International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 4 Issue 4, June 2020 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

# Numerical Investigation of Heat Transfer and Friction Characteristics of solar Air Heater Duct using Broken 'S' Shaped Ribs Roughness

**Sushma Dangi[1], Dr. S. K. Nagpure[2]**

[1]M Tech Scholar, [2]Associate Professor,
[1,2]SCOPE College of Engineering, Bhopal, Madhya Pradesh, India

**ABSTRACT**

The solar air heater has an important place among solar heat collectors. It can be used as sub-systems in many systems meant for the utilization of solar energy. Possible applications of solar air heaters are drying or curing of agricultural products, space heating for comfort regeneration of dehumidifying agents, seasoning of timber, curing of industrial products such as plastics. When air at high temperature is required the design of a heater becomes complicated and very costly. As far as the ultimate application for heating air to maintain a comfortable environment is concerned, the solar air heater is the most logical choice. In general solar heaters are quite suitable for low and moderate temperatures application as their design is simple. These solar air heaters have low heat transfer efficiency which can be improved using geometrical modifications like optimizing duct geometry or adding artificial roughness.The use of artificial roughness on the underside of the absorber plate is an effective and economic way to improve the thermal performance of a solar air heater. Several experimental investigations, involving different types of roughness elements, have been carried out to improve the heat transfer from the absorber plate to air flowing in solar air heaters. In this paper the CFD analysis on heat transfer and friction in rectangular ducts roughened with broken 'S' shaped ribs has been presented. The relative gap width (g/e) is varied from 0.5 to 2.5 and other parameter are constant. The effects of gap width(g/e) on Nusselt number, friction factor and thermo-hydraulic performance parameter have been discussed and results compared with smooth duct under similar conditions. It is found that the maximum heat transfer and friction characteristic at a relative gap width of 1.

***KEYWORDS:*** *Solar air heater, Nusselt number, Heat transfer, Friction factor, Relative gap width*

***How to cite this paper:*** Sushma Dangi | Dr. S. K. Nagpure "Numerical Investigation of Heat Transfer and Friction Characteristics of solar Air Heater Duct using Broken 'S' Shaped Ribs Roughness" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-4 | Issue-4, June 2020, pp.1259-1264, URL: www.ijtsrd.com/papers/ijtsrd31418.pdf

IJTSRD31418



## I. INTRODUCTION

Solar air heater is one of the basic equipment through which solar energy is converted into thermal energy .The main application of solar air heater are space heating ,seasoning of timber ,curing of industrial products and these can also be effectively used for curing/drying of concrete/clay building components .A solar air heater is simple in design and required little maintenance . However the value of the heat transfer coefficient between the absorber plate and air is low and this results in a lower efficiency .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].Several methods including the use of fins , artificial roughness and packed beds in the ducts ,have been proposed for the enhancement of thermal performance .Artificial roughness in form of ribs and in various configuration has been used to create turbulence near wall or to break laminar sub-layer . Artificial roughness results in high friction 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 .The use of artificial roughness in solar air heaters owes its origin to several investigations carried out in connection with the enhancement of heat transfer in nuclear reactors and turbine blades .Several investigations have been carried out to study effect of artificial roughness on heat transfer and friction factor for two opposite roughened surface by Han[2,3].Han et al.[4-5], Wrieght et al.[7], Lue et al,[8-10], Taslim et al. and Hwang[12],Han and Park[14],Park et al.[15] developed by different investigators .The orthogonal ribs i.e. ribs arranged normal to the flow were first used in solar air heater and resulted in better heat transfer in comparison to that in conventional solar air heater by Prasad k, Mullick S. C. et al [16].Many investigators Gao x sunden B[17], Han J. C, Glicksman LR, Rohsenow WM[18],Prasad BN, Saini JS{19], Taslim ME, Li T, Kercher Dm[20],Webb RL, Eckert Erg, Goldstein RJ[21] have reported in detail the Nu and f for orthogonal and inclined rib-roughened ducts. The concept of V-shaped ribs evolved from the fact that the inclined ribs produce longitudinal vortex and hence higher heat transfer .In principal ,high heat transfer coefficient region can be increased two folds with V-shape ribs and hence result in even higher heat transfer et al. [20].The beneficial effect on Nu and f caused by V-shaping of ribs in comparison to angled ribs has been experimentally endorsed by several investigators Geo X,Sunden B{22], Karwa R.[23], Kukreja RT, Lue SC, McMillin RD[24],Lau SC, McMillin RD, Han JC[25], for different roughness parameters and duct aspect ratios .For V-shape ribs, the inter-rib local heat transfer coefficient reduces from leading edge(s) to trailing edge(s) in transvers direction[19,21,22],However in the flow direction ,the inter- rib local heat transfer coefficience varies like saw tooth [20,22,23].In addition ,multiple V-ribs have also been investigated with the anticipation that the more number of secondary flow cells may result in still higher heat transfer et at Lanjewar A, Bhagoria JL, Sarviya RM[26],Hans VS, Saini RP, Saini JS[27]. Based on the experimental studies carried out by various investigators, correlations for heat transfer and friction were developed. Chao et al.[28]examined the effect of an of angle of attack and number of discrete ribs, and reported that the gap region between the discrete ribs accelerates the flow, which increases the local heat-transfer coefficient. In a recent study ,Chao et al.[29] investigated the effect of a gap in the inclined ribs on heat transfer in a square duct and reported that a gap in the inclined rib accelerates the flow and enhances the local turbulence, which will result in an increase in the heat transfer. They reported that the inclined rib arrangement with a downstream gap position shows higher enhancement in heat transfer compared to that of the continuous inclined rib arrangement. Aharwal et al. [30] carried out experimental investigation of heat transfer and friction factor characteristics of a rectangular duct roughened with repeated square cross-section split-rib with a gap, on one broad wall arranged at an inclination with respect to the flow direction. A gap in the inclined rib arrangement enhances the heat transfer and friction factor of the roughened ducts. The increase in Nusselt number and friction factor is in the range of 1.48–2.59 times and 2.26–2.9 times of the smooth duct, respectively, for the range of Reynolds numbers from 3000 to 18,000. The maximum values of Nusselt number and friction factor are observed for a gap in the inclined repeated ribs with a relative gap position of 0.25 and a relative gap width of 1.0.Table 2 summarizes the various arrangements of discreatizing the ribs employed by these investigators. The studies of Han et al.[5],Lau et al.[8] and Taslim et al.[11] not covered the wide range of roughness and operating parameters as would be required for detailed analysis for detailed optimal design or selection of roughness parameter to be used in conventional solar air heaters .Most of the investigations carried out so far have applied artificial roughness on two opposite wall with all four walls being heated .However in case of solar air heater ,roughness elements are applied to heated wall while remaining three walls are insulated .Heated wall consists of absorber plate and is subjected to uniform heat flux(insulation).This makes fluid flow and heat-transfer characteristics distinctly different from those found in case of two roughened walls and four heated wall duct Producing a gap in the inclined rib is found to enhance the heat transfer by breaking the secondary flow and producing higher level of turbulence in the fluid downstream of the rib .A similar gap in both the limbs of v-rib further enhances the heat transfer by introducing similar effects in both the limbs. Further the use of multi v-rib across the width of the plate is found to enhance the heat transfer by increasing the number of secondary flow cells several times. It is thought that producing gaps in all the limbs of multi-v geometry will bring about considerably large enhancement in comparison to that of simple single v-rib arrangement. It will therefore be pertinent to investigate the effect of various geometrical and flow parameters on the heat transfer and friction characteristics of rectangular duct having its absorber plate roughened with 'Sshaped with gap.

## II. Computational Fluid Dynamics

Computational fluid dynamics or CFD is the analysis of systems involving fluid flow, heat transfer and associated phenomena such as chemical reactions by means of computer-based simulation. The technique is very powerful and spans a wide range of industrial and non-industrial application areas. The 2-dimensional solution domain used for CFD analysis has been generated in ANSYS version 14.5 (workbench mode) as shown in Fig.1.The solution domain is a horizontal duct with broken 'S' shaped ribs roughness on the absorber plate at the underside of the top of the duct while other sides are considered as smooth surfaces.

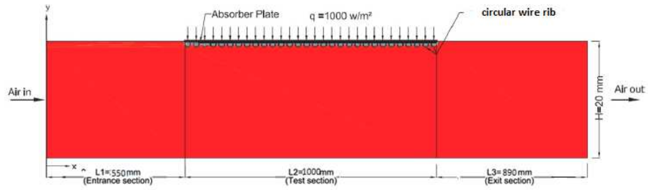



**Fig.1. Showing the geometric dimension of the working model**

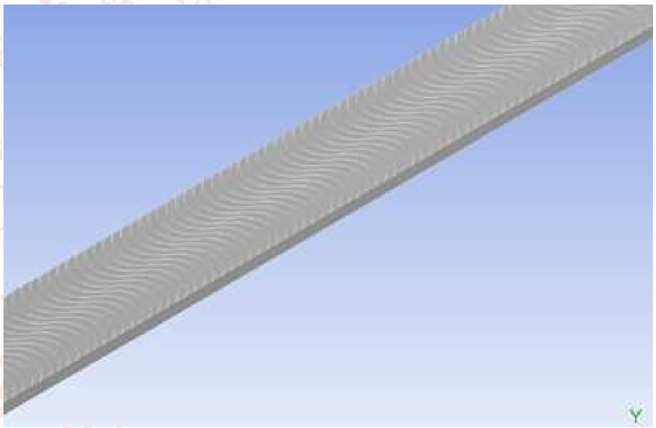


**Fig. 2 Geometry of Broken 'S' arc rib**

Complete duct geometry is divided into three sections, namely, entrance section, test section and exit section. A short entrance length is chosen because for a roughened duct, the thermally fully developed flow is established in a short length 2–3 times of hydraulic diameter. The exit section is used after the test section in order to reduce the end effect in the test section. The top wall consists of a 0.5 mm thick absorber plate made up of aluminum. Artificial roughness in the form of small diameter galvanized iron (G.I) wires is considered at the underside of the top of the duct on the absorber plate to have roughened surface, running perpendicular to the flow direction while other sides are considered as smooth surfaces. A uniform heat flux of 1000 w/m$^2$ is considered for computational analysis.

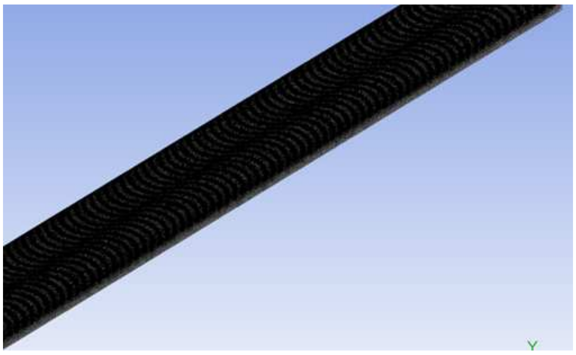


Fig.3 **Meshing of computational Domain for broken 'S' ribs Roughness**

A non-uniform mesh is shown in Fig.3Present mesh contained 191,061 quad cells with non-uniform quad grid of 0.21 mm cell size. This size is suitable to resolve the laminar sub-layer. For grid independence test, the number of cells is varied from 113,431 to 207,147 in five steps. It is found that after 191,0481 cells, further increase in cells has less than 1% variation in Nusselt number and friction factor value which is taken as criterion for grid independence.

In the present simulation governing equations of continuity, momentum and energy are solved by the finite volume method in the steady-state regime. The numerical method used in this study is a segregated solution algorithm with a finite volume-based technique. The governing equations are solved using the commercial CFD code, ANSYS Fluent 14.5. No-slip conditions for velocity in solid surfaces are assumed and the turbulence kinetic energy is set to zero on all solid walls. The top wall boundary condition is selected as constant heat flux of 1000 W/m$^2$ and bottom wall is assumed at adiabatic condition. A uniform air velocity is introduced at the inlet while a pressure outlet condition is applied at the exit. The Reynolds number varies from 2000 to 16000 at the inlet. The mean inlet velocity of the flow is calculated using Reynolds number. Constant velocity of air is assumed in the flow direction. The temperature of air inside the duct is also taken as 300 K at the beginning. At the exit, a pressure outlet boundary condition is specified with a fixed pressure of 1.013x10$^5$ Pa.

## III. RESULTS AND DISCUSSION

### A. Heat Transfer Characteristics and Friction Factor Characteristics

Fig.4 shows the effect of Reynolds number on average Nusselt number for different values of relative gap width (g/e) and fixed other parameter. The average Nusselt number is observed to increase with increase of Reynolds number due to the increase in turbulence intensity caused by increase in turbulence kinetic energy and turbulence dissipation rate.

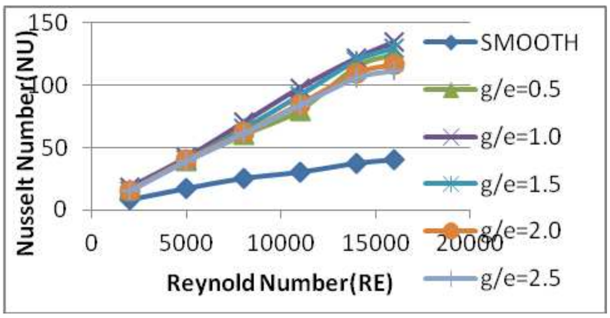
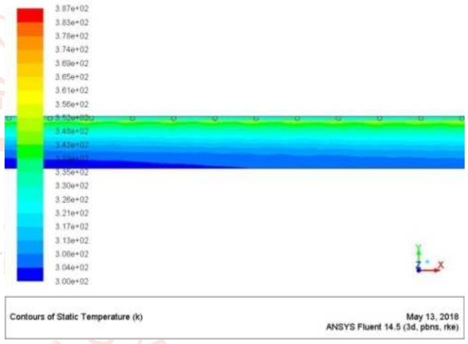


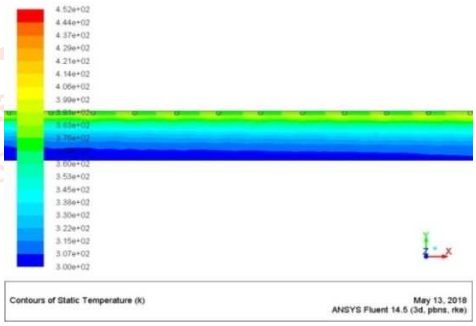

**Fig. 4.Variation of Nusselt number with Reynolds number for different Values of relative gap width (g/e).**

Effect of the relative gap width (g/e) on heat transfer is also shown typically in Fig. 4. It can be seen that the enhancement in heat transfer of the roughened duct with respect to the smooth duct also increases with an increase in Reynolds number. It can also be seen that Nusselt number values increases with the increase in relative gap width (g/e) of up to 1 and then decrease for a fixed value of roughness pitch (*P*). The roughened duct having broken 'S' shaped with relative gap width (g/e) of 1 provides the highest Nusselt number at a Reynolds number of 16000. For circular rib the maximum enhancement of average Nusselt number is found to be 2.45 times that of smooth duct for relative gap width (g/e) of 1.0 at a Reynolds number of 16000.

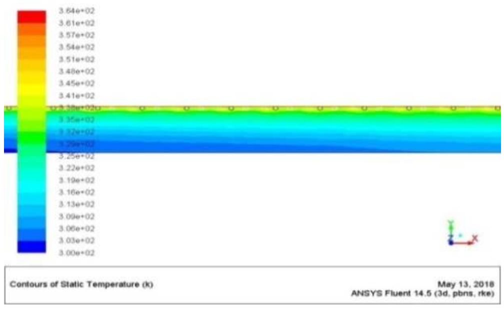
The heat transfer phenomenon can be observed and described by the contour plot of turbulence intensity. The contour plot of turbulence intensity for broken 'S' shaped ribs is shown in Fig.5 (a, b and c).The intensities of turbulence are reduced at the flow field near the rib and wall and a high turbulence intensity region is found between the adjacent ribs close to the main flow which yields the strong influence of turbulence intensity on heat transfer enhancement.




**(a)**




**(b)**




**(c)**

**Fig. 5 Contour plot of turbulent intensity for circular rib (a) Re=4000 (b) Re=8000 (c) Re=12000**

Fig. 6 shows the effect of Reynolds number on average friction factor for different values of relative gap width (g/e) and fixed value of roughness pitch. It is observed that the friction factor decreases with increase in Reynolds number because of the suppression of viscous sub-layer.

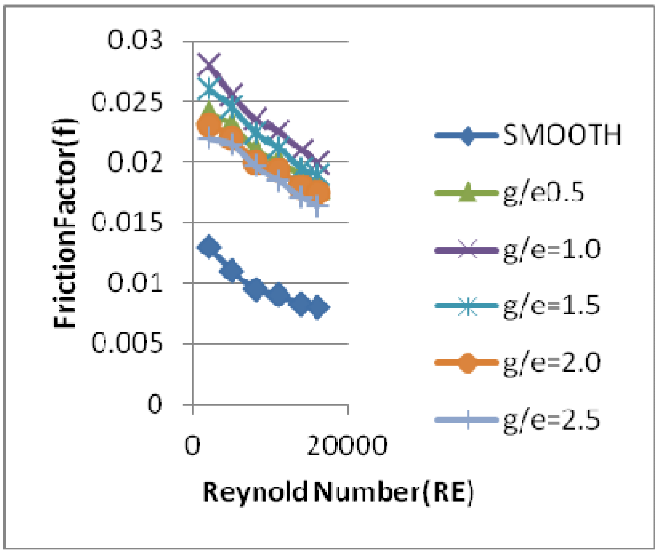



**Fig. 6 Variation of Friction factor and Reynoldsnumber at different gap width(g/e)**

Figure. 6 also shows that the friction factor decreases with the increasing values of the Reynolds number in all cases as expected because of the suppression of laminar sub-layer for fully developed turbulent flow in the duct. It can also be seen that friction factor values increase with the increase in relative gap width (g/e) up to 1 and then decrease for fixed value of roughness pitch, attributed to more interruptions in the flow path.

### B. Thermo-Hydraulic Performance

It has also been observed from Figures 4 and 6 that the maximum values of Nusselt number and friction factorcorrespond to relative gap width of 1.0, thereby, meaning that an enhancement in heat transfer is accompanied by friction power penalty due to a corresponding increase in the friction factor. Therefore, it is essential to determine the effectiveness and usefulness of the roughness geometry in context of heat transfer enhancement and accompanied increased pumping losses. In order to achieve this objective, Webb and Eckert [23] proposed a thermo-hydraulic performance parameter 'η', which evaluates the enhancement in heat transfer of a roughened duct compared to that of the smooth duct for the same pumping power requirement and is defined as,

$$\text{Thermal enhancement factor} = \frac{Nu/Nu_s}{\left(f/f_s\right)^{\frac{1}{3}}}$$

The value of this parameter higher than unity ensures that it is advantageous to use the roughened duct in comparison to smooth duct. The thermo-hydraulic parameter is also used to compare the performance of number of roughness arrangements to decide the best among these. The variation of thermo-hydraulic parameter as a function of Reynolds number for different values of relative gap width (g/e) and investigated in this work has been shown in Fig. 7. For all values of relative gap widths, value of performance parameter is more than unity. Hence the performance of solar air heater roughened with broken 'S' shaped ribs is better as compared to smooth duct.

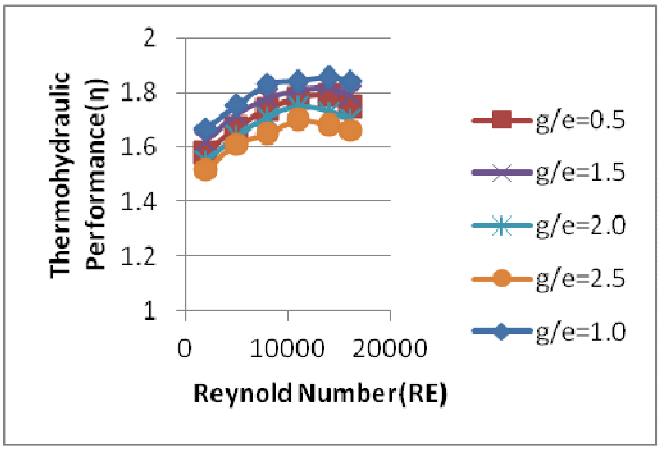



**Figure No. 7 Thermo-hydraulic performance parameter as a function of Reynolds Number for different relative gap width (g/e)**

**Conclusion:**

The Numerical investigations were conducted on solar air heater duct roughened with broken 'S' shaped ribs.. The following conclusions are drawn from the present study:

A 3-dimensional CFD analysis has been carried out to study heat transfer and fluid flow behavior in a rectangular duct of a solar air heater with one roughened wall having circular and broken 'S' rib roughness. The effect of Reynolds number and relative roughness pitch on the heat transfer coefficient and friction factor have been studied. In order to validate the present numerical model, results have been compared with available experimental results under similar flow conditions. CFD Investigation has been carried out in medium Reynolds number flow (Re = 2000–16,000). The following conclusions are drawn from present analysis:

1. The Renormalization-group (RNG) k-ε turbulence model predicted very close results to the experimental results, which yields confidence in the predictions done by CFD analysis in the present study. RNG k-ε turbulence model has been validated for smooth duct and grid independence test has also been conducted to check the variation with increasing number of cells.
2. The roughened duct having broken 'S' shaped rib with relative gap width of 1.0 provides the highest Nusselt number at a Reynolds number of 16000.
3. For rectangular rib the maximum enhancement of average Nusselt number is found to be 2.46 times that of smooth duct for relative gap width of 1.0 at a Reynolds number of 11000.
4. The roughened duct having broken 'S'shaped rib with relative gap width of 1.0 provides the highest friction factor at a Reynolds number of 3500.
5. For broken 'S' shaped rib the maximum enhancement of average friction factor is found to be 3.48 times that of smooth duct for relative gap width of 1.0.

It is found that the thermal hydraulic performance of relative gap width of 1.0 is maximum.

**References**


[1] Sharma AK and Thakur NS. "CFD based Fluid Flow and Heat Transfer Analysis of a V-Shaped Roughened Surface Solar Air Heater". International Journal of Engineering Science and Technology, 2012, 5, 2115-2121.

[2] Kaltschmitt M, Streicher W, Wiese A. Renewable energy: technology, economics and environment. 1st ed. New York: Springer; 2007.

[3] AtulLanjewar, J.L. Bhagoria, R.M. Sarviya, "Experimental study of augmented heat transfer and friction in solar air heater with different orientations of W-Rib roughness Experimental Thermal and Fluid Science 35 (2011) 986–995.

[4] Li X. Green energy: Basic concepts and fundamentals. 1st ed. New York: Springer; 2011.

[5] Maczulak A. Renewable energy: sources and methods. 1st ed. New York: Infobase Publishing; 2011

[6] Foster R, Ghassemi M, Cota A. Solar energy: renewable energy and the environment. New York: CRC Press Taylor & Francis group; 2010.

[7] Kalogirou S. Solar energy engineering: processes and systems. London: Academic Press; 2009.

[8] Yadav AS, Bhagoria JL, Renewable energy sources- An application guide. International Journal of Energy Science 2013; 3(2): 70-90.

[9] Sukhatme SP, Nayak JP. Solar energy. 3rd ed. New Delhi: Tata McGraw Hill; 2011.

[10] J. C. Han, P. R. Chandra, C. R Alexandra, "Heat transfer and friction behaviors in rectangular channels with varying number of ribbed walls" International Journal of Heat and Mass Transfer 46 (2003) 481–495.

[11] Han JC. Heat transfer and friction in channels with two opposite rib-roughened walls. J. Heat Transfer 1984; 106 (4): 774-81.

[12] Bertram RW. Testing and standards for thermal solar collectors, Solar Energy Conversion II (Selected lectures from the 1980 International Symposium on Solar Energy Utilization, London), Edited by A. F. Janzen and R. K. Swartman. New York: Pergamon Press; 1980, pp. 73-91.

[13] Bhushan B, Singh, A review on methodology of artificial roughness used in duct of solar air heaters. Energy 2010; 35: 202–12.

[14] Quaschning V. Understanding renewable energy systems. 3rd ed. London: Earthscan; 2005.

[15] Garg HP, Gupta CL. Flat plate collector experimental studies and design data for India. Proc. ISEC Congress New Delhi 1978; 733-738.

[16] Verma SK, Prasad BN. Investigation for the optimal thermo-hydraulic performance of artificially roughened solar air heaters. Renewable Energy 2000; 20: 19–36.

[17] Han JC, Chandra PR, Lau SC. Local heat/mass transfer distributions around sharp 180 degree turns in two-pass smooth and rib roughened channels. J. Heat Transfer 1988; 110 (February): 91–98.

[18] Han JC, Glicksman LR, Rohsenow WM. 1978. An investigation of heat transfer and friction for rib-roughened surfaces. International Journal of Heat and Mass Transfer 1978; 21(8):1143–56.

[19] Gupta D, Solanki SC, Saini JS. Heat and fluid flow in rectangular solar air heater ducts having transverse rib roughness on absorber plates. Solar Energy 1993; 51(1): 31–7.

[20] Zhang YM, Gu WZ, Han JC. Heat transfer and friction in rectangular channels with ribbed or ribbed-grooved walls. J. Heat Transfer 1994; 116 (1): 58–65.

[21] Park JS, Han JC, Huang Y, Ou S. Heat transfer performance comparisons of five different rectangular channels with parallel angled ribs. International Journal of Heat and Mass Transfer 1992;35(11):2891-903..

[22] Taslim ME, Lengkong. 45 degree staggered rib heat transfer coefficient measurements in a square channel. ASME J. Turbomach. 1998; 120: 571– 580.

[23] Karwa R, Solanki SC, Saini JS. Heat transfer coefficient and friction factor correlations for the transitional flow regime in rib-roughened rectangular ducts. Int J Heat Mass Transfer 1999; 42: 1597–15.

[24] Momin AME, Saini JS, Solanki SC. Heat transfer and friction in solar air heater duct with v-shaped rib roughness on absorber plate. Int J Heat Mass Transfer 2002; 45: 3383–96.

[25] Anil SinghYadav, J.L.Bhagoria, "Heat transfer and fluid flow analysis of solar air heater: A review of CFD approach", Renewable and Sustainable Energy Reviews 23 (2013) 60–79.

[26] Han JC, Zhang YM. High performance heat transfer ducts with parallel broken and V-shaped broken ribs. International Journal of Heat and Mass Transfer 1992;35(2):513-23.

[27] Chaube A, Sahoo PK, Solanki SC. Analysis of heat transfer augmentation and flow characteristics due to rib roughness over absorber plate of a solar air heater. Renewable Energy 2006; 31: 317-31.

[28] Ryu DN, Choi DH, Patel VC. Analysis of turbulent flow in channels roughened by two-dimensional ribs and three-dimensional blocks. Part I: Resistance. International Journal of Heat and Fluid Flow 2007; 28: 1098–1111.

[29] Layek A, Saini JS, Solanki SC. Heat transfer and friction characteristics for artificially roughened ducts with compound turbulators. International Journal of Heat and Mass Transfer 2007; 50: 4845–54.

[30] Kamali R, Binesh AR. The importance of rib shape effects on the local heat transfer and flow friction characteristics of square ducts with ribbed internal Surfaces. International Communications in Heat and Mass Transfer 2008; 35: 1032–1040.

[31] Saini RP, Verma J. Heat transfer and friction factor correlations for a duct having dimple-shaped artificial roughness for solar air heaters. Energy 2008; 33: 1277–87.

[32] Saini SK, Saini RP. Development of correlations for Nusselt number and friction factor for solar air heater with roughened duct having arc-shaped wire as artificial roughness. Solar Energy 2008; 82: 1118–30.

[33] Chaudhary S, Varun, Chauhan MK. Heat transfer and friction factor characteristics using continuous M shape ribs turbulators at different orientation on absorber

plate solar air heater. Int J energy and environment 2012; 3(1):33-48.

[34] Bopche SB, Tandale MS. Experimental investigations on heat transfer and frictional characteristics of a turbulator roughened solar air heater duct. Int J Heat and Mass Transfer 2009; 52: 2834–48.

[35] Lanjewar A, Bhagoria JL, Sarviya RM. Heat transfer and friction in solar air heater duct with W-shaped rib roughness on absorber plate. Energy 2011; 36:4531-41.

[36] Hans VS, Saini RP, Saini JS. Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with multipleV-ribs. Sol Energy 2010;84:898–91

[37] Singh S, Chander S, Saini JS. Heat transfer and friction factor correlations of solar air heater ducts artificially roughened with discrete V-down ribs. Energy 2011; 36: 5053-64.

[38] Launder BE and Spalding DB. Lectures in mathematical models of turbulence. London, England: Academic Press; 1972.