CFD Analysis of Solar Air Heater for Enhancement of Heat Transfer through W Shaped RIB Roughness

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Abstract: A 3-dimensional CFD analysis has been carried out of solar air heater to study heat transfer and fluid flow behavior in a rectangular duct of a solar air heater with one roughened wall having combination of circular and square transverse wire rib roughness. The effect of Reynolds number, roughness height, roughness pitch, relative roughness pitch and relative roughness height 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. 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 W shaped wire rib roughness. a numerical analysis of convective heat transfer enhancement in solar air heaters with artificially roughened absorber is presented in this project. CFD numerical simulations were carried out to analyze the flow and heat transfer in the air duct of a solar air heater provided with transverse ribs (W shaped).W-shaped roughness gives better heat transfer rate as compare to the V rib roughness because of more secondary flow development in W rib under similar operating conditions. the maximum value of Nusselt number for W-shaped roughness is obtained with the relative roughness pitch (P/e) of 10 beyond that it starts decreasing i.e. at P/e = 12. The maximum increment in Nusselt number for W-shaped roughness is found to be 2.34 times as compare to the smooth surface at Re = 14000.The maximum increment in Nusselt number is found to be 1.15 times as compare to the V rib roughness at Re = 14000.

Keywords: *CFD Analysis, Absorber plate, Enhancement Factor, Reynolds's No., Nusselt No*

I. INTRODUCTION

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. India is blessed with an abundance of sunlight, water and biomass. Vigorous efforts during the past two decades are now bearing fruit as people in all works of life are more aware of the benefits of renewable energy, especially decentralized energy where required in villages and in urban or semi-urban centers. India has the world's largest programmed for renewable energy. Government created the Department of Non-conventional Energy Sources (DNES) in 1982. Energy is defined as the ability or the capacity to do work. Energy is the basic ingredient to sustain life and development. Work means moving or lifting something, warming or lighting something. There are many sources of energy that help to run the various machines invented by man. There has been an enormous increase in the demand for energy since the middle of the last century as a result of industrial development and population growth. World population grew 3.2 times between 1850 and 1970, per capita use of industrial energy increased about twenty fold, and total world use of industrial and traditional energy forms combined increased more than twelve fold.

II. LITERATURE SURVEY

D. Jansangsuk, C. Khanoknaiyakarn and P. Promvonge,[1991] The exploration work introduces a experiment consider on heat transfer and weight drop attributes in a rectangular channel fitted with occasional triangular v-design ribs. The ribs are tried for pointing downstream (v-down) to the stream. The channel has an angle proportion (width to tallness proportion), AR = 10 what's more, tallness, H = 30 mm; the rib-to-channel stature, e/H = 0.1, 0.2, and 0.3; the rib pitch to channel tallness, PR=P/H = 3 and 4; the assault point (α) of 30° in respect to the stream bearing. The analysis has been directed by differing wind stream speed keeping in mind the end goal to change Reynolds number range from 5000 to 20,000. The upper plate of channel is consistently heated as a steady heat motion while the entire test segment is secured with protection to lessen heat misfortune to environment. These limit conditions compare intently to those established in sun oriented air heaters. The exploratory outcomes demonstrate a noteworthy impact of the nearness of the ribs on the heat transfer rate and weight drop over the plain channel. The deliberate information demonstrates that the triangular v-sort rib with e/H = 0.3 and PR =3 yields higher heat transfer rate regarding Nusselt number, Nu, and the weight drop as grinding factor, f, than the others and furthermore substantially higher than the smooth divider channel.

N. Depaiwa, T. Chompookham and P. Promvonge, [1993] The constrained convection heat transfer and grinding loss behaviors for turbulent wind current through a consistent heat transition channel sun oriented air heater with rectangular winglet vortex generator (WVG) are tentatively explored in this work. The rectangular winglet sets are considered with two unique game plans by pointing upstream (PU) and pointing downstream (PD) of the stream. Ten sets of the WVGs with different assault edges (α) of 60°, 45° and 30° are mounted on the test pipe entrance divider to make longitudinal vortex streams over the tried channel. Estimations are done for the rectangular channel air heater of perspective proportion, AR = 10 and tallness, H = 30 mm with the WVG stature, b/H = 0.4 and a transverse pitch proportion, P/H = 1. The stream rate is as far as Reynolds numbers in light of the delta water driven distance across of the channel extending from 5000 to 23,000. The test comes about demonstrate that the sun based air heater channel with rectangular WVG gives essentially higher heat transfer rate and grinding loss than the smooth divider channel. The utilization of bigger assault edge esteem prompts higher heat transfer rate and contact loss than that of lower one. The PD-WVGs performs higher heat transfer rate and grinding loss than the PU one for comparable working conditions. In examination, the biggest assault point ($\alpha = 60°$) of the PD-WVGs yields the most astounding increment in Nusselt number and grating element while the least assault edge ($\alpha = 30°$) of the PU-WVGs demonstrates the best thermal execution.

Hequan Wu, [1995] Summary form only given. In the start of the second decade of this century, the request on broadband, portable and universal application keeps on expanding. The extent of number of 3G endorsers of aggregate versatile supporters is 7.5% up to April 2011, and 49.5% in new expanded portable endorsers amid Jan to Apr 2011 in China. Worldwide portable information activity in 2010 (237 PB/month) was more than three times more prominent than the aggregate worldwide Internet movement in 2000 (75 PB/month). Worldwide portable information movement initially surpassed voice in December 2009 and 1.5 times voice in Q2'2010. Web of Things and omnipresent system applications will likewise disturb request on transfer speed .For instance, During the Shanghai World Expo 2010, 10,000 surveillance cameras were introduced on transports, trucks, and crisis vehicles. At the point when live observing is required, video is transmitted over the portable system at 2 outlines for each second. In the event that each edge is 0.5 MB, at that point a hour of this video creates 3.6 GB. On the off chance that half of these vehicles transmitted 2 minutes of video through the span of a day, this would create 18 Peta-bytes of versatile information movement of a month, progressively that aggregate worldwide portable information activity in 2007. The innovation advance starts to experience bottleneck regardless of the idealistic market estimates. System advancement confronted to a few difficulties, for instance, versatility, omnipresent, control utilization, security, Quality of Service, administration, and so on.

C. S. Woei, C. K. Feng, W. Huiru, H. C. Chin and K. J. Ken ,[2002] This research work presents the consequences of an arrangement of numerical and exploratory investigations for stream and heat transfer in a spiral channel roughened by skew ribs more than two inverse endwalls. The trial Nusselt number (Nu) conveyances, weight drop coefficients (f) and thermal execution factors (η) for the winding ribbed channel are analyzed alongside the stream structures decided from the CFD investigation. The correlations of Heat Transfer Enhancement (HTE) proportions measured from the ribbed winding channel with other passive sorts of HTE gadgets affirm the positive HTE exhibitions for the winding divert with the in-line skew ribs. An ensuing plan and item improvement for the fluid cooling unit utilizing the ribbed winding channel is depicted with the weight drops and thermal resistances exhibited. This investigation affirms the accessibility of the improved fluid cooling execution utilizing the winding ribbed channel for the electronic chipset(s) with higher power densities.

III. PROBLEM IDENTIFICATION AND RESEARCH OBJECTIVES

1. To make solar air heater more efficient there is in need of increase in heat transfer capability in SAH duct which can be done by creating turbulence in a duct by introducing artificial roughness geometry in it.
2. All above paper has performed in solar air heater in the different type of ribs like square, triangular, semicircular, circular, V-shaped, Dimple shaped, Chamfered, transverse wedge shaped, metal grit ribs, inclined ribs, multi V-shaped ribs etc.
3. 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.

The Objectives is as follows:

1. The application of artificial roughness geometry (in different shapes) has been recommended to enhance the heat transfer coefficient by several investigators.
2. Optimum geometry for heat enhancement study of heat transfer and fluid flow behavior in a rectangular duct for heat transfer and fluid flow.
3. To evaluate the effect of Reynolds number, roughness height, roughness pitch relative roughness pitch and the heat transfer coefficient and friction factor can be evaluated.
4. Validation of results of previous studies in the present numerical models available experimental results under similar flow conditions to results of CFD analysis.
5. Geometry of plate and its effect on heat transfer rate and thermal resistance.

IV. METHODOLOGY

The steps that should be followed for solving a numerical problem are as follows

Mathematical model:-The starting point of the any numerical problem is to define the mathematical model, i.e. set of partial differential equations and boundary conditions that represents your computational analysis and depending upon the the application of the problem one should select proper governing equation for solving the problem.

Discretization method:-After selecting the mathematical model, it is necessary to choose a suitable discretization method, i.e. a method of approximating the differential equations by a system of algebraic equations for the variable at some set of discrete location in space and time. There are many approaches, but the most important of which are

1. Finite Difference Method:
It describes the unknown Φ of flow problem by means of point sample at node points of grid. For this Truncated Taylor Series is used.

2. Finite Element Method:
It uses simple piecewise function (Exa. Linear or quadratic) to describe unknown flow variable Φ. Residual is defined to measure the errors and this residual or errors is minimized by multiplying it by weighing function and integrating as a result we get set of algebraic equation for unknown coefficient of

approximating function. It is mainly used for structural analysis.

3. Finite Volume Method:
It is developed as special finite difference formulation. Following CFD Codes like FLUENT, PHOENICS, FLOW-3D and STAR-CD uses FVM. It consists of integration of governing equations of fluid flow over all control volume of solution domain and discretisation involves substitution of finite difference approximation representing flow properties such as convection, diffusion. This converts it in to algebraic equation and solution of algebraic equation is by iterative method.

Turbulent flows are characterized by fluctuating velocity fields. These fluctuations mix transported quantities such as momentum, energy, and species concentration, and cause the transported quantities to fluctuate as well. Since these fluctuations can be of small scale and high frequency, they are too computationally expensive to simulate directly in practical engineering calculations. Instead, the instantaneous (exact) governing equations can be time-averaged, ensemble-averaged, or otherwise manipulated to remove the small scales, resulting in a modified set of equations that are computationally less expensive to solve. However, the modified equations contain additional unknown variables, and turbulence models are needed to determine these variables in terms of known quantities.

For selecting appropriate model for CFD analysis of roughened solar air heater, Yadav et al. [12] have carried out validation of various turbulence models such as Standard k-model, Renormalization-group k-model, Realizable k-model, Standard k-model and Shear Stress Transport (SST) k model by comparing the Nusselt number predicted using these turbulence models with Dittus–Boelter [13] and Blasius correlations [14] for smooth duct . The variation of the Nusselt number with Reynolds number of different turbulence models is shown in Fig. 7. They observed that the results obtained by Renormalization-group (RNG) k-ε model shows 72.58% absolute percentage deviation in predicted values and the values calculated from Dittus–Boelter correlations. The results generated from Realizable k-model and Standard k-model are under predict, where as that obtained from Standard k-model and SST k-model are over predicted. Since the results obtained by Renormalization-group(RNG) k- (turbulence model are in good agreement with the Dittus–Boelter and Blasius correlation results, this model was selected for the CFD analysis of a solar air heater.

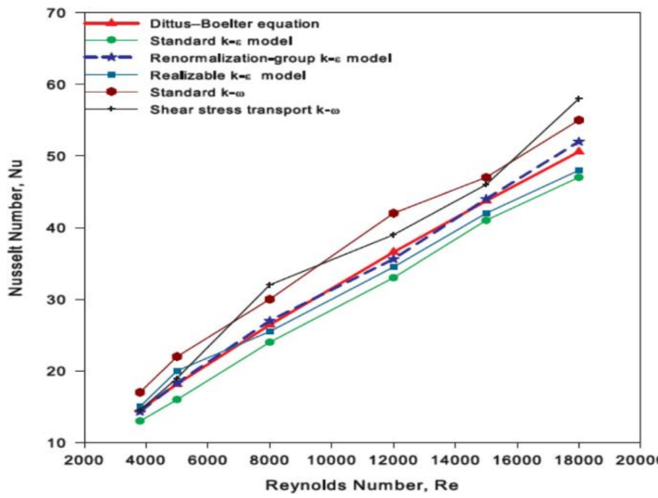

Figure 1: Performance evaluation of turbulent model

V. RESULT AND ANALYSIS

In order to validate the set up used during the analysis, computational results obtained is compared with the data obtained theoretically. As in present study the numerical data obtained for heat transfer characteristics of solar air heater of smooth surface has been compared with theoretical values obtained by using Dittus-Boelter equation for nusselt number.

$$Nu_s = 0.024\ Re^{0.8}\ Pr^{0.4}$$

The above value of nusselt number gives the theoretical value of nusselt number for the smooth surface of solar air heater duct. The value of friction factor and nusselt number obtained from the CFD analysis where compared with the values obtained from correlation of the Dittus-Boelter equation for the nusselt number and modified Blasius equation for the friction factor. Modified Blasius equation

$$f_s = 0.085(Re)^{-0.25}$$

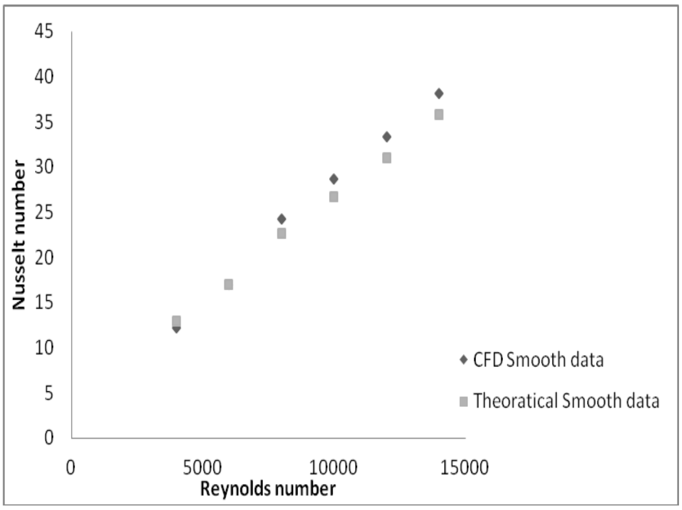

Figure 2: Comparison of computational and formulated value of Nusselt no. vs Reynolds no. for smooth plate

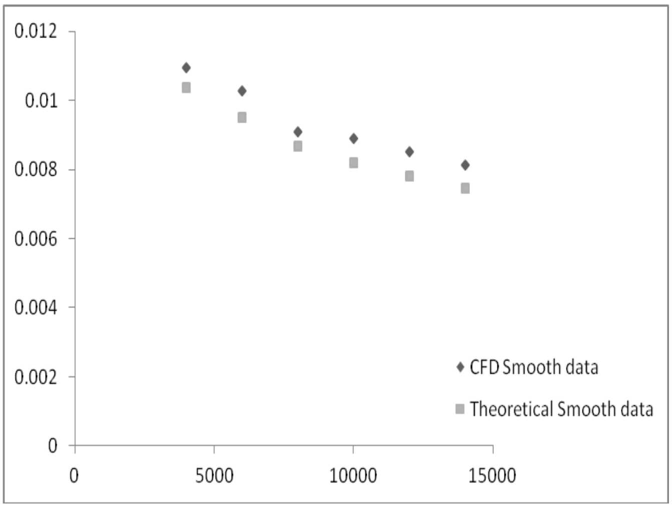

Figure 3: Comparison of computational and formulated value of Friction factor Vs Reynolds no. for smooth plate

From the above graphical representation in Figure 2 and Figure 3 it is clear that the numerical analysis using CFD have a better agreement with the theoretical values obtained from the correlation of the Dittus-Boelter equation for the Nusselt number and modified Blasius equation for the friction factor. The variation occurs in both the values lies in between ±10 to ±15 % which is in considerable limit.

Table 1: Observation table for smooth surface

Re	Nu	F	Nus	Fs
4000	12.21401	0.009424	12.9124	0.010377
6000	16.91603	0.010285	16.9863	0.009496
8000	24.22077	0.009099	22.58985	0.00866
10000	28.6598	0.008912	26.71556	0.008203
12000	33.28073	0.085	30.93558	0.007824
14000	38.18756	0.008115	35.774	0.007467

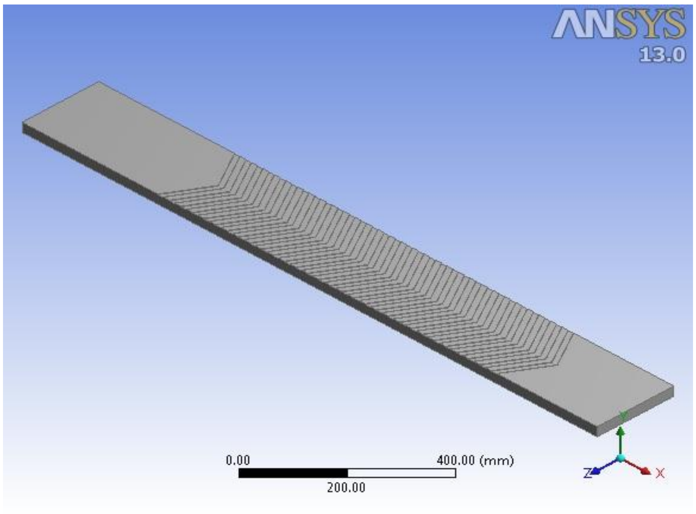

Figure 3: Computational domain of V rib roughness

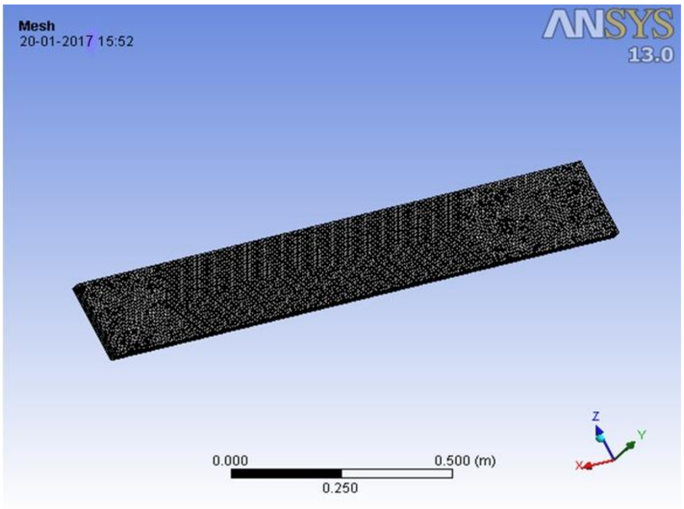

Figure 4: Meshing of Computational Domain

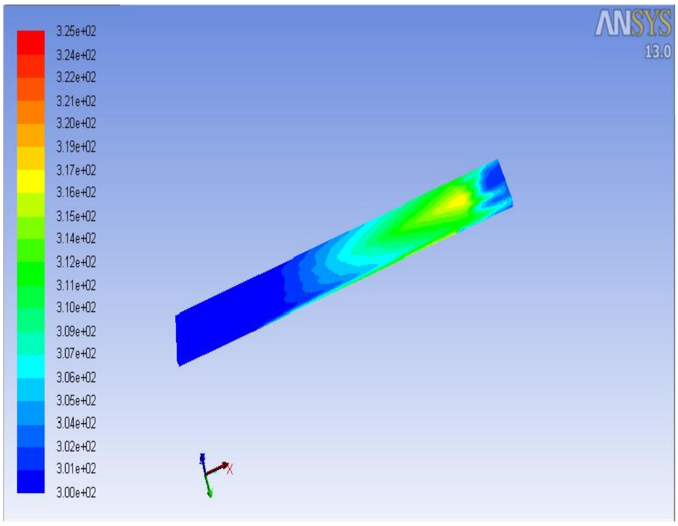

Figure 5: Temperature contour of computational analysis of V RIB

By the computational analysis of the roughened solar air heater duct through CFD following data has been generated with the V shaped roughness geometry. The parameters used during investigation of V rib roughness are shown in Table 2. From the results it is observed that by using V rib roughness the Nusselt number increases 2.22 times as compare to the smooth duct. The enhancement in Nusselt number is shown in Fig. 5.

Table 2: Operating parameters and range for V rib roughness

PARAMETERS	RANGE
Width of duct (W)	200mm
Height of duct (H)	25mm
Hydraulic diameter (Dh)	44.44mm
Duct aspect ratio (W/H)	8
Rib height (e)	2 mm
Relative roughness pitch (P/e)	10
Angle of attack (α)	60^{o}
Range of Reynolds number	4000-14000

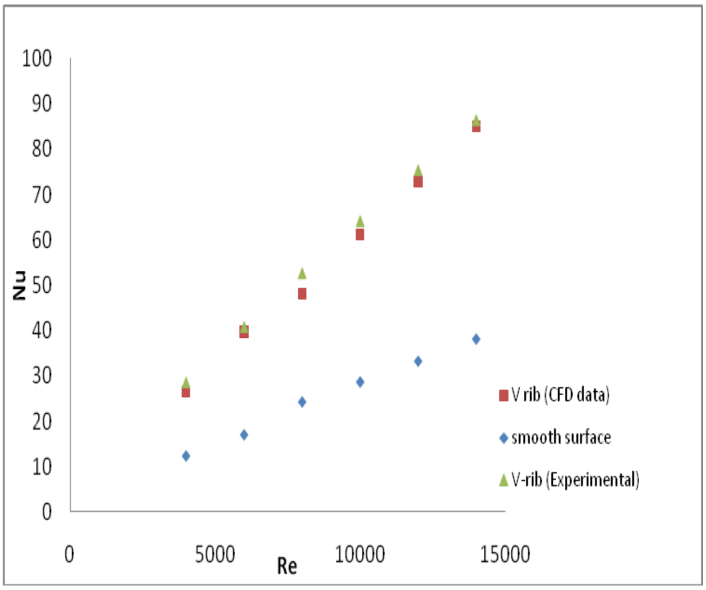

Figure 6: Variation of Nusselt number against Reynolds number for V-rib roughness

Table 3: Observation table for the V-plate having P/e=10

Ti	To	Tf	Tp	Dh	Re	v	M	Q	h	Nu
300	316.99	308.495	350.21	0.044	4000	1.163636	0.007127	121.87099	14.60757	26.43971
300	315.12	307.56	344.72	0.044	6000	1.745455	0.010691	162.68593	21.88993	39.62077
300	311.32	305.66	336.19	0.044	8000	2.327273	0.014255	162.39901	26.59663	48.1399
300	308.78	304.39	327.7	0.044	10000	2.909091	0.017818	157.44957	33.77297	61.12907
300	307.34	303.67	323.31	0.044	12000	3.490909	0.021382	157.95169	40.21173	72.78324
300	306.45	303.225	320.45	0.044	14000	4.072727	0.024945	161.93276	47.00515	85.07933

The numerical analysis of V rib roughness has been studied under the same operating conditions and parameters in order to analyse the enhancement of heat transfer characterisatics and fluid flow of present roughness i.e. W-shaped rib roughness. The enhancement in Nusselt number has been observed as compare to the smooth surface of solar air heater. From the literature review it has been observed that by increasing the inclination of geometry enhance the number of secondary flows inside the duct of solar air heater which increase the hear transfer coefficient of flowing air. Hence a W-shaped rib roughness geometry has been analysed with different relative roughness pitch during present study.

CONCLUSIONS

The present CFD based study carried out by using W-shaped roughened solar air heater for analyzing fluid flow and heat transfer characteristics and it also shows that the CFD results found in agreement with experimental results. As we increase the Reynolds number the Boundary layer thickness decreases which increase the convective heat transfer between the absorbing plate and the air by decrease the convective resistance it results increase in Nusselt number. The following conclusion has been made to for present analysis

1. Multi inclination geometry increases the heat transfer characteristics of solar air heater.
2. W-shaped roughness gives better heat transfer rate as compare to the V rib roughness because of more secondary flow development in W rib under similar operating conditions.
3. The maximum value of Nusselt number for W-shaped roughness is obtained with the relative roughness pitch (P/e) of 10 beyond that it starts decreasing i.e. at P/e = 12.
4. The maximum increment in Nusselt number for W-shaped roughness is found to be 2.34 times as compare to the smooth surface at Re = 14000.
5. The maximum increment in Nusselt number is found to be 1.15 times as compare to the V rib roughness at Re = 14000.

Still there is a scope of increasing the heat transfer and fluid flow characteristics of solar air heater by providing artificial roughness on the rectangular duct. As explained and discussed the effect of roughness height and relative roughness pitch on the heat transfer characteristics we can analyse more parameters by using CFD analysis. In order to validate the present numerical study, the results have been compared with the earlier reported experimental results under similar flow conditions. Only few 3-D analyses has been done so far to analyse the different artificial roughness, hence still there is an scope of analysing different geometries with different geometrical parameters.

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