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An Investigation of Heat Transfer and Fluid Flow Analysis of An Artificially Roughness of Solar Air Heater with Combination of Triangular and Pentagon Ribs on The Absorber Plate Based on CFD (Computational Fluid Dynamics)"

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***Abstract* - This article presents the numerical investigation of an artificially roughened solar air heater having combination of triangular and pentagon transverse ribs on the absorber plate by using computational fluid dynamics (CFD). The effects of small diameter of transverse wire rib roughness on heat transfer and fluid flow have been investigated. The input parameters for the analysis are taken as Reynolds number (Re), relative roughness pitches (P/e) and relative roughness height (e/D) are chosen as design variables. A 3-Dimensional CFD simulation is performed using the ANSYS FLUENT 14.5 code with Renormalization-group (RNG) k-ε turbulence model is selected as the most appropriate one. It is apparent that the turbulence created by small diameter of transverse wire ribs result in greater increase in heat transfer over the duct. Due to artificial roughness heat transfer increase as compared to the smooth duct. The present CFD investigation shows the effect of input design parameter on various thermal properties like Nusselt number, average friction factor and thermo hydraulic performance parameter. The condition for optimum performance has been determined in term of heat transfer coefficient. A maximum value of heat transfer has been found to be 34.35154 w/m2k and thermo-hydraulic performance 1.163 for the range of parameters investigated.**

INTRODUCTION

Solar air heater is one of the basic equipment through which solar energy is converted into thermal energy. Solar air heaters, because of their simple designing, are cheap and most widely used as a collection device of solar energy. The main applications of solar air heater are space heating, seasoning of timber, curing of industrial products and these can also be effectively used for curing or drying of concrete or clay building components. A conventional solar air heater generally consists of an absorber plate, a rear plate, insulation below the rear plate, transparent cover on the exposed side, and the air flows between the absorbing plate and rear plate. A solar air heater is simple in design and requires little maintenance. However, the value of the heat transfer coefficient between the absorber plate and air is low and this result in lower efficiency. For this reason, the surfaces are sometime roughened in the air flow passage.

The main applications of solar air heaters are space heating, seasoning of timber, curing of industrial products, and these can also be effectively used for curing or drying of concrete or clay building components. The solar air heater occupies an important place among solar heating system because of minimal use of materials and cost. The thermal efficiency of solar air heaters in comparison of solar water heaters has been found to be generally poor because of their inherently low heat transfer capability between the absorber plate and air flowing in the duct. In order to make the solar air heaters economically viable, their thermal efficiency needs to be improved by enhancing the heat transfer coefficient. There are two basic methods for improving the heat transfer coefficient between the absorber plate and air. The first method involves increasing the area of heat transfer by using corrugated surfaces or extended surfaces called fins without affecting the convective heat transfer coefficient. The second method involves increasing the convective heat transfer by creating turbulence at the heat-transferring surface. This can be achieved by providing artificial roughness on the underside of absorber plate.

Heat transfer enhancement is a subject of considerable interest to researchers as it leads to saving in energy and cost. Because of the rapid increase in energy demand in all over The world, both reducing energy lost related with ineffective use and enhancement of energy in the meaning of heat have become an increasingly significance task for design and operation engineers for many system. In the past few decades numerous researches have been performed on heat transfer enhancement. These researches focused on finding a technique not only increasing heat transfer, but also achieving high efficiency. Achieving higher heat transfer rates through various enhancement techniques can result in substantial energy saving, more compact and less expensive equipment with higher thermal efficiency. Heat transfers enhancement technology has been improved and widely used in heat exchanger application; such as refrigeration, automotives, process industry, chemical industry, etc. One of the widely-used heat transfer enhancement technique is inserting different shaped elements with different geometries in channel flow.

LITRATURE REVIEW

Yadav and Bhagoria [1] performed a numerical investigation is conducted to analyze the two-dimensional incompressible Navier–Stokes flows through the artificially roughened solar air heater for relevant Reynolds number ranges from 3800 to 18000. Twelve different configurations of equilateral triangular sectioned rib (P/e = 7.14–35.71 and e/d = 0.021–0.042) have been used as roughness element. The governing equations are solved with a finite-volume-based numerical method. The commercial finite-volume based CFD code ANSYS FLUENT is used to simulate turbulent airflow through artificially roughened solar air heater. The RNG k–e turbulence model is used to solve the transport equations for turbulent flow energy and dissipation rate.Prasad and Saini [2] developed the relations to; calculate the average friction factor and Stanton- number for artificial roughness of absorber plate by small diameter protrusion wire. They used these relations to compare the effect of height and pitch of roughness element on heat transfer and friction factor with already available experimental data. The friction factor for one side rough duct is determined by assuming that the total shear force in the one side rough duct is approximately equal to combined shear force from three smooth walls in a four sided smooth duct and the shear- force from one rough wall in a four sided rough duct. They used the friction similarity law and heat momentum transfer analogy.saini and Verma [3] performed an experimental setup on fluid flow and heat transfer characteristics of solar air heater duct having dimple-shaped artificial roughness. Authors found maximum value of nusselt number corresponds to relative roughness height (e/D) of 0.0379 and relative roughness pitch (P/e) of 10. Authors also found minimum value of friction factor correspond to relative roughness height (e/D) of 0.0289 and relative pitch (P/e) of 10. Lanjewar, Bhagoria, Sarvaia [4] performed experimental investigations on heat transfer and friction factor characteristics of rectangular duct roughened with W-shaped ribs. Author reported that thermo-hydraulic performance improved with angle of attack of flow and relative roughness height and maxima occurred at angle of attack 60^0.Performed experiments to determine the effect of relative roughness pitch, relative roughness height and wedge angle on the heat transfer and friction factor in a solar air heater roughened duct having wedge shaped rib roughness. Authors found maximum enhancement of Nusselt number up to 2.4 times while the friction factor up to 5.3 times for the range of parameters investigated.Gupta [5] investigated the effect of roughness and operating parameters on thermal as well as on the hydraulic performance of roughened solar air heaters and compared the thermo-hydraulic performance of roughened solar air heaters with that of conventional smooth solar air heaters. The optimum design and operating conditions were determined. On the basis of thermo-hydraulic considerations it was found that the systems operating in a specified range of Reynolds number (3800-18000) showed better thermo-hydraulic performance. Authors reported that the roughened solar air heaters were thermo-hydraulically advantageous for lower Reynolds numbers. Beyond a certain limiting value of Reynolds number, a smooth solar air heater will perform thermo-hydraulically better, although the thermal efficiency of a roughened solar air heater might be more than that of a smooth heater. This limiting Reynolds number was found to lie in the range of 3800-18000.Prasad and Mullick [6]developed a protruding wires on the underside of the absorber plate of an unglazed solar air heater for cereal grains drying to improved the heat transfer characteristics and hence the plate efficiency factor. Investigate on solar air heater with protruding wires in underside of the absorber plate. They found improvement of 9% (from 63% to 72%) in plate efficiency (FP) for Reynolds number of 40,000. The plate efficiency is 44.5% higher in cross corrugated sheet with protruding wire than plane galvanized iron sheet.Karwa, Saini, Solanki [7] studied and found that the artificial roughness in the form of chamfered ribs groove on the absorber plate result in considerable enhancement of heat transfer. This enhancement is, however, accompanied by a substantial increase in the friction factor. It is therefore desirable to select the roughness geometry such that the heat transfer coefficient is maximized while keeping the friction losses at the minimum possible value. Considering the heat transfer and friction characteristics can fulfill this requirement the collector simultaneously.

Lanjewar and Bhagoria [8] performed the study of heat transfer and fluid flow processes in an artificially roughened solar air heater by using computational fluid dynamics (CFD). The effects of small diameter of transverse wire rib roughness on heat transfer and fluid flow have been investigated. The Reynolds number, relative roughness pitches (P/e) and relative roughness height (e/D) are chosen as design variables. A two-dimensional CFD simulation is performed using the ANSYS FLUENT 12.1 code. The Renormalization-group (RNG) keε model is selected as the most appropriate one. Results are validated by comparing with available experimental results.Yadav and Bhagoria [9] performed the study of heat transfer and fluid flow processes in an artificially roughened solar air heater by using computational fluid dynamics (CFD). The effects of small diameter of transverse wire rib roughness on heat transfer and fluid flow have been investigated. The Reynolds number, relative roughness pitches (P/e) and relative roughness height (e/D) are chosen as design variables. A two-dimensional CFD simulation is performed using the ANSYS FLUENT 12.1 code. The Renormalization-group (RNG) k-ε model is selected as the most appropriate one. Results are validated by comparing with available experimental results. It is apparent that the turbulence created by small diameter of transverse wire ribs result in greater increase in heat transfer over the duct.

Verma and Prasad [10] developed of a 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 enhancement of the heat transfer rate; however it is achieved at the cost of the increase in the pressure drop across the surfaces on which the scene elements are mounted. This paper is an attempt to summarize and conclude the investigation involving the use of small height elements and surface protrusions on absorber plate and channel walls as artificial roughness elements of various geometries and its effect on heat transfer and friction factor through experiments. It also summarizes the various correlations which have been developed for Nusselt number (Nu) and Friction factor (f) and reported in the previous investigations. The comparative study has been done to understand the results of these investigations for solar air heaters with different roughness elements on its absorber surface. Yadav and Bhagoria [11]performed of an artificial roughness in the form of repeated ribs on a surface are an effective technique enhances the rate of heat transfer. A numerical investigation on the heat transfer and fluid flow characteristics of fully developed turbulent flow in a rectangular duct having repeated transverse square sectioned rib roughness on the absorber plate has been carried out. The commercial finite-volume CFD code ANSYS FLUENT (ver. 12.1) is used to simulate turbulent airflow through artificially roughened solar air heater. The Navier-Stokes equations and the energy equation are solved in conjunction with a low Reynolds number RNG k-e 3 turbulence model. Twelve different configurations of square sectioned rib (P/e ¼ 7.14 e 35.71 and e/D ¼ 0.021 e 0.042) have been considered. The flow Reynolds number of the duct varied in the range of (3800-18000) most suitable for solar air heater. It has been found that the square sectioned transverse rib roughened duct with P/e ¼ 10.71 and e/D ¼ 0.042 offers the best thermo-hydraulic performance parameter for the investigated range of parameters.

Bopche and Tandale [12] Performed for the thermo-hydraulic performance of solar air heaters with inverted U-shaped ribs on the absorber plate. They concluded that their roughness element is efficient in heat transfer even at lower Reynolds number (Re-

5000). They further concluded that the turbulence is created only in the viscous sub-layer resulting in higher thermo-hydraulic performance than smooth solar air heaters. Yadav and Bhagoria [13] performed a numerical investigation of turbulent flows through a solar air heater roughened with semicircular sectioned transverse rib roughness on the absorber plate. The physical problem was represented mathematically by a set of governing equations, and the transport equations were solved using the finite element method. The numerical results showed that the flow-field, average Nusselt number, and average friction factor are strongly dependent on the relative roughness height. The thermo-hydraulic performance parameter was found to be the maximum for the relative roughness height of 0.042.Yadav and Bhagoria [14] Performed circular sectioned rib roughness on the absorber plate to predict heat transfer and fluid friction behavior of an artificially roughened solar air heater by adopting CFD approach. ANSYS FLUENT 12.1 and RNG k–e turbulence model were employed in their simulation. The maximum average Nusselt number ratio and friction factor ratio are found to be 2.31 and 3.14, respectively for the investigated range of parameters.Yadav and Bhagoria [15]performed a CFD based investigation of turbulent flows through a solar air heater roughened with square sectioned transverse rib roughness. Three different values of rib pitch (P) and rib-height (e) were taken such that the relative roughness pitch (P/e = 14.29) remains constant. The relative roughness height, e/D, varies from 0.021 to 0.06 and Reynolds number, Re, varies from 3800 to 18,000. The results predicted by CFD showed that the average heat transfer, average flow friction and thermo-hydraulic performance parameter were strongly dependent on the relative roughness height. A maximum value of thermo-hydraulic performance parameter was found to be 1.8 for the range of parameters investigated. Chandra [16] investigated the effect with varying number of transverse ribbed walls with the parameters Re¼ 10,000–80,000; P/e¼ 8; e/D_h¼ 0.0625 channel length to the hydraulic ratio (L/D_h)¼ 20 for fully turbulent flow in the square channel. They concluded that one ribbed wall has the heat transfer increase of 2.43–1.78 for Re¼ 12,000– 75,000, with two opposite ribbed walls the increment was 2.64–1.92, with three ribbed walls, the increment of 2.81–2.01 and with four ribbed walls, an increment of 2.99–2.12 which is the maximum when compared to all the types. The maximum increase in the friction factor was found to be 9.50 with four sided ribbed walls and minimum with one ribbed wall of 3.14.They also compared the performance factor {(Str/Stss)/(fr/fss)} of four cases and concluded that, it is highest at 1.78– 1.17 for one wall ribbed surface. Kumar and Saini [17] performed a CFD analysis of fluid flow and heat transfer characteristics of a solar air heaters having arc shaped rib roughness on the absorber plate. The heat transfer and flow analysis of artificially roughened solar air heater were carried out using

3-D model. FLUENT 6.3.26 commercial CFD code was used as a solver. In order to find out the best turbulent model, authors tested four different turbulent models namely shear stress transport keu, standard ke 3, Renormalization group (RNG) ke 3 and realizable ke 3 for smooth solar air heater. Renormalization group (RNG) ke 3 models were employed to simulate the fluid flow and heat transfer. The results of the simulation were successfully validated with experimental results. Overall enhancement ratio with a maximum value of 1.7 was obtained for the roughness geometry corresponding to relative arc angle (a/90) of 0.333 and relative roughness height (e/D) of 0.0426 by adopting CFD approach. Karmare and Tikekar [18] performed CFD investigation of fluid flow and heat transfer in a solar air heater duct with metal grit ribs as roughness elements on the absorber plate. Commercial CFD code FLUENT 6.2.16 was used as a solver. Standard k-e turbulence model was used to simulate turbulent airflow through artificially roughened solar air heater. Circular, triangular and square shape rib grits with the angle of attack of 54^0, 56^0, 58^0, 60^0 and 62^0 were tested for the same Reynolds number. Authors reported that amongst the different shapes and orientations analyzed, the absorber plate of square cross-section rib with 58^0 angle of attack gave the best results. The percentage increase in the heat transfer for 58^0 rib inclination plate over smooth plate was found to be about 30%. In order to validate CFD results, experimental investigations were carried out in the laboratory. Gandhi and Singh [19] performed a numerical investigation to investigate the effect of artificial surface roughness on flow through a rectangular duct having bottom wall roughened with repeated transverse ribs of wedge shaped cross-section. Two dimensional numerical modeling of the duct flow using FLUENT showed reasonably good agreement with the experimental observations except for the friction factor. Numerical results obtained by commercial computational fluid dynamics (CFD) code FLUENT were compared with the experimental results. Sethi and Thakur [20] conducted a CFD study to investigate the heat transfer and friction loss characteristics in a solar air heater having attachments of V-shaped ribs roughness at 60^0 relative to flow direction pointing downstream on underside of the absorber plate. The computations based on the finite volume method with the SIMPLE algorithm were conducted for the airflow. For validating the accuracy of numerical solutions, the computations of fully developed turbulent flow forced convection in a smooth rectangular duct was carried out to compare with the exact solution for the Nusselt number and friction factor.

All above paper has performed in solar air heater in the different type of ribs like square, triangular, semicircular, circular, V-shaped, W-shaped, Dimple shaped, Chamfered, transverse wedge shaped, metal grit ribs, inclined ribs, multi V-shaped ribs etc; in different type of pitch, height and different in Reynolds number. Some are performed in experimental investigation and some are in CFD analysis in different type of CFD code ANSYS FLUENT like 12.1, 14.1 etc; which have different type of heat transfer and thermo-hydraulic performance in result.

In this article we performed a CFD analysis in the CFD code ANSYS FLUENT (ver.14.5) in the solar air heater with fixed value of height and pitch is in different value (10,15,20,25 mm) with different Reynolds number (8000,12000,15000).

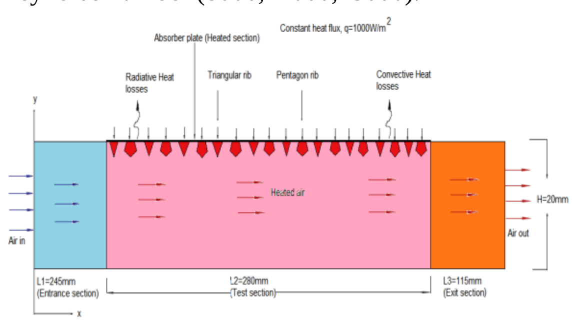

Fig. 1 Computational domain for solar air heater with combination of pentagon and triangular ribs

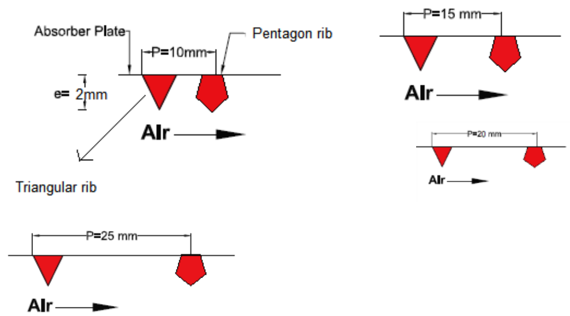

Fig.2 Different configurations on SAH of pentagon and triangular rib roughness

Table 1. Range of operating parameter for CFD:-

Operating parameters	Range
Uniform heat flux, ‘q’	1000 w/m^2
Reynolds number, ‘Re’	8000,1200,15000 (3 values)
Prandtl number, 'Pr’	0.71
Relative roughness pitch, ‘P/e’	5,7.5,10,12.5 (4 values)
Relative roughness height, ‘e/D’	0.060
Duct aspect ratio, ‘W/H’	5

Table 2.Thermo-physical properties of air and absorber plate for CFD analysis:-

Properties	Working fluid (air)	Absorber plate (aluminum)
Density, ‘*p*’ (kg/m^3)	1.117	2719
Specific heat, ‘Cp’ (Jkg^{-1}K^{-1})	1007	871
Viscosity, ‘l’ (Nsm^{-2})	1.7894e $^{-0.5}$	-
Thermal conductivity, ‘k’(Wm^{-1}K^{-1})	0.0262	202.4

Table 3. Geometric parameters of Solar air Heater with ribs (combination of triangular and pentagon ribs) geometry combination.

L_1(mm)	L_2(mm)	L_3(mm)	W(mm)	H(mm)	D(mm)	e(mm)	P(mm)
245	280	115	100	20	33.33	2	10, 15, 20, 25

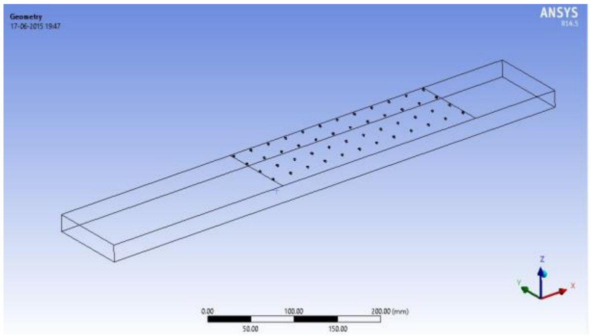

Fig.3 3-D domain SAH DUCT with combination of triangular and pentagon ribs on the absorber plate with P = 25mm

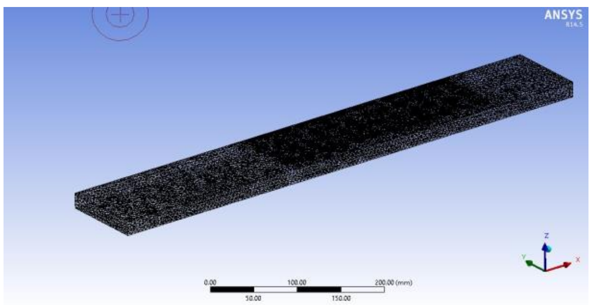

Fig.4 Plate-Triangular -Pentagon-e=2- , P=25-mesh1

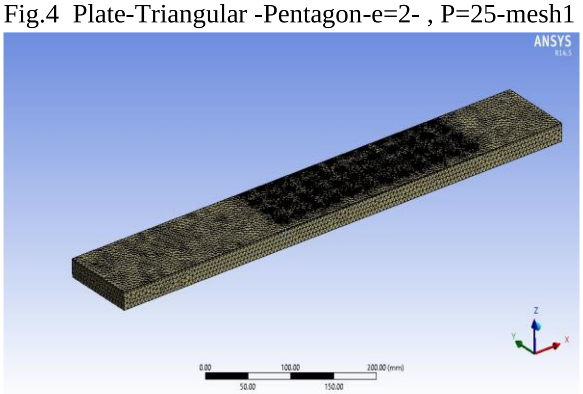

Fig.5 Plate-Triangular -Pentagon-e=2- , P=25-mesh2

Table4

Rib pitch (P)mm	No. of nodes	No. of element
10	71932	185110
15	52315	136258
20	38379	101371
25	32573	87532

RESULT AND DISCUSSION

This chapter presents the predicated airflow velocity, pressure and temperature profiles during forced-air flow over rib geometry in the duct which were considered in this research work. The CFD analysis has been performed for combination of triangular and pentagon ribs on the absorber plate of SAH and result has been compared with the case of smooth duct operating under the same condition to evaluate the enhancement in heat transfer.

The data collected using ANSYS FLUENT 14.5 included the temperature distribution, pressure distribution and airflow velocity at all node points in the model duct. We can see the following result:-

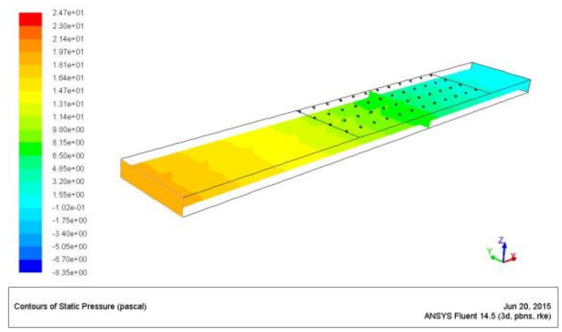

Fig. 6 Plate-triangular-pentagon-e=2-p=25-Re-15000-pressure of the absorber plate

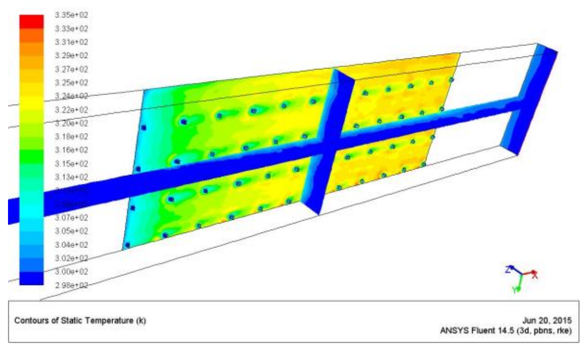

Fig. 7 Plate-triangular-pentagon-e=2-p=25-Re-15000-pressure-temperature of the absorber plate

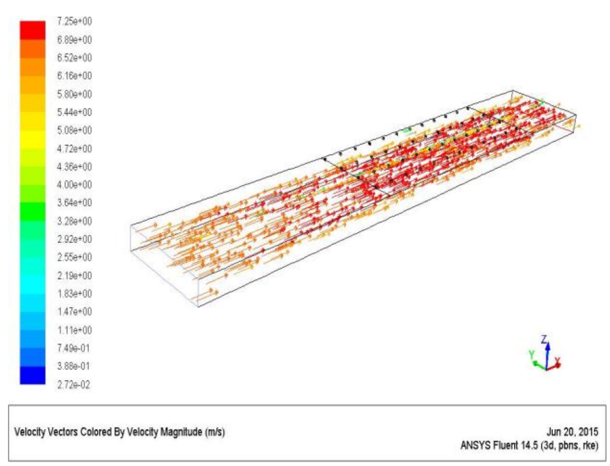

Fig. 8. Plate-triangular-pentagon-e=2-p=25-Re-15000-velocity-vector of the absorber plate

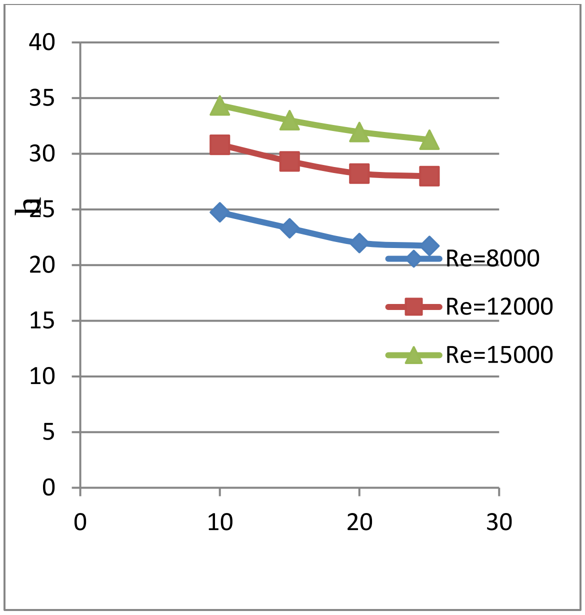

Fig. 9.Comparison of h between P with Re

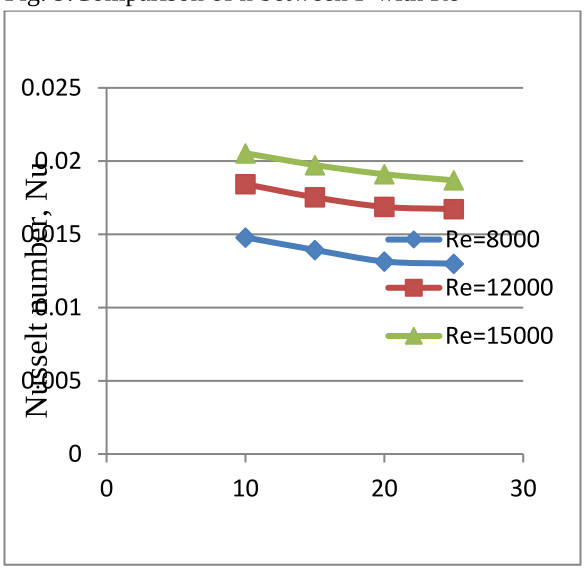

Fig. 10Comparison of Nu between P with Re

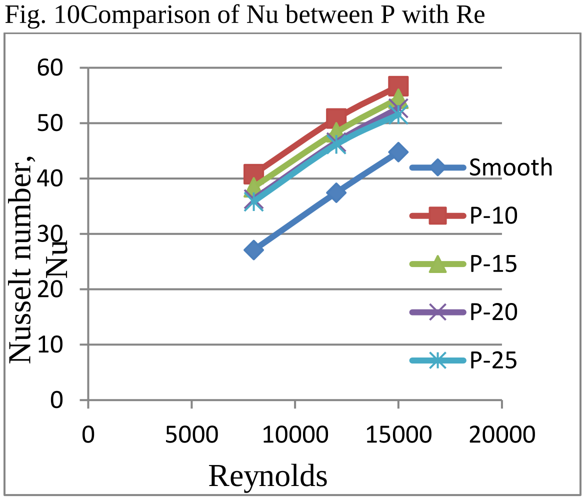

Fig. 11Comparison of Nu between Re with Pitch

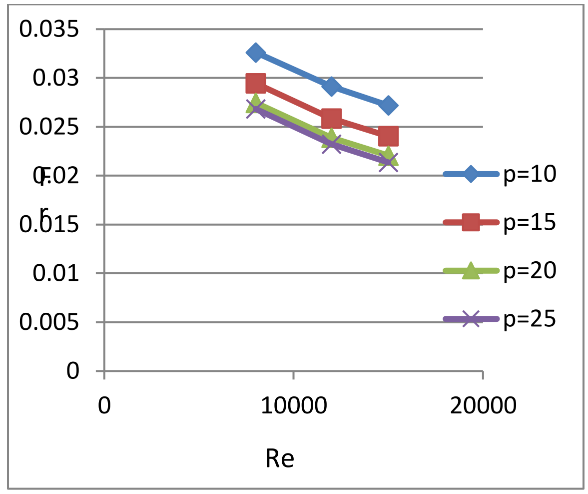

Fig. 12Comparison of Fr between Re with Pitch

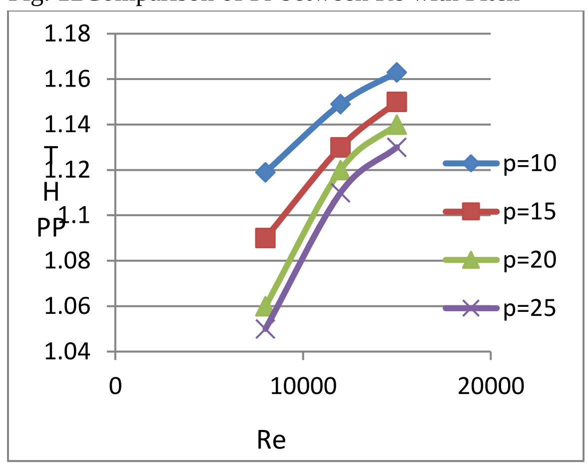

Fig. 13Comparison of THPP between Re with Pitch

REFERENCES

[1] Yadav A.S, Bhagoria J.L, A CFD based thermo-hydraulic performance analysis of an artificially roughened solar air heater having equilateral triangular sectioned rib roughness on the absorber plate. Heat and mass transfer 70 1016–1039 (2013).

[2] Prasad K and Saini J.S, A experimental investigation in transverse ribs on the absorber plate by assuming that the total shear force, Heat and mass transfer 40 976-993 (1997).

[3] Saini R.P, Verma J, An experimental setup on the fluid flow and heat transfer of solar air heater duct having dimple –shaped artificial roughness, Energy 33 (2008) 1277–1287.

[4] Lanjewar A, Bhagoria J.L, Sarvaiya R.M "Augmentation of heat transfer coefficient by

using 90^0 broken transverse ribs on absorber plate of solar air heater". Renewable Energy 36 (2011) 4531–4541 (2005).

[5] Gupta D, Investigations on fluid flow and heat transfer in solar air heaters with roughened absorbers,Ph.D.thesis, University of Roorkee, India, 1994.

[6] Prasad K, Mullick S.C, Heat transfer characteristics of a solar air heater used for drying purposes,Appl. Energy 13 (2) (1983) 83–93.

[7] Karwa R, Solanki S.C, Saini S.C, Thermo-hydraulic performance of solar air heaters having integral chamfered rib roughness on absorber plates.26 (2001) 161–176 (2001).

[8] Bhagoriya J.L, Lanjewar A,Heat transfer coefficient and friction factor correlations for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate, Renewable Energy 25 (2002) 341– 369.

[9] Yadav A.S, Bhagoria J.L, A CFD based heat transfer and fluid flow analysis of a solar air heater provided with circular transverse wire rib roughness on the absorber plate, Energy 55 (2013)1127–1142.

[10] Verma S.K, Prasad B.N, Investigation for the optimal thermo-hydraulic performance of artificially roughened solar air heaters, Renewable Energy 20 (2000) 19–36

[11] Yadav A.S, Bhagoria J.L, Modeling and simulation of turbulent flows through a solar air heater having square sectioned transverse rib roughness on the absorber plate, Sci. World J. 2013 (2013)

[12] Bopche S.B, Tandale M.S, Experimental investigations on heat transfer and frictional characteristics of a turbulator roughened solar air heater duct, Int. J. Heat Mass Transfer 52 (2009) 2834–2848

[13] Yadav A.S, Bhagoria J.L, A CFD based heat transfer and fluid flow analysis of a conventional solar air heater, J. Eng. Sci. Manage. Educ. 6 (2) (2013) 138–147

[14] Yadav A.S, Bhagoria J.L, Numerical investigation of flow through an artificially roughened solar air heater, Int. J. Ambient Energy, 2013

[15] Yadav A.S, Bhagoria J.L, A numerical investigation of turbulent flows through an artificially roughened solar air heater, Numer. Heat Transfer A, 2013

[16] Yadav A.S, Bhagoria J.L, Heat transfer and fluid flow analysis of an artificially roughened solar air heater: a CFD based investigation, Front. Energy, 2013

[17] Kumar S, Saini R.P, CFD based performance analysis of a solar air heater duct provided with artificial roughness, Renewable Energy 34 (2009) 1285–1291

[18] Karmare S.V, Tikekar A.N. Heat transfer and friction factor correlation for artificially roughened duct with metal grit ribs, Int. J. Heat Mass Transfer 50 (2007) 4342–4351

[19] Aharwal K.R, Gandhi B.K, Saini R.P, Experimental investigation on heat transfer enhancement to a gap in an inclined continuous rib arrangement in a rectangular duct of solar air heater, Renewable Energy 33 (2008) 585–596

[20] Sethi M, Varun N.S, Thakur, Correlations for solar air heater duct with dimpled shape roughness elements on absorber plate, Sol. Energy 86 (2012) 2852–2861