International Journal of LNCT
Volume-3 Issue-13 August -2019
ISSN: (Online):2456-9895

A Review on Heat Transfer and Flow Friction Characteristics of Artificially Roughened Solar Air Heaters with Different Roughness Geometries using CFD Analysis.

Shubham Agrawal[1] , Dr. Vimal Kumar Chouksey [2]
M.Tech. Scholar, Department of Mechanical Engineering, LNCT, Bhopal[1], M.P. India
Assistant Professor, Department of Mechanical Engineering, LNCT, Bhopal[2] M.P. India

Abstract- ***Applications of artificial roughness on the underside of absorber plate in solar air heater duct have been widely used to repair heat transfer with moderate increase of friction factor. The design of the roughness shape and arrangement is very important to optimize the roughened surfaces. The heat transfer and friction features of artificially roughened solar air heaters with different roughness geometries have been reviewed in this article. The article presents the authoritative account of the current progress on topic, discusses the previous developments, and throws light on the future directions. An attempt has been made to comparition the performance of solar air heater having different types of roughness geometries based on correlations proposed in the literature. Thermal efficiency, thermal efficiency improvement factor (TEIF), Thermo-hydraulic efficiency, effective efficiency, and exergetic efficiency performance parameter are evaluated to gauge the performance of different roughness geometries.***

Keywords- ***Solar energy, artificial roughness, efficiency***

Introduction

The ever increasing need of useful energy and depletion of conventional energy resources give rise to highly energy efficient and compact thermal systems. In our nature, abundant amount of solar energy, that will be extensively used as an energy source. Artificial roughness thus provided penetrates the viscous sub layer which increases the intensity of turbulence in the duct and causes enhancement in heat transfer from the roughened surface as compared to smooth surface. It is clear from literature review that so far no heat transfer study on arc shaped rib with gap has been done. The roughness elements used in a duct are attached to absorber plate that breaks the thermal boundary layer on heated surface and enhances the heat transfer. The current trend glancing towards sustainable energy sources, especially towards the solar energy to fulfill the enormous energy demand of the future. Energy in various forms has played an increasingly important role in worldwide economic progress and industrialization. Solar energy is considered a vital energy source to meet the increased energy demand for sustainable development and to control the global climate change. Approximately one-third of the world's population lives in rural regions without access to the electric grid, and about half of these same people live without access to safe and clean water. Solar energy is masterly in that it can cheaply provide electricity and purified water for these people today with minimal infrastructure requirements by using local energy resources that promote local economic evolvement. There are many different types of energy. Kinetic energy is energy available in the motion of an object, particles wind energy is one example of this. Potential energy is the energy available because of the position between object For example, water stored in a dam, the energy in a coiled spring, and energy stored in molecules (gasoline). There are many examples of energy: mechanical, thermal, electrical, magnetic, chemical, nuclear, tidal, biological, geothermal, and so on. Renewable energy denotes a clean energy, nontoxic energy source that cannot be exhausted.

Literature review

In the field of solar energy with application of CFD has focused in the research and try to find out the meet of research gap in present scenario. So, some research paper has been discussed at here for developing understanding of CFD analysis in artificial roughness.

In the sequence A.M. Lanjewar et al. (2015) carried out the study of concept of artificial roughness on plain surface is an important technique to enhance heat transfer rate of air flowing in solar air heater. Different rib geometries have been designed to investigate heat transfer and friction her act eristic's of solar air heater. Different rib geometries employed for creating artificial roughness has been discussed. Performance evaluation for different to orientations of double arc rib roughness were presented.

For improvisation of thermo hydraulics with surface roughness has been studied by Anil Kumar et al. (2015). The artificial roughness on underside of heated surface has been found to be effective technique to increase thermo hydraulic performance of solar air heater duct. In elongation to the previous researches, the present study discloses the effect of discrete Multi v-rib on heat transfer and friction in a flow through artificially roughened solar air heater duct. The experimentations were performed to store the data on heat transfer and friction by varying the Reynolds number (Re) between 2,000 and 20,000, relative width ratio (W/w) from 1 to 10, for the fixed values of relative gap distance Gd/Lv = 0.69, relative gap width/e = 1.0, relative roughness pitch P/e = 8, relative roughness height e/D = 0.043 and angle of attack a = 60°. The present roughness geometry with relative width ratio of 6.0 corresponding to flow Re of 20,000 yields the best thermo hydraulic performance.

Anil Kumar Patil et al. (2015) investigate on the methods to enhance heat transfer rate. Roughness applied on abroad wall of a solar air heater significantly enhances the heat transfer to the flowing fluid with the moderate rise in fluid friction. It is imperative to select the roughness pattern and its geometrical parameters which are responsible for the change in fluid flow behavior steering the level of heat transfer and friction. With a view to survey the mechanism of heat transfer governed by the fluid flow pattern over the roughened wall, the distinct roughness patterns used in solar air heaters are reviewed with a fresh prospective. The interpretation of the fluid turbulence and heat transfer mechanism in case of different rib geometries has been expeditious based on available literature. Optimally usable range of Reynolds number and Temperature rise parameter for roughness geometries are moved on the basis of effective efficiency of roughened collector.

In this article Anil Singh Yadav (2015) defined solar air heater devices. Solar air heaters are cheap and extensively used solar energy collection devices for space heating, seasoning of timber, curing of industrial products and can also be effectively used for curing/drying of concrete/clay building components and in air-conditioning systems. In this article, the effect of relative roughness height on Nusselt number and friction factor in an artificially roughened solar air heater having circular-sectioned transverse rib roughness (duct aspect ratio, AR = 5:1) is studied by adopting CFD (computational fluid dynamics) views.

Numerical solutions are obtained using commercial CFD software ANSYS FLUENT v12.1. Computations based on the limited volume method with the SIMPLE algorithm have been conducted. Circular-sectioned transverse ribs are applied at the base of the top of the duct, that is, on the absorber plate. The rib pitch (P) and rib height (e) are various by keeping rib-pitch-to-rib-height ratio constant (P/e = 14.29). The rib-height-to-hydraulic-diameter ratio (e/D) study is 0.021, 0.03, 0.042, and 0.06. For each rib height-to-hydraulic-diameter ratio (e/D), simulation are executed at six Reynolds numbers from 3800 to 18,000 (relevant in solar air heater). The thermal development factor for e/D = 0.042 is found to be the best for the investigated range of Parameters and is about 1.635.

Anil Singh Yadav et al. (2015) numerical investigated the heat transfer and flow friction characteristics in an artificially roughened solar air heater having square-sectioned transverse ribs considered at underside of the top wall, where constant heat flux condition is applied. The effect of relative roughness pitch on average Nusselt number, average friction factor, and thermo hydraulic performance parameter (THPP) has been investigated. This investigation covers relative roughness pitch in the range of 7.14 ≤ P/e ≤ 17.86 and relevant Reynolds numbers in the range of 3800

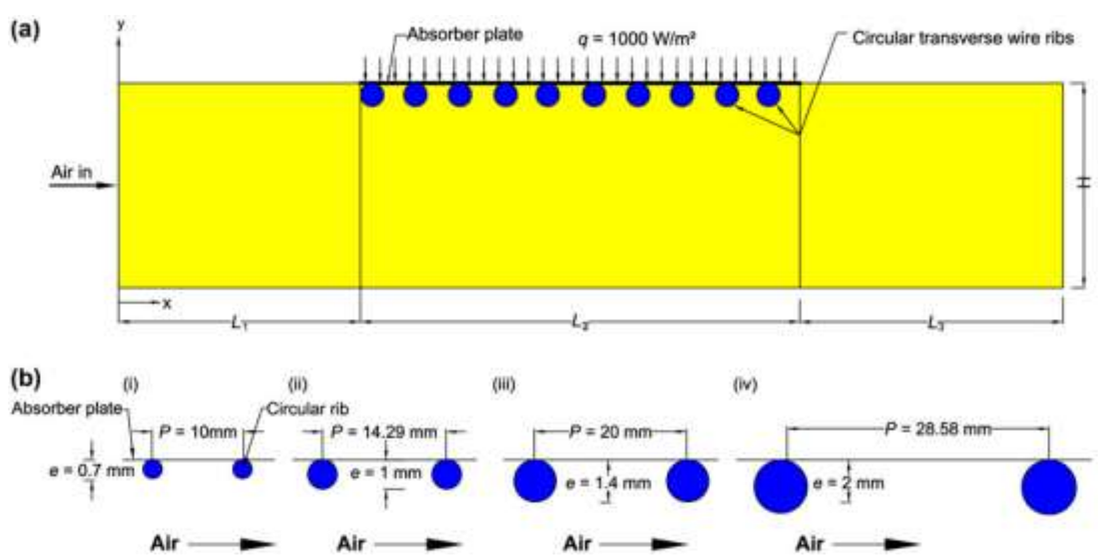

Figure 1.(a) Schematic of 2D computational domain and (b) different arrangement of circular-sectioned transverse ribs on the underside of the absorber plate [4].

≤ Re ≤ 18,000. The two-dimensional steady, turbulent flow, and heat transfer governing equations are solved using the finite volume method with the semi-implicit method for pressure-linked equations algorithm. The THPP under the same pumping power constraint is calculated in order to examine the overall effect of the relative roughness pitch. For the present range investigated, the maximum THPP of 1.82 is achieved by the use of the ribs with P/e of 10.71.

Dongxu Jin et al. (2015) numerically investigated the heat transfer and fluid flow characteristics in a solar air heater duct having multi V-shaped ribs on the absorber plate is presented in this study. The computations are performed for different rib geometries with a varying span wise V-rib number, relative rib pitch, relative rib height, and angle of attack, and for different Reynolds numbers. The effects of the rib geometrical parameters on the Nusselt number, friction factor, and flow structure are obtained and analyzed. Clearly, the multi V-shaped ribs greatly superior the heat transfer. The maximum value of the thermal presentation parameter was found to be 1.93 for the range of parameters investigated. The multi V-shaped ribs generate stream wise helical vortex flows, which promote the fluid mixing between the colder conventional fluid and the warmer fluid near the absorber wall. In addition, the moving subsidiary vortex structure at the inter-rib province further enhances the local fluid mixing.

Khushmeet Kumar et al. (2015) carried out different facts for the performance of solar air heater artificial surface roughness is used to increase the thermal performance of a solar air heater. The intent is to improve heat transfer between the absorber plate and air flowing through the duct. However, roughness also increases the force required to flow air through the duct, which leads to an increase in the pumping power requisite in the duct, thus resulting in a decrease in the effective or overall efficiency of the solar air heater duct. In this article effectual efficiency of various geometries used in solar air heater are computed by the use of heat transfer and friction factor experimental correlations. A comparison is also presented for the selection of optimum roughness geometry.

Anil Kumar et al. (2015) investigated the performance of discrete multi V-rib and presented outcome of CFD model. This work presents the outcomes of a computational fluid dynamics (CFD) analysis of thermal-fluid flow character in solar air channel having discrete multi V-rib with staggered rib roughness. Four different turbulence models (RNG k–e model, realizable k–e model, standard k–e model and SST k–x model) were tested for smooth solar air channel. The RNG k–e model was finally selected as the most suitable one. The effect of relative width ratios of discrete multi V-rib with staggered rib shape on the average Nusselt number, average friction factor and overall thermal performance have been studied. The average Nusselt number has the maximum value in the discrete multi V-rib with staggered rib shape for a relative width ratio of 6.0.

A.M. Lanjewar et al. (2015) investigate the techniques for enhancement of heat transfer rate Concept of artificial roughness on plain surface is an important technique to enhance heat transfer rate of air flowing in solar air heater. Over the years different rib geometries have been designed to explore heat transfer and friction characteristics of solar air heater. In this paper an attempt is made to review development of different rib geometries engaged for creating artificial roughness. Heat transfer and friction factor correlations increase by various investigators are presented.

Sanjay K. Sharma n et al. (2015) investigated the enhancement of heat transfer in the solar air heater ducts can be achieved by several means like using baffles, fins, ribs and groves. Until now, various attempts have been made to investigate the effects of these geometries on the enrichment of the heat transfer rate; however it is achieved at the cost of the increase in the pressure drop across the surfaces on which these elements are mounted. This paper is an attempt to abridge and conclude the investigations involving the use of small height elements and surface protrusions on absorber plate and channel walls as artificial roughness elements of different geometries and its effect on heat transfer and friction factor through experiments. It also summarizes the diverse correlations which have been developed for Nusselt number (Nu) and Friction factor (f) and reported in the previous investigations. The relative study has been done to understand the results of these investigations for solar air heaters with different roughness elements on its absorber surface.

In this article the thermo hydraulic performance have been investigated by Sukhmeet Singh et al. (2015). This paper presents thermo-hydraulic performance comparison of rib roughness under investigation, 'V-down ribs with gap' and parallel reported rib roughness geometries used in solar air heater duct. The present rib roughness has flow-attack-angle and relative roughness height of 601 and 0.043, respectively. The duct has aspect ratio of 12 and the Reynolds number ranged from 3000 to 15,000. The roughened wall was uniformly heated while the remaining three walls were insulated. These boundary conditions communicate closely to those found in conventional solar air heaters. Five rib roughened plates having relative roughness pitch of 4, 6, 8, 10 and 12 have been tested. The Nusselt number & friction factor were found to be highest for relative roughness pitch of 8. Maximum enhancement in Nusselt number and friction factor has been found to be 2.70 & 2.86, respectively. Thermo-hydraulic performance parameter ranged from 1.27 to 1.93.

Skullong et al. (2015) investigated experimentally on turbulent heat transfer and friction loss behaviors of airflow through a constant heat-fluxed solar air heater channel fitted with rib turbulators. The experiment was conducted for the airflow rate in terms of Reynolds numbers based on the hydraulic diameter of the channel in a range of 5000 to 24,000. In the present work, a comparative study between square and thin ribs (90°-rib) with three rib arrangements, namely, one ribbed wall, in-line and staggered ribs on two opposite walls was first introduced. The study shows a momentous effect of the presence of the ribs on the heat transfer rate and friction loss over the smooth wall channel. The comparison made at a single rib pitch and height also revealed that the thin rib excecution better than the corresponding square one. Among the three provision, the in-line rib array provides higher heat transfer and friction loss than the staggered and the single one. However, the staggered thin rib provides the highest thermal excecution. With this reason, only the staggered thin ribs at four different relative heights (B_R = 0.1, 0.2, 0.3 and 0.4) and three relative pitches (P_R = 0.5, 0.75 and 1.33) are investigation further. It is found that the staggered rib at B_R = 0.4 and P_R = 0.5 yields the highest heat transfer and friction factor but the maximum thermal performance is at B_R = 0.2 and P_R = 0.75.

Sukhmeet Singh et al. (2015) investigated on the concept of friction factor. A 3-dimensional CFD (computational fluid dynamics) investigation has been carried out to study the heat transfer and friction characteristics of solar air heater duct roughened with periodic sloping rib. The selected rib roughness is a new concept it has non-uniform cross-section in the form of saw-tooth. For comparison, transverse ribs with even cross-section of circular, square and trapezoidal have also been investigated. The Nusselt number and friction factor have been determined for Reynolds number range of 3000 to 15,000. The k-ε turbulence model was selected for analysis. The non-uniform cross-section saw tooth rib was found to result in higher Nusselt number than uniform cross-section ribs for Reynolds number above 7000 due to reduced low heat transfer area downstream of the rib caused by disruption in re-circulations. The maximum enhancement in Nusselt number for duct roughened with saw-tooth rib and trapezoidal rib was 1.78 and 1.50 respectively. The friction factor was found to be lower for saw-tooth rib as compare to uniform cross-section ribs investigated. The maximum enhancement in friction factor for duct roughened with saw-tooth and trapezoidal rib was 2.49and3.58 respectively.

Sukhmeet Singh n et al. (2015) investigated on friction factor and Nusselt number. This paper presents thermo-hydraulic performance similitude of rib roughness under investigation, ‘V-down ribs with gap’ and similar reported rib roughness geometries used in solar air heater duct. The present rib roughness has flow-attack-angle and relative roughness height of 601 and 0.043, respectively. The duct has aspect ratio of 12 and the Reynolds number ranged from 3000 to 15,000. The roughened wall was uniformly heated while the remaining three walls were insulated. These boundary conditions communicate closely to those found in conventional solar air heaters. Five rib roughened plates having relative roughness pitch of 4, 6, 8, 10 and 12 have been tested. The Nusselt number and friction factor were found to be highest for virtual roughness pitch of 8. Maximum enhancement in Nusselt number and friction factor has been found to be 2.70 & 2.86, respectively. Thermo-hydraulic performance parameter ranged from 1.27 to 1.93. Thermo-hydraulic comparison with similar rib geometries shows that the present roughness geometry performs better for Reynolds number range of 3000–12,000.

In this article Tareq Salameh et al. (2015) carried out the concepts for improvement of thermo hydraulic performance. In the present work, an experimental investigation of convective heat transfer and pressure drop was carried out for the turning portion of a U-channel where the outer wall was prepared with ribs. The shape of the ribs was varied. The investigation aims to give guidelines for improving the thermo-hydraulic performance of a solar air heater at the turning portion of a U-channel. Both the U-channel and the ribs were made in acrylic material to allow ocular access for measuring the surface temperature by using a high-resolution technique based on narrow band thermo chromic liquid crystals and a CCD camera placed to face the turning portion of the U-channel. The uncertainties were estimated to 5 & 7 % for the Nusselt number and friction factor, respectively. The pressure drop was approximately the same for all the consider shapes of the ribs while the dimpled rib case gave the highest heat transfer coefficient while the grooved rib presented the highest performance index.

For enhancement of Nusselt number Vipin B. Gawande et al. (2015) performed experimental approach. An experimental and 2-dimensional computational fluid dynamics (CFD) analysis of a solar air heater has been carried out using chamfered square rib as artificial roughness on the absorber plate. The relative roughness pitch (P/e = 7.14 –17.86), chamfer angle (α = 0°- 40°), Reynolds number (Re = 3800 – 18,000) and relative roughness height (e/D = 0.042) are chosen as design variables for analysis. A uniform heat flux of 1000 W/m^2 is maintained on the surface of absorber plate. CFD code, ANSYS 16 with renormalization group k-ε model was chosen. An enrichment in Nusselt number and friction factor with decrease in relative roughness pitch (P/e) is presented and discussed with reference to experimental and CFD analysis. The effect of chamfer angle and Reynolds number on enhancement of Nusselt number & friction factor is also presented. Optimum configuration of roughness factor for artificially roughened solar air heater has been determined in terms of thermo-hydraulic performance parameter. The chamfer angle of 20° on square rib and relative roughness pitch of 7.14 provide best thermo-hydraulic performance of 2.047 considering the maximum heat transfer & minimum pressure drop.

Mohamed Taher Bouzaher et al. (2016) presents a new concept via the use of flexible ribs to control flow and heat transfer inside the air duct of a solar air collector is proposed. The new model uses flexible ribs instead of conventional fixed ribs, to improved the control efficiency and, therefore, to seek better energy extraction performance. The effect of flow mass rates on flow and heat transfer behavior has been investigation. It is apparent that the turbulence generated by flexible ribs provides a greater improve in heat transfer over the air duct. Results show also that the thermal enhancement factor tends to improve with the rise of Reynolds number where the highest value of this factor is registered for the flexible ribs configuration.

For the enhancement of Nusselt number and thermo hydraulic Narinderpal Singh Deo et al. (2016)- An experimental study has been conducted to investigate heat transfer, friction factor and thermo hydraulic performance characteristics of flow in a rectangular duct artificially roughened on one side with multi-gap V-down ribs combined with staggered ribs. The rectangular duct used had aspect ratio of 12 and the Reynolds number based upon the mass flow rate of air at inlet of the duct ranged from 4000 to 12,000. The rib pitch-to-height (P/e) ratio was varied from 4 to 14, rib height-to-hydraulic diameter (e/Dh) ratio from 0.026 to 0.057 and angle of attack (a) from 40° to 80° while, gap width to rib height (g/e) ratio of 1, staggered rib length to rib height ratio (w/e) of 4.5, relative staggered rib pitch (p/P) value of 0.65 &two number of gap (n) on each side of the V-leg were used as fixed parameters during the experimentation. Results show two peaks for Nusselt number corresponding to the P/e value of 6 & 12 and decrease in the Nusselt number was observed for increase in the e/Dh value beyond 0.044. The maximum enhancement achieved in Nusselt number and thermo hydraulic performance parameter was of 3.34 and 2.45 times respectively.

Rajesh Maithani et al. (2015) evaluated the performance of a solar air heat are duct roughened with V-ribs with symmetrical gaps to enhance heat transfer. The roughness produced for enhancing the heat transfer from the absorber plate also enhances the pressure drop due to the increased friction. The heat transfer enhancement of absorber plate has been experimentally determined by using V-ribs with symmetrical gaps. The duct has relative roughness height (e/D) of 0.0433, relative roughness pitch (P/e) of 10 and angle of attack (α) of 60°. Relative gap width (g/e) and number of gaps (Ng) were varied in the range of 1–5. The maximum enhancement in the Nusselt number and friction factor is observed to be 2.59 and 2.87 times, respectively as compared to the smooth duct. The relative gap width of 4 and the number of gaps of 3 shows the maximum value of thermo-hydraulic performance parameter.

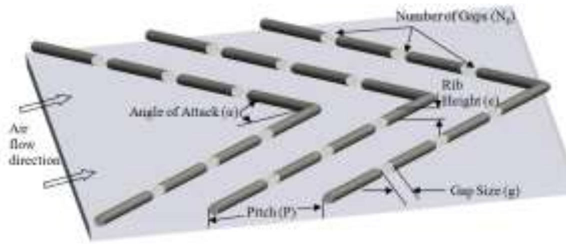

Figure2.Sketch of V-Ribs with symmetrical gaps[19].

Rajesh Maithani et al. (2016) - carried out experimentally for enhancement of heat transfer coefficient of a solar air heater having roughened air duct artificially roughened in the form of V-ribs with symmetrical gaps as turbulence promoter. In present work an experimental investigation of heat transfer and friction of synthetic roughness in the form of V-ribs with symmetrical gaps were investigated. The investigation encompassed Reynolds number (Re) ranging from 4000 - 18,000, Number of gaps (Ng) values of 1–5, relative gap width (g/e) values of 1–5, relative roughness pitch (P/e) values of 6–12, angle of attack (a) range of 30° to 75°and relative roughness height (e/D) values of 0.043. For Nusselt number (Nu), the maximum enhancement of the order of 3.6 times that of smooth duct has been obtained, similarly friction factor (f) also increases by 3.67 folds of that of the smooth duct. The rib parameters corresponding to maximum increase in Nu and f were Ng = 3, g/e = 4, P/e = 10 and a = 60°. Based on the experimental data, connections for Nu and f have been developed as function of roughness parameters of V-ribs with symmetrical gap and flow Reynolds number.

The experimental and numerical investigation of forced convection heat transfer is carried by Vipin B. Gawande et al. (2016). A solar air heater is a thermal system which uses artificial roughness in the form of repeated ribs on the absorber plate to enlarge the heat transfer rate. Forced convection heat transfer of air in a solar air heater with reverse L-shaped ribs has been carried out experimentally & numerically. Thermal execution of solar air heater is studied with design variables such as relative roughness pitch (7.14 6 P/e 6 17.86), Reynolds number (3800 6 Re 6 18,000), heat flux (1000 W/m^2) and constant relative roughness height (e/D = 0.042). A two dimensional CFD simulation is carried out with using CFD code, ANSYS 16 and RNG k–e turbulence model, for solving turbulence terms in governing equations. The presence of reverse L-shaped rib shows a significant effect on heat transfer and friction factor characteristics, relative to change in relative roughness pitch (P/e) & Reynolds number (Re). Thermo hydraulic performance parameter (T.H.P.P) of 1.90 considering heat transfer augmentation with same pumping power, has been evaluated for optimum configuration of the roughness element for artificially roughened solar air heater. It has been found that the numerical results are in good agreement with the experimental results for the range of parameters investigated. Correlations for Nusselt number & friction factor have been developed as a function of roughness and flow parameters.

In this article different approaches used by Vipin B.Gawande et al. (2016) to investigate the thermal performance of solar air heater. A solar air heater is experimentally investigated by many researchers to study the effect of operating and geometrical parameters on heat transfer & fluid flow characteristics. The availability of highly advanced computer hard ware and development in numerical methods, heartening the future researchers to carry out the simulations of solar air heater using various roughness geometries with different ranges of operating and geometrical parameters. CFD is emerging as an efficient tool to perceive the optimum configuration of rib for its maximum thermo hydraulic performance before carrying out actual experimentation. This article discusses different approaches used to investigate the thermal execution of solar air heater. The computational approach, i.e. CFD methodology is discussed using the reference of commercial CFD software ANSYS16. The main aim of the article is to present a detailed review of the literature that deals with the application of CFD (computational fluid dynamic) in the design of solar air heater. The paper has a concise summary of each reviewed article in the form of, type of computational domain (2D/3D), turbulence model used, type of CFD commercial software used, range of operating and geometrical parameters and best results obtained from CFD. The article also tabulated the optimum values of relative roughness pitch (P/e) & relative roughness height (e/D) for maximum heat transfer enhancement in roughened solar air heater duct.

Tabish Alam et al. (2017) works on this article to understand the result of application of article roughness. Applications of artificial roughness on the inside of absorber plate in solar air heater duct have been widely used to improve heat transfer with moderate increase of friction factor. The design of the roughness shape & arrangement is most important to optimize the roughened surfaces. The roughness parameters & ribs arrangement are responsible to alter the flow structure and heat transfer mechanism are mainly governed by flow structure. The critical reviews on various artificial roughness elements available in literature have been conducted and the effects of the roughness patterns are debated. The Nusselt number and friction factor correlations for various roughness elements have been summarized. A comparison study of thermo hydraulic performance of different roughness elements has also been reported to understand the results of applications of artificial roughness.

R.S. Gilla et al. (2017) investigate on the study of solar air heater with broken arc rib. In present paper, solar air heater duct having facet ratio 12 roughened with broken arc rib has been investigated. The broken arc is formed by creating symmetric gap in continuous arc with gap width equal to roughness height. It has been planned to investigate the influence of position of gap in arc rib on Nusselt number as well as on friction factor. For this purpose, five broken arc rib roughened plates having relative gap position ranging 0.2-0.8 have been investigated for values of Reynolds number 2000–16000. The remaining roughness parameters like relative roughness height, arc angle, & relative roughness pitch were taken as 0.043, 30o and 8 respectively. The presence of broken arc ribs enhanced the Nusselt number, friction factor and thermo-hydraulic performance up to 2.37, 2.55 & 1.94 respectively, compared to smooth duct. The results of ducts roughened with broken arc rib & continuous arc rib have been compared under similar flow conditions. The effect of gap in continuous arc rib on the flow pattern has also been observed using ANSYS Academic Research CFD 16.0.

In this paper Rajneesh Kumar et al. (2017) numerical simulated an commercial ANSYS fluent software. Solar air heater absorbs thermal radiations from Sun and utilizes it to heat air. The thermal performance of SAH can be increased by using ribs on the absorber plate. In this paper, rectangular geometry of ribs is measured over the absorber plate. The fluid flow characteristics & heat transfer in ribbed triangular duct (with an apex angle of 60°) SAH is analyzed using computational fluid dynamics (CFD). The roughened side of duct is subjected to a constant heat flux of 1000 W m−2, whereas, roughness elements are adiabatic in nature. The 3-dimensional model of SAH is developed and numerical simulations are carried out by developing CFD code with the help of finite volume method. The numerical simulations are performed on commercial ANSYS 16 software. A new roughness parameter called rib aspect ratio (e/w) is introduced in this study and its cause on friction factor (f) and Nusselt number (Nu) is investigated along with relative roughness height (e/D) and relative roughness pitch (P/e) for the Reynolds number ranges from of 4000 - 18,000. The values of rib aspect ratio (e/w), roughness height (e/D) and relative roughness pitch (P/e) range from 0.25 to 4.0, 0.02 to 0.04 and 5 to 15, respectively. A considerable increase in friction factor (f) & Nusselt number (Nu) is observed due to rectangular rib in comparison to smooth one. The numerically predicted results are compared with the available results and a good agreement between them is observed with maximum error of±4.04%. A significant variation in friction factor (f) and Nusselt number (Nu) is observed by varying rib aspect ratio (e/w) values from 0.25 - 4.0. The maximum value of thermo hydraulic performance parameter (TPP) is found 1.89 in case of relative roughness pitch (P/e), rib aspect ratio (e/w) and relative roughness height (e/D) value of 10, 4.0 and 0.04, respectively, at the Reynolds number (Re) of 15,000.

In this article Sanjay K. Sharma et al. (2017) numerically investigated the solar air heater with different rib arrangements. Ribs on the inside of the absorber plate of solar air heater increase the convective heat transfer rate of the air flowing through it. Several experimental and numerical investigations, with different rib geometry & flow conditions, have been carried out. This paper is one such stab of experimental and numerical investigations of solar air heater. It presents the effect of rib arrangements on the heat transfer and frictional loss characteristics of a rib roughened solar air heater. The geometrical and flow conditions of the present work circumscribe with aspect ratio (W/H) of 10 for the duct, blockage ratio (e/H) is 0.1, relative roughness height (e/d) of 0.055, relative roughness pitch (P/e) of 10, angle of attack (a) of 90° and Reynolds number (Re) from 4000 to 16000. Two thin transverse continuous and two abridged ribs are used for one pitch length. Four different rib arrangements are considered for the heat transfer, friction factor and thermo hydraulic performance parameter (THPP) investigations. A three dimensional (3D) numerical simulation is carried out with the commercial CFD code ANSYS ver. 16.0 and RNG k–e turbulence model. The enhanced wall treatment as wall function is used, keeping the Y+ criteria < 1. The numerical results are in first-class agreement with the experimental results. Three important outcomes are observed in the present investigation. Rib arrangement 1, with mid ribs placed at 3.3% and 6.67% truncation from the sidewalls gives the highest heat transfer enhancement. Arrangement 3, with mid ribs placed at 5% truncation from the side walls gives the best overall THPP results and arrangement 4, with two transverse continuous ribs in between the truncated ribs shows the best average friction factor.

Anup Kumar et al. (2018) experimentally investigated the effect of twisted rib of solar air heater. Researchers are working to enhance the performance of the solar air heater through infusing various turbulators of different geometry and size over the absorber plate. The present work studied the effect of twisted rib over the absorber plate of solar air heater. Experimentations are performed varying roughness parameters such as relative roughness pitch (P/e) values of 6–10, rib inclination angle (α) in the range of 30°–90°, twist ratio (y/e) of 3–7 and Reynolds number in the range of 3500–21000, to acquire its influences on heat propagation rate and flow friction. The heat transfer and flow friction characteristic with this roughness are compared with a smooth surface for similar flowing conditions. The maximum enhancement for heat propagation characteristic and friction factor had been noticed to be 2.58 and 1.78 times that of smooth surface respectively. The thermo hydraulic performance had been evaluated for the optimum range of roughness geometric parameters.

Inderjeet Singha et al. (2018) estimate the performance of thermo hydraulic for the uniform and non-uniform rib. In this investigation, the thermal & hydraulic performance of solar air heater duct roughened with non-uniform cross-sectioned square wave profiled transverse rib is carried out in ANSYS 16.0. The three-D investigation considered parameters as relative roughness pitch 4 to 30 and Reynolds number 3000 to 15,000, while relative roughness height has been fixed as 0.043. The turbulence model RNG k-ε with enhanced wall treatment and one periodic length was chosen for analysis. The CFD methodology has been validated with the experimental results vacant in literature. The maximum augmentation in Nusselt number and friction factor over smooth duct was found to be 2.14 times and 3.55 times respectively at relative roughness pitch of 10 and Reynolds number of 15,000. The heat transfer and fluid flow process are discussed and visualized using streamlines & contours. The maximum thermo hydraulic performance parameter was observed to be 1.43 at relative roughness pitch of 10 and Reynolds number of 12,000. The thermo hydraulic performance for the non uniform rib was also observed to be more than uniform cross-sectioned rib.

Ajeet Pratap Singh et al. (2018) experimentally examine new solar air heater design. In this paper, we details the investigation of various curved solar air heater designs that shows significant enhancement of heat transfer. We have taken the initial design proposed in the reference: Mahboub, C., Moummi, N., Brima, A., Moummi, A., 2015 investigational study of new solar air heater design. International Journal of Green Energy 13, 521–529, and included promising design modifications to further look for the avenues for thermal efficiency enhancement features. The Computational Fluid Dynamic (CFD) model was first validated by the results reported by Mahboub et al. It was observed that secondary vortex formation near the absorber wall growing the Nusselt number significantly. New correlations for friction factor and Nusselt number has been developed as a function of Reynolds number and various geometric parameters such as relative groove height and pitch ratios for different design of air heaters. It is hoped that data of parameters i.e. Nusselt number (Nu), outlet air temperature (T_O), thermal efficiency (ηth) and friction factor (f) presented in this paper would help researchers and industry in developing efficient designs of solar collectors.

Prashant Singh et al. (2018) experimentally and numerically carried out the detailed mechanism of heat transfer. This paper presents findings from experimental & numerical study of heat and fluid flow in a straight square duct featuring rib tabulators in a criss-cross pattern formed by 45 ° angled rib turbulators. Two ribbed configurations with criss-cross pattern Inline and staggered, have been studied where the baseline case was smooth duct with no heat transfer enhancement feature. Detailed heat transfer coefficients were calculated using momentary liquid crystal thermography by employing 1-D semi-infinite conduction model. Heat transfer and pressure drop measurements were carried out for Reynolds number ranging from 30,000 - 60,000. For understanding of heat transfer enhancement mechanism, numerical investigations were carried out using SST k-x turbulence model. Numerical predictions of near-wall fluid dynamics and turbulent transfer has been presented in coincidence with experimentally obtained detailed heat transfer coefficients to demonstrate the heat transfer characteristics of ribbed duct. Nusselt numbers normalized with respect to Dittus-Boelter correlation for developed turbulent flow in circular duct varied between 2.7 and 3.1 for inline and staggered configurations and the thermal hydraulic performance varied between 1.2 & 1.5 for the range of Reynolds number investigated.

For the application of solar air heater an investigation is done by the Vijay Singh Bishta et al. (2018)- Solar air heater is an eco-friendly, economical and simple device which is used to harness solar energy for space heating, process heating and agricultural applications. The thermal performance of solar air heater can be increased by the application of artificial roughness on the inside of absorber surface. The heat transfer and friction characteristics of artificially roughened solar air heaters with different roughness geometries have been scrutinyed in this article. The article presents the authoritative account of the current progress on topic, discusses the previous developments, and throws light on the future directions. An attempt has been made to evaluate the performance of solar air heater having different types of roughness geometries based on correlations proposed in the literature. Thermo-hydraulic performance parameter (η), thermal efficiency (η_{th}), thermal efficiency improvement factor (TEIF), effective efficiency (η_{eff}), & exergetic efficiency (η_{ex}) are evaluated to gauge the performance of different roughness geometries.

Conclusion

Artificially roughened solar air heaters have enhanced rate of heat transfer as compared to smooth solar air heaters under the same operating conditions are

1. Enhancement of heat transfer and friction factor, hence the thermal enhancement factor of artificially roughened solar air heaters, depends upon the values of flow Reynolds number (Re), relative roughness pitch (P/e), and relative roughness height (e/D).
2. The Nusselt number of roughened solar air heaters increases with the increasing values of flow Reynolds numbers and relative roughness heights for a given value of relative roughness pitch.
3. Friction factor of roughened solar air heater increases with the decreasing values of flow Reynolds number and increasing values of relative roughness height for a given value of relative roughness pitch.
4. It is observed that the rate of increase of friction factor is higher than that of the Nusselt number.

Reference

1. A.M. Lanjewar, J.L.Bhagoria, M.K. Agrawal "Review of development of artificial roughness in solar air heater and performance evaluation of different orientations for double arc rib roughness", Renewable and Sustainable Energy Reviews, 43(2015)1214–1223.

2. Anil Kumar, R. P. Saini, J. S. Saini "Effect of roughness width ratio in discrete Multi v-shaped rib roughness on thermo-hydraulic performance of solar air heater", ORIGINAL, 51(2015)209–220.

3. Anil Kumar Patil," Heat transfer mechanism and energy efficiency of artificially roughened solar air heaters—A review", Renewable and Sustainable Energy Reviews, 42(2015)681–689.

4. Anil Singh Yadav," CFD investigation of effect of relative roughness height on Nusselt number and friction factor in an artificially roughened solar air heater", the Chinese Institute of Engineers, 38(2015)494-502.

5. Anil Singh Yadav and J.L. Bhagoria," Numerical investigation of flow through an artificially roughened solar air heater", International Journal of Ambient Energy, 36(2015)87-100.

6. Dongxu Jin, Manman Zhang, Ping Wang, Shasha Xu," Numerical investigation of heat transfer and fluid flow in a solar air heater duct with multi V-shaped ribs on the absorber plate", Energy, 89(2015)178-190.

7. Khushmeet Kumar, D.R. Prajapati, Sushant Samir," Determination of Effective Efficiency of Artificially Roughened Solar Air Heater Duct Using Ribs", Distributed Generation & Alternative Energy Journal, 30(2015)57-77.

8. Anil Kumar, Man-Hoe Kim," Effect of roughness width ratios in discrete multi V-rib with staggered rib roughness on overall thermal performance of solar air channel", Science Direct, 119(2015) 399–414.

9. A.M.Lanjewar, J.L.Bhagoria, M.K.Agrawal," Review of development of artificial roughness in solar air heater and performance evaluation of different orientations for double arc rib roughness", Renewable and Sustainable Energy Reviews, 43(2015)1214–1223.

10. Sanjay K. Sharma n, Vilas R. Kalamkar," Thermo-hydraulic performance analysis of solar air heaters having artificial roughness–A review", Renewable and Sustainable Energy Reviews, 41 (2015) 413–435.

11. Sukhmeet Singh, Subhash Chander b, J.S.Saini c, "Thermo-hydraulic performance due to relative roughness pitch in V-down rib with gap in solar air heater duct—Comparison with similar rib roughness geometries", Renewable and Sustainable Energy Reviews, 43(2015)1159–1166.

12. Sompol Skullong · Chinaruk Thianpong · Pongjet Promvonge "Effects of rib size and arrangement on forced convective heat transfer in a solar air heater channel", ORIGINAL, 10.1007/s00231-015-1515-5.

13. Sukhmeet Singh a, Bikramjit Singh b, V.S. Hans b, R.S. Gill b," CFD (computational fluid dynamics) investigation on Nusselt number and friction factor of solar air heater duct roughened with non-uniform cross-section transverse rib", Energy, 84(2015) 1-9.

14. Sukhmeet Singh n, SubhashChander b, J.S.Saini c," Thermo-hydraulic performance due to relative roughness pitch in V-down rib with gap in solar air heater duct—Comparison with similar rib roughness geometries", Renewable and Sustainable Energy Reviews, 43(2015)1159–1166.

15. Tareq Salameh1 · Abdul Hai Alami1 · Bengt Sunden2," Experimental investigation of the effect of variously shaped ribs on local heat transfer on the outer wall of the turning portion of a U channel inside solar air heater", ORIGINAL, 52(2016)539-546.

16. Vipin B. Gawande1 · A. S. Dhoble1 · D. B. Zodpe1 · Sunil Chamoli2," Experimental and CFD based thermal performance prediction of solar air heater provided with chamfered square rib as artificial roughness", TECHNICAL PAPER, 10.1007/s40430-015-0402-9.

17. Mohamed Taher Bouzaher, Mohamed Tahar Baissi· Chebana abdelbasset," CFD analysis of solar air collector equipped with flexible ribs", TECHNICAL PAPER, 38(2016)2289-2297.

18. Narinderpal Singh Deo, Subhash Chander, J.S. Saini," Performance analysis of solar air heater duct roughened with multi gap V-down ribs combined with staggered ribs", Renewable Energy, 91(2016) 484 - 500.

19. Rajesh Maithani , J. S. Saini," Performance evaluation of solar air heater having V-ribs with symmetrical gaps in a rectangular duct of solar air heater", International Journal of Ambient Energy, 38(2015)400-410.

20. Rajesh Maithani , J.S. Saini," Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with V-ribs with symmetrical gaps", Experimental Thermal and Fluid Science, 70(2016)220–227.

21. Vipin B. Gawande, A.S. Dhoble a, D.B. Zodpe a, Sunil Chamoli b," Experimental and CFD investigation of convection heat transfer in solar air heater with reverse L-shaped ribs", Science Direct, 131(2016) 275–295.

22. Vipin B.Gawande a,n, A.S.Dhoble a, D.B.Zodpe a, SunilChamoli b," A review of CFD methodology used in literature for predicting thermo-hydraulic performance of a roughened solar air heater", Renewable and Sustainable Energy Reviews, 54(2016)550–605.

23. Tabish Alam, Man-Hoe Kim,"A critical review on artificial roughness provided in rectangular solar air heater duct", Renewable and Sustainable Energy Reviews, 69(2017) 387–400.

24. R.S. Gilla, V.S. Hansb,, Sukhmeet Singhb," Investigations on thermo-hydraulic performance of broken arc rib in a rectangular duct of solar air heater", International Communications in Heat and Mass Transfer, 88(2017)20–27.

25. Rajneesh Kumar, Anoop Kumar, Varun Goel," A parametric analysis of rectangular rib roughened triangular duct solar air heater using computational fluid dynamics", Solar Energy, 157(2017)1095–1107.

26. Sanjay K. Sharma, Vilas R. Kalamkar," Experimental and numerical investigation of forced convective heat transfer in solar air heater with thin ribs", Solar Energy, 147 (2017) 277–291.

27. Anup Kumar, Apurba Layek," Thermo-hydraulic performance of solar air heater having twisted rib over the absorber plate", International Journal of Thermal Sciences, 133(2018)181–195.

28. Inderjeet Singha, Sukhmeet Singhb," CFD analysis of solar air heater duct having square wave profiled transverse ribs as roughness elements", Solar Energy, 162(2018)442–453.

29. Ajeet Pratap Singh, O.P. Singh,"Performance enhancement of a curved solar air heater using CFD", Solar Energy, 174 (2018) 556–569.

30. Prashant Singh, Yongbin Ji, Srinath V. Ekkad," Experimental and numerical investigation of heat and fluid flow in a square duct featuring criss-cross rib patterns", Applied Thermal Engineering, 128(2018) 415–425.

31. Vijay Singh Bishta, Anil Kumar Patilb, Anirudh Guptac," Review and performance evaluation of roughened solar air heaters", Renewable and Sustainable Energy Reviews, 81(2018)954–977.