A CFD (Computational Fluid Dynamics) Based Heat Transfer and Fluid Flow Analysis of Solar Air Heater Provided with Combination of Circular and Square Section Transverse Rib Roughness on the Absorber Plate

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***Abstract* - 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 circular and square transverse wire rib roughness on heat transfer and fluid flow have been investigated. The Reynolds number, relative roughness pitch (P/e) and relative roughness height (e/D) are chosen as design variables. A 3-D CFD simulation is performed using the ANSYS FLUENT 14.5 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. However, the use of artificial roughness results in higher friction losses. The present CFD investigation clearly demonstrates that the average Nusselt number and average friction factor increase with increase in the relative roughness height. The condition for optimum performance has been determined in term of thermal enhancement factor1.39. A maximum value of heat transfer coefficient has been found to be 31.6467 for the range of parameters investigated.**

1.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 systems. 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 exchanger application, such as refrigeration, automotive, process 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 industry, chemical industry, etc. One of the widely used heat transfer enhancement technique is inserting different shaped elements with different geometries in channel flow.

2. LITRATURE REVIEW

Yadav and Bhagoria [1] 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.
Yadav and Bhagoria [2] 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.

Yadav and Thapak[3] Solar air heater is the cheapest and extensively used solar energy collection device for drying of agriculture products ,space heating, seasoning of timber and curing of industrial products. The use of an artificial roughness on a surface is an effective technique to enhance the rate of heat transfer to fluid flow in the duct of a solar air heater. Use of artificial roughness in solar air heater has been topic in research for the last thirty years. The investigate the relative performance of different types of artificially roughened solar air heater. The objective of this article is toper form such a study. In this article twenty known different shape sand orientations of roughness elements are considered for comparative analysis. In order to obtain the results numerically, codes are developed in MATLAB-7.

Lanjewar, Bhagoriya, Sarvaiya[4] Carried out an 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 600.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.

Yadav and Bhagoria [5] 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 [6] 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 was 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 Bhagoriya [7] 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.

Yadav and Bhagoriya [8] In this article, 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

Operating parameters	Range
Uniform heat flux, ‘q’	1000 w/m^2
Reynolds number, ‘Re’	5000, 8000, 10000 (3 values)
Prandtl number, ‘Pr’	0.71
Relative roughness pitch, ‘P/e’	20,13.33,10,8,6.66,5.71,5 (7 values)
Relative roughness height, ‘e/D’	0.015,0.0225,0.030,0.075,0.045, 0.0525,0.060 (7 values)
Duct aspect ratio, ‘W/H’	5

roughened solar air heater. The RNG k–e turbulence model is used to solve the transport equations for turbulent flow energy and dissipation rate.

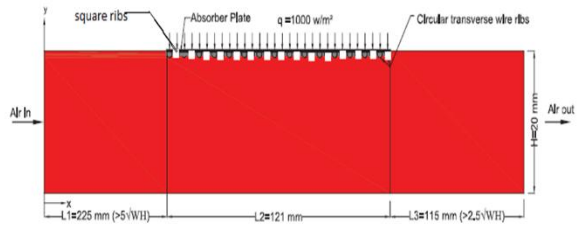

Fig.no.1 Computational domain for solar air heater with combination of Square and Circular ribs

Table 1 Range of operating parameter for CFD

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)
225	121	115	100	20	33.33	.5,.75,1,1.25,1.5,1.75,2	10

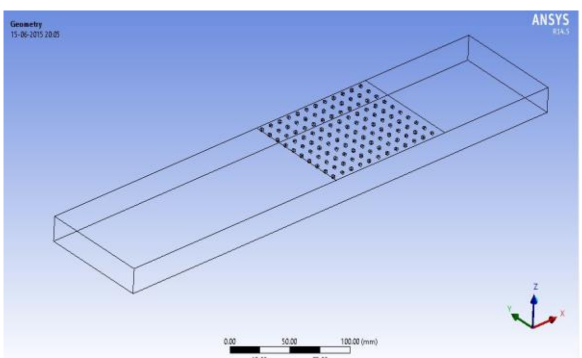

Fig.2-3-D domain SAH DUCT with combination of circular and square rib with e =2mm

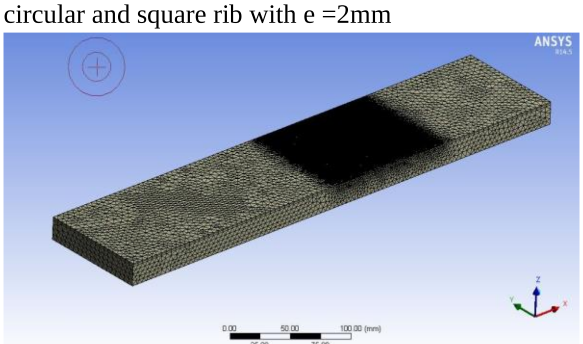

Fig.3- Plate-square-circular-p10-e-2.00-mesh

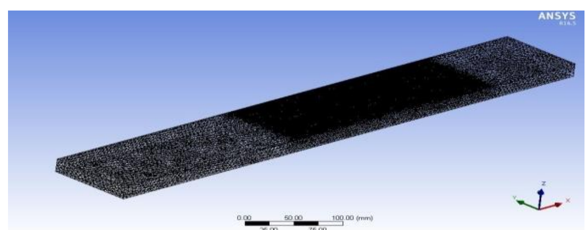

Fig.4- Mesh model 2 of SAH of e=2mm

Table 4

Rib height (e)	No. of nodes	No. of element
0.5	115183	300267
0.75	110008	287502
1.00	107380	281559
1.25	107420	282571
1.50	107294	281270
1.75	109047	286813
2.00	112875	299284

3.RESULTS

Till date lots of CFD analysis has been carried out to enhance the heat transfer and fluid flowing of SAH. My objective is to do CFD analysis using the artificial

roughness geometry combination of circular and square ribs with e = 0.5-2mm, and pitch, P = 10mm under side of in the rectangular duct of a SAH to enhance the heat transfer and fluid flowing inside it.
In this analysis, a 3-D computational roughened SAH is made, which is similar to the computational domain of Yadav and Bhagoriya. The computational domain is simply the physical region having the dimensions of length 461mm, height 20mm and width 100mm. The computational domain is a simple rectangle of length 461 mm and consisted of three sections, namely, entrance section (L1 = 225 mm), test section (L2 = 121 mm) and exit section (L3 = 115 mm). In the present numerical work, 3-D equilateral circular sectioned transverse ribs have been considered as roughness element. The equilateral circular sectioned transverse ribs are considered on the underside of the top absorber plate while other sides are considered as smooth surfaces. Rib height is taken in the range of 0.5-2mm.

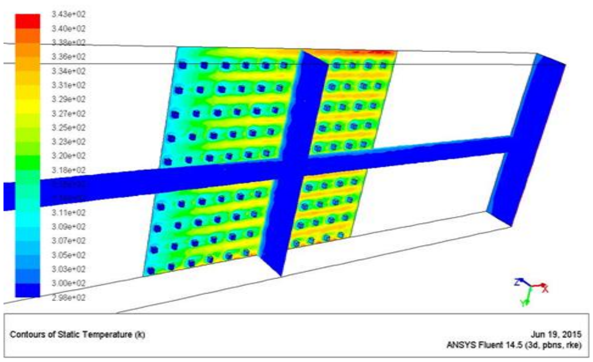

Fig.5 Plate-square-circular-p10-e-2-re-10000-temperature

We can see in fig.7 the average nusselt number increases with increase in Reynolds number in all cases for different value of rib roughness height. We can see in fig. 8 the average nusselt number increases with increase in rib height in all cases for fixed value of Reynolds number. We can see in fig. 9 the average friction factor decreases with increase in relative Reynolds number in all cases for value of rib roughness height.
We can see the maximum value of nusselt number enhancement ratio has been found to be 1.62 times compared to smooth duct corresponds to relative roughness height (e/D) of 0.06 and relative roughness pitch (P/e) of 5 at Reynolds number 5000 in the range of parameter investigated. We calculated the nusselt number for fixed value of relative roughness height (e/D=0.015 to .06) and relative roughness pitch (P/e=20 to 5).

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. Average Nusselt number increases with an increase of Reynolds number. The maximum value of average Nusselt number is found to be 43.577 for relative roughness pitch of 5 and for relative roughness height of 0.06 at a higher Reynolds number, 10,000.
3. Average friction factor decreases with an increase of Reynolds number. The maximum value of average friction factor is found to be 1.698 for relative roughness pitch of 5 and relative roughness height of 0.06 at a lower Reynolds number, 5000.
4. It is found that the circular and square transverse wire rib roughness with P/e ¼ 5 and e/D ¼ 0.06 provides better thermal enhancement factor for the studied range of Reynolds number and hence can be employed for heat transfer augmentation.

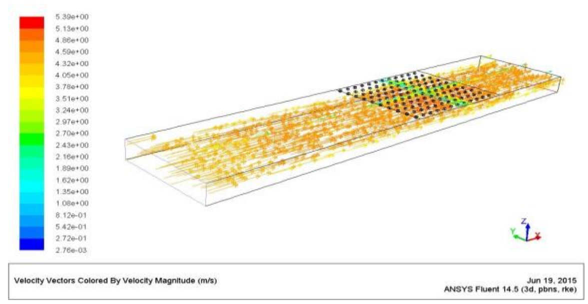

Fig.6 Plate-square-circular-p10-e-2-re-10000-velocity vector

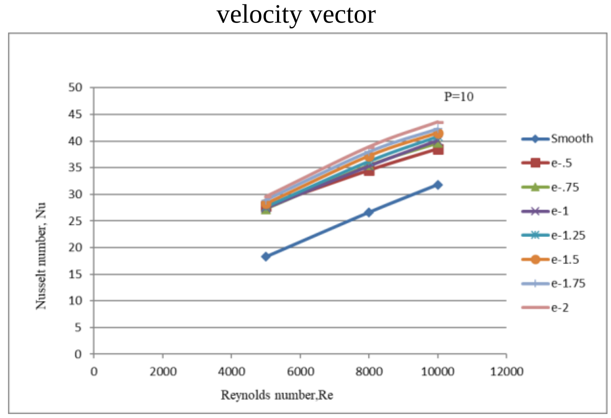

Fig. no.7-Comparison of Nu between Re

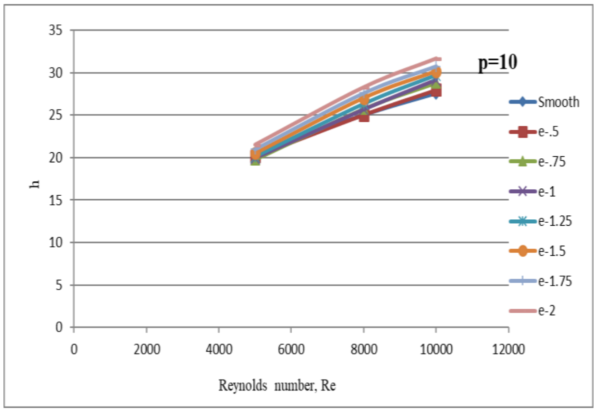

Fig.no.8- Comparison of h between Re

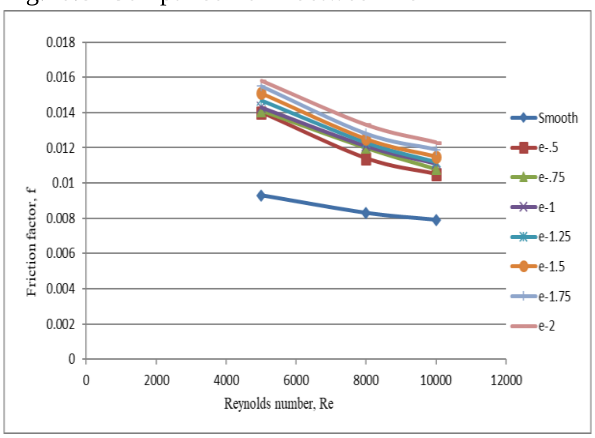

Fig.no.9- Comparison of Fr between Re

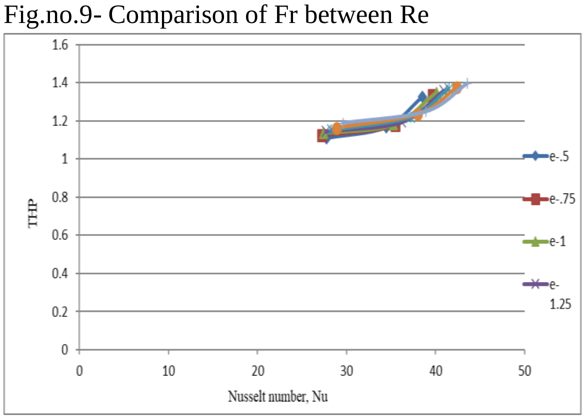

Fig.no.10-Comparison of THPP between Nu with Pitch

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