. (2019) presented the experimental stud for a SAH to see the effect of roughness parameters on Nu and f over absorber plate. Experiments were designed with Design Expert Software based on response surface methodology. The effect of Re, g/e, d/x and Ng is investigated on Nusselt number and friction factor.

In order to explore the heat transfer and its amplification owing to circular rib roughness placed on the absorber plate subjected to heat flux at the uniform condition, Kumar and Layek (2019) researched based on a comparative analysis of a solar air heater utilising LCT approach and computational method. The key conclusions are: At a Reynolds number of 8551-11149, the precise heat transmission and its distribution have been studied at rib heights (e=1.2 mm). To observe the Nusselt number distribution in the solar air heater, a circular shaped rib roughness is employed over the absorber plate using LCT technique and computational approach. It has been shown that both procedures produce similar results for the heat transmission.

A verified geometrical model of a SAH duct was utilised for the CFD simulation by Jain et al. (2019), and a thorough parametric analysis was performed to examine the impact of discrete V-shaped perforated baffles employed as a roughness element on the SAH absorber plate. The performance of discrete V-shaped perforated baffles with roughened SAH has been compared to that of smooth SAH as well as to the roughened SAH examined by other researchers recently. The basis for comparison is the improvement in heat transmission and the reduction in pumping caused by higher friction. Key discoveries for isolated V-shaped perforated baffles roughened with SAH.

Jain et al. (2019) conducted experimental studies to determine the THP of a SAH with an absorber plate that was roughened with arc-shaped ribs that had several gaps. For the investigated roughness parameters and Reynolds number ranging from 3000 to 18000, heat transport and friction characteristics have been identified. The data derived from experimental findings and typical correlations for smooth duct have been found to be in good agreement.

The 2-dimensional heat transfer and fluid flow characteristics of a roughened rectangular duct with pentagonal ribs were examined numerically by Debnath et al. (2019). On heat transmission and friction factor, it was found the effects of the Reynolds number, non-dimensional relative height, and non-dimensional relative pitch. The predicted Renormalization-group k-model findings closely match the outcomes of the experiments. For all the tested parameters, the largest improvement in the Nusselt number by 70% and the friction factor by 67.2% was found at e/D = 0.045, P/e = 8.

A study on creating holes in longitudinally curved delta-shaped baffles was conducted by Baissi et al. (2020). Investigation of the rate of heat transfer and the properties of air flow in a rectangular channel are of special interest. Investigated was how the inserted baffle affected the transition of the flow regime from laminar to turbulent and the intensity of turbulent flow. It is also investigated how the combination of main and secondary flow is affected by the insertion of holes. The relative longitudinal length of the obstacles on the absorber plate and the relative transverse length of the obstacles on the absorber plate are roughness characteristics that have been used throughout this work to gather substantial experimental data on heat transfer and flow friction.

Conclusion

The use of artificially rough surfaces with a variety of roughness geometries has been found to be the most effective technique for increasing the heat transfer rate in a fluid flowing from a hot surface, at the cost of a moderate increase in fluid friction. The use of protrusions on the absorber plate is an effective technique to increase the heat transfer rate, is less expensive and with no additional load on the absorber plate. An increase in the Nusselt number and friction factor has been observed by many researchers with the use of an artificial roughness element. Therefore, the use of artificial roughness elements is desirable. The correlations developed for heat transfer and friction factor for solar air heater ducts with artificial roughness of different geometries for different investigators are shown in tabular form. These correlations can be used to predict the thermal efficiency, and hydraulic performance of rough solar air heater ducts. There is great scope for the use of flow visualization techniques to analyze the flow and enhance the process in artificially roughened solar air heaters. The information in the present paper may be useful to beginners in this area of research to explore and optimize new element geometries to enhance heat transfer.

Recent research has suggested that adding artificial roughness to the underside of the absorber plate might significantly increase the rate of heat transfer of a solar air heater. a tiny diameter protrusion wire on the absorber plate is used for fully developed turbulent flow in a solar air heater duct. The performance of the continuous, 60-degree-inclined ribs was improved. It has been discovered that when the relative roughness height rises, the optimal operational flow rate shifts to a lower value. The absorber plate was given chamfered rib roughness, and it was discovered that at low flow rates, solar air heaters with roughness components having a greater relative roughness height function better. It has been noted that, in the case of solar air heaters, friction factor augmentation needs to be seriously considered. Use only those shapes that significantly improve heat transmission while without significantly increasing friction losses. But it has been noted that attaching tiny wires to the absorber plate is a laborious job that might not be financially viable. The majority of academics have experimented with optimizing various geometries; however, this process is time-consuming and laborious. The numerical analysis of fluid flow and heat transfer in a solar air heater is presented in this paper utilising computational fluid dynamics (CFD), which saves time and money.

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