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Solar Air Heater Duct Roughened with Broken Double ARC Shaped Ribs

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Abstract – Solar air heaters provides the economical use of alternative energy, that uses the absorbent plate to soak up the incoming solar radiations, changing it to thermal energy at its surface, and transferring the thermal energy to the fluid which is flowing through the collector. It's been discovered that the potensial of flat plate solar heatre is slow due to convective heat transfer which is constant between absorbent plate and also the air flowing over it.It is the very common and effective technique to improve the performance of the solar air heater is to produce artificial roughness components on the face of the absorbent plate. But many investigations are administered to determine the impact of assorted roughness component geometries on heat transfer and friction think about solar heaters.

Keywords – Solar air Heater, Rib.

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I. INTRODUCTION

Renewable energies are sources of unpolluted, inexhaustible and progressively competitive energy. They take issue from fossil fuels mainly in their diversity, abundance and potential to be used anyplace on the earth, however in particular therein they turn out neither greenhouse gases – that cause temperature change – nor polluting emissions. Their costs are also falling and at a low rate, whereas the ultimate worth trend for fossil fuels is at intervals the incorrect method in spite of their gift volatility. The importance of renewable energy is increasing in last years with the growing concern of energy need of the world. Energy independence was illustrious as a result of the main driver for whole clean and renewable energy at intervals the country at intervals the wake of the two oil shocks of the 1970. The growth within the value of oil, uncertainties related to its offer and therefore the adverse impact on the balance of payments. Because of a growing world population and increasing modernization, world energy demand is projected to over double throughout the first half of the twenty first century and to over triple by the top of the century.

A. Renewable Energy Alternatives

Solar energy has become quite practical to use and many applications have created for it. First of these is solar heaters. Whether it is industrial grade water heating or simple heating to cook food, solar energy can be utilized quite easily. With the development of solar panels and photovoltaic cells, it can also be used to create and store energy as needed. Windmills are employed by several for an extended time. The initial use was to maneuver machines that might grind wheat into flour. Taking inspiration from this old technique, scientists were able to produce windmills that might spin at higher speeds. Wind mill energy conversion plant is installed at a place where the amount of wing is available through the year in viable amount, with constant speed.

B. Solar Energy

Solar energy is called renewable source of energy because of their unlimited availability and as it is available for a very long as sun continues to shine. Estimates for the remaining life of the main stage of the sun are another 4-5 billion years. The energy which we get from sun is in the form of electromagnetic radiations. The other main renewable energies are wind, bio energy, geothermal, hydro, tides and waves. Wind energy drived from the uneven heating of the surface of the planet because of additional heat input at the equator with the attendant transport of water and thermal energy by evaporation and precipitation. In this sense rivers and dams for hydro energy are stored solar energy. Transformation of solar energy to biomass by the process of photosynthesis is the third aspect of solar energy conversion.

1) Disadvantages of Solar Energy

Following are the disadvantages of solar energy.

- Solar cells/panels, etc. can be very expensive.
- Solar power cannot be created at night

2) Solar Energy Collectors

A solar collector is a special kind of heat exchanger, which collects solar radiant energy, and transfers it to a fluid- usually water or air. It converts solar radiation to thermal .energy of fluid and delivers the heated fluid for use. Collectors are classified as under depending on the relative area of exposure and the absorber area:

1. Flat plate collectors.
2. Concentrating collectors

C. Solar Air Heater

A conventional solar air heater typically consists of associate absorbent material plate with a parallel plate below forming a passage of high ratio through that the air to be heated flows. As within the case of the liquid flat-plate collector, a clear cover system is provided higher than the absorbent material plate, whereas a flat solid instrumentation crammed with insulation is provided on bottom and sides.

D. Improvement in Performance of Solar Air Heater

Solar air heaters, because of their characteristic simplicity, are low cost and most generally used as heating device. The thermal potential is very low as it is not available for continues time with same power of radiations, so the thermal potential of solar air heater is also low as because of the poor heat transfer capability between plate and air flow inside the duct. In order to increase the thermal potential of solar air heater, its heat transfer constant has to be increased. Turbulence promoters either in the form of surface roughness or in the form of three dimensional surface Pro-tolerances tends primarily to increase the heat transfer coefficient due to disturbance or destruction of the viscous sub-layer near the wall. The key dimensions of the roughness geometry are the relative roughness height, the relative roughness spacing and the shape of the roughness element. The best geometry of roughness depends totally on dynamic conditions within the physical phenomenon and on the properties of fluid. Basically, ribs increase or enhance the heat transfer of solar air heater, by adding the sub layer wall. This addition of the ribs in the solar air heater of turbulence, separation and new attachment will results in greater heat transfer from the surface. Flowing to the existence of ribs effective heat transfer surface will increase. Several researchers are disbursed on heat transfer improvement achieved by totally different ribs.

The phenomenon of heat transfer enhancement:

- Breaking of laminar sub layer
- Creation of local wall turbulence
- Variance in the thermal resistance.

But Drawbacks are higher friction and hence higher pumping power requirements

II. LITERATURE REVIEW

Wang et al [4] investigates the Numerical calculations on heat transfer and flow characteristics in a very straight channel with completely different geometric parameters wavy ribs. Wavs ribs are the best because of its influence on the working of non-rotating channel area which is calculated numerically in this work. In a wavs rib each parameter are explained with target surface which is determined and the other corresponding parameters are evaluated, to discover however wavy ribs have an effect on channel heat transfer, particularly the ribbed wall. Rib height (he=e−3e), rib spherical radius (r=0–5 mm), and rib angle (α =20–55°) square measure the 3 key geometric parameters to review. The investigated Reynolds number is 25000 and also the channel ratio is 1:1.

R. Karwa et al, [6] Investigational studies of increased heat transfer and friction in unsymmetrically heated rectangular ducts with ribs on the heated shut, inclined, v-continuous and v-discrete pattern, are studied in Heat and Mass Transfer

Anil k patil et al [7] These results represents that position of Gap in brken V-rib with combined roughness with staggered rib on thermo hydraulic performance of air heater of broken riub on heat transfer during the flow through solar air heater duct.

Rahul nadda et al [8] This study explained that the single arc ribs in solar heater with air jets are based on PSI approach. The experimentations were accomplished to gather the information on heat transfer and friction by varied the Reynolds no. (Re) between 3000 and 17,000, relative gap position(s0=s) from 0.2 to 0.8, for the mounted values of relative staggered rib pitch p0=p D 0:6, relative staggered rib size r=e D 1, relative roughness pitch p=e D 10, relative roughness height e=Dh D 0:043, relative gap size g=e D 1, and angle of attack ̧ D 60ı. The current roughness geometry with relative gap position (s0=s) of 0.6 cherish flow Reynolds no. (Re) of 13,150 yields the simplest thermo hydraulic performance

Han et al. [9] experimentally investigated the results of rib form, angle of attack and pitch-to-rib height quantitative relation on friction issue and heat transfer constant. Author rumored that ribs with 45° inclinations created higher heat transfer performance than ribs with 90° orientations, compared at a similar friction power.

Han [10] investigated the developing heat transfer in rectangular channels with rib tabulators for rib angle varied from 90° to 30°. The combined effects of rib angle and aspect ratio of heat transfer constant were studied. The results indicate that the simplest heat transfer in sq. channel was obtained with angular ribs at 30- 45° and was regarding 30% above the 90° crosswise ribs for constant pumping power. Aspect rough duct is decided by assumptive that the full shear force within the one aspect rough duct is or so adequate the combined shear force from 3 sleek walls in a very many-sided sleek duct and also the shear force from one rough wall up a many-sided rough duct. They used the friction similarity law and heat–momentum transfer analogy.

Gupta et al. [12] performed an experimental examination on solar air heater with angulate ribs with circular cross-sectional. they need investigated the result of relative roughness height (e/D), inclination of rib with relevance flow direction and Reynolds range on fluid flow characteristics in transitionally rough flow region and evaluated the thermo hydraulic presentation of solar air heaters.

Zhang et al. [13] in this, author has find that the while adding a grooves between the ribs will increase the turbulences which is nearer to the rib. And increasing the square ribs between the with the grooves will increase the heat transfer capabilities of the surface with some amount of pressure drop, which is negligible. It seems that, ribs will added with artificially rough surface including with the chamfered rib combined with grooves which is present between the two ribs in order to attain with a decrease of roughness of pitch and finishing of heat transfer surface. Visible of the upper than associate experimental Investigation has been planned to analysis the heat and fluid flow characteristics of artificially scratchy surface with chamfered rib-grooved roughness.

Park et al. [14] this study shows the result of heat transfer and friction data in five cases od rectangular promoters. Author studied the combined effects of the channel aspect ratio, rib angle of attack, and flow Reynolds number on heat transfer and pressure drop in rectangular channels with two opposite ribbed walls. The channel aspect ratio (width to height, W/H, ribs on side W) varied from ¼ to ½ , to 1, 2 and 4, while the corresponding rib angles of attack were 90°, 60°, 45°, and 30°, respectively. The Reynolds number range was 10,000–60,000. The results represents that the aspect ratio of (W/H = 1), the 60°/45°angled ribs provided the best heat transfer performance. For the narrow aspect ratio channel (W/H=1/4 or 1/2), the 45°/60°angled ribs were recommended while the 30°/45°angled ribs were better for wide aspect ratio channels (W/H = 4 or 2)..

Solanki et al. [16] experimented on integral chamfered rib roughness on the heated wall and reportable that the chamfer angle of 15° provides the most heat transfer. Most of the investigations administrated thus far are with ducts of circular cross section or of rectangular section having 2 opposite chapped walls and with all the four walls heated. It must be mentioned that for the appliance of this idea of improvement of heat transfer within the case of solar air heaters, roughness components ought to be thought of solely on one broad wall, that is that the solely heated wall. This application makes the fluid flow and heat transfer characteristics clearly totally different from those found within the case of 2 chapped walls and 4 heated wall ducts. In solar air heaters, only 1 wall of the oblong air duct is subjected to uniform heat flux (isolation) whereas the remaining 3 walls are insulated. It's recently been planned by many investigators that providing artificial roughness on the absorbent plate may well enhance the warmth transfer capability of a solar air heater.

Taslim and Lengkong [15] experimentally investigated the heat transfer and friction in channel cracked with angular formed and separate ribs on 2 opposite walls for Reynolds range starting from 5,000 to 30,000. The results showed that the 90° crosswise ribs created very lowest heat transfer performance. The 45° angular formed ribs created the very best heat transfer performance compared to alternative rib configurations. For formed ribs facing downstream of flow, the one with lowest blockage quantitative relation had higher heat removal rate. The separate ribs additionally created higher performance compared to the crosswise ribs.

III. OBJECTIVE

The objectives of this CFD analysis are:

1. To develop a CFD model that can be used to predict fluid flow and heat transfer characteristics in a solar air heater having circular and broken double arc shaped ribs on the absorber plate.

2. To conduct analysis of different configurations of and broken double arc shaped roughened ribs on fluid flow and

heat transfer using FLUENT as a CFD analyzing Code.

Compare the results of different configurations of broken double arc shaped ribs and find out the best rib configuration and also compare with continuous rib and smooth surface. To accomplish said objectives, the work is carried out in the following four steps:

Step 1: To conduct an extensive literature survey of heat transfer enhancement by various ribs inserts in solar air heater duct by different researchers.

Step 2: In order to modeled CFD model of artificial rough solar air heater surface a circular and double arc-rib with different size of gaps have a fix value of pitch (P=20mm).

Step 3: To conduct analysis of above rib configurations on fluid flow and heat transfer using

FLUENT 14.5 as CFD analyzing CODE and extract comprehensive data in the form of average Nusselt number and friction factor.

Step 4: Have to compare the above mention results of ribs and has to be optimize the best rib which will enhance the heat transfer with minimum power.

IV. METHODOLOGY

A. Computational Fluid Dynamics

Computational fluid dynamics (CFD) could be a computer-based simulation methodology for analyzing fluid flow, heat transfer, and connected phenomena like chemical reactions. This project uses CFD for analysis of flow and heat transfer. Few examples of are: aerodynamic force and drag (i.e. airplanes or windmill wings), station combustion, chemical processes, heating/ventilation, and even medicine engineering (simulating blood flow through arteries and veins).

B. Governing Equations

It involves the conservation laws of the physics.

- Mass is conserved i.e. Continuity equation
- Rate of change of momentum equals the sum of forces i.e. Newtons second law or conservation of momentum.
- Rate of change of energy is equal to sum of rate of heat addition to rate of work done i.e. First law of thermodynamics or conservation of energy.

1) Continuity Conservation

- Mass balance equation is given by
- Rate of increase of mass in fluid element = Net rate of flow of mass element in to fluid element
- Law of Conservation of Mass: Fluid mass is always conserved

$$\frac{\partial \rho}{\partial t} + div\ (\rho u) = 0 \qquad (1)$$

This is unsteady, 3D mass conservation or continuity equation in compressible fluid. For incompressible fluid it is given by,

div (u) = 0

or

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \qquad (2)$$

2) Momentum Conservation

Rate of increase of momentum = Sum of forces

$$\frac{\partial (\rho \vec{v})}{\partial t} + \nabla \cdot (\rho \vec{v}\ \vec{v}) = \rho g - \nabla P + \nabla \cdot (\vec{\tau}) \qquad (3)$$

3) Energy Conservation

Rate of increase of energy = Net heat added + Net rate of work done

$$\frac{\partial (\rho E)}{\partial t} + \nabla \cdot (\vec{v}(\rho E + p)) = \nabla \cdot (k_{eff} \nabla T + (\vec{\tau}_{eff} \cdot \vec{v})) \qquad (4)$$

C. Geometric Modeling (Solution Domain)

The 2D model is designed for the CFD simulations is generated in ANSYS 14.5 FLUENT as represent in figure 1. The domain for the solution is a horizontal duct with double arc shaped roughness at inside of the top duct of the absorber plate while other side is a smooth surface.

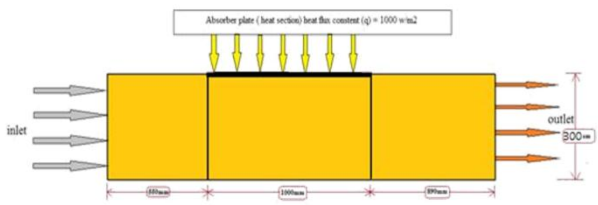


Fig. 1 Showing the geometric dimension of the working model

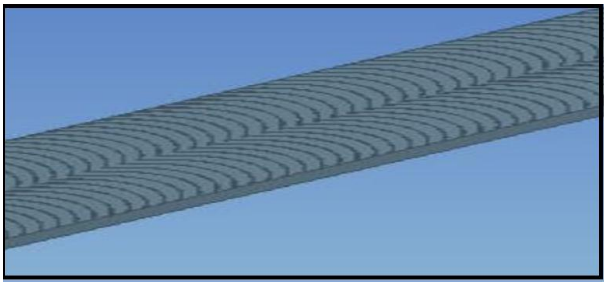


Fig. 2 Schematic diagram broken double arc rib

D. Meshing Of Geometry

Type of meshing: - Tetrahedral

No. of element: - 72450

No of face: - 1751098

No of nodes: -91154

Interval Size: - 1

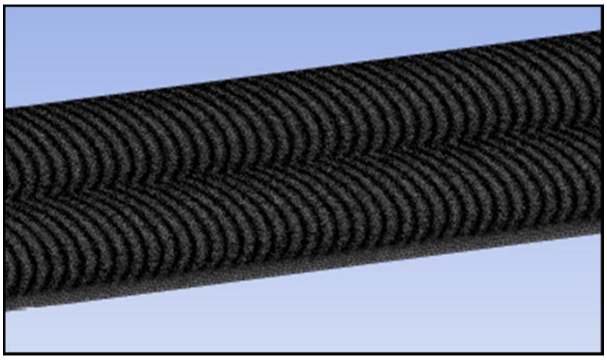


Figure 3 Meshing of duct with roughened absorber plate

The 2-dimensional solution domain used for CFD analysis has been generated in ANSYS version 14.5 as shown in Fig. 3. The domain on which we are working is the double arc shaped rib on the plate at top of the duct and the other sides are considered as the smooth surface.

V. RESULT

The different results of air flow in a broken double arc and continuous double arc roughened duct as well as smooth duct are obtained. These results are based on different relative gap width and different Reynolds number of fluid flow and analysis the effect of relative gap width and Reynolds number on the heat transfer, friction characteristics and thermo hydraulic performance for broken double arc shaped ribs under the identical operating conditions.

A. Heat Transfer and Friction Factor Characteristics

Table 1 shows the values of heat transfer coefficient generated from CFD for different values of relative gap width and Reynolds number at a fixed value of roughness pitch.

The variation of Nusselt variety and friction issue with Reynolds number in broken double arc formed rib for relative gap breadth (g/e) of 0.5, 1.0, 1.5, 2.0 and 2.5 has been shown in Figs. 4 and 5 severally. It will be ascertained that the Nusselt variety will increase and friction issue decreases with the rise in as painter variety (Re) from 2000 to 16000 for various values of relative gap breadth. For all Reynolds number, the very best price of Nusselt variety and friction issue has been ascertained adore relative gap breadth (g/e) of 1.0, and it declines on each aspect of this price of relative gap breadth. This variation in Nusselt variety and friction issue is thanks to the variation in turbulence close to the rib region caused by compounding of 2 vortices moving on the broken double arc ribs with the most flow. The variation of turbulence more depends on 2 factors (i) speed of air (ii) rate of flow of air free from the gap toward the double arc rib piece. Massive speed of air through gap causes a lot of turbulence that leads to increase in Nusselt variety and friction in flow, whereas smaller rate of flow of air through gap causes lesser turbulence that end in decrease in Nusselt variety and friction in flow. That the quantity of turbulence within the flow is that the combined result of speed and rate of flow of air free through the gap. It's anticipated that for this study, the combined result of those 2 factors is a lot of for relative gap breadth price of one.0 that resulted in highest price of average Nusselt variety and friction issue at relative gap breadth price of 1.0.

Table 1 Values of heat transfer coefficient generated from CFD.

Reynold no (Re)	NUSSELT NUMBER(Nu)					
	Continuous rib	g/e=1.5	g/e=1.0	g/e=2.0	g/e=2.5	g/e=0.5
2000	8	13	18	19	18	18
5000	17	37	43	44	35	32
8000	25	55	63	65	63	58
11000	30	72	86	87	78	75
14000	37	90	115	118	108	101
16000	40	98	123	126	116	109

Fig. 4 shows the effect of Reynolds number on average Nusselt number for different values of relative gap width (g/e) and fixed value of roughness pitch (*P*) in broken double arc rib. 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.

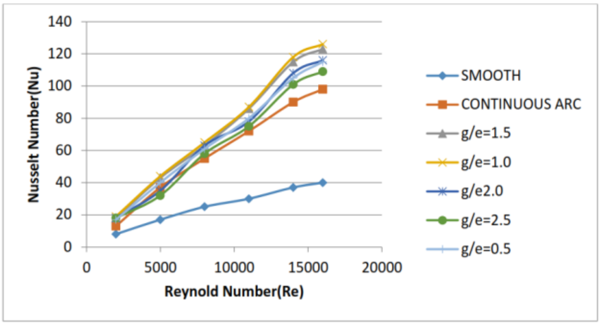
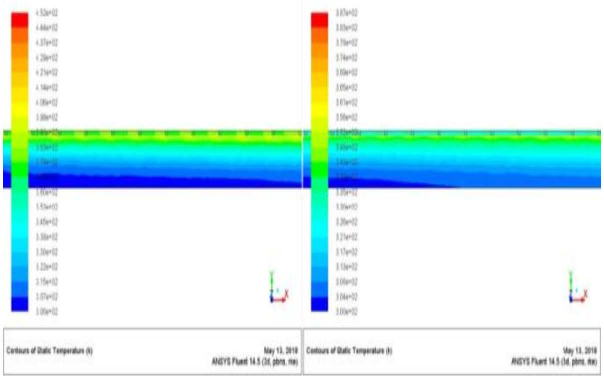
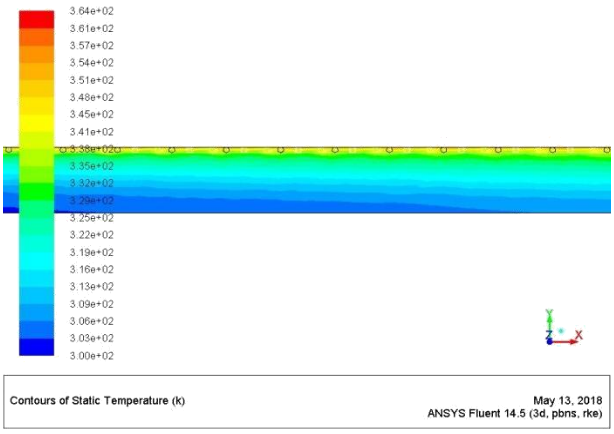


Fig. 4 Variation of Nusselt number with Reynolds number for different Values of relative gap width (g/e).



(a)



(b)

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

B. Enhancement of Heat Transfer

The enhancement in Nusselt number as a result of providing artificial roughness in the form of rib with a gap can be represented in terms of Nusselt number ratio defined as ratio of Nusselt number of an artificially roughened duct to that of the smooth duct under similar operating conditions. From Fig. 6, it is seen that the highest values of Nusselt number ratio is observed at relative gap width of 1.0 and its lowest value is observed at relative gap width of 2.5.

Table 2 Values of enhanced heat transfer coefficient generated from CFD.

Reynold no (Re)	NUSSELT NUMBER(Nu)						
	Continuous rib	g/e=1.5	g/e=1.0	g/e=2.0	g/e=2.5	g/e=0.5
2000	1.625	2.25	2.375	2.22	2.12	2.21
5000	2.2	2.529412	2.654	2.38	2.35	2.31
8000	2.2	2.867	2.98	2.786	2.48	2.6
11000	2.43	3.1	3.2	2.998	2.72	3
14000	2.425	3.129	3.25	2.984	2.61	2.95
16000	2.41	3.121	3.23	2.981	2.6	2.92

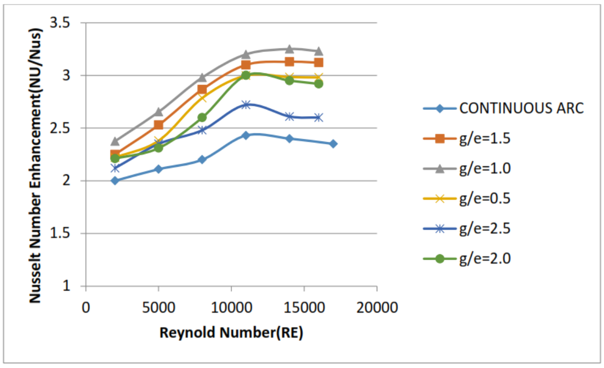


Fig. 6: Enhancement of Nusselt number with Reynolds number for various relative gap width (g/e)

A. Fluid Friction Characteristics

Table 3 shows the values of friction factor across the duct generated from CFD for different values of relative gap width and Reynolds number at a fixed value of roughness pitch in broken double arc ribs.

Table 3 Values of friction factor generated from CFD at different relative gap width (g/e).

REYNOLD NUMBER (Re)	FRICTION FACTOR						
	SMOOTH	CONTINUOUS ARC	g/e=0.5	g/e=1.0	g/e=1.5	g/e=2.0	g/e=2.5
2000	0.013	0.022	0.023	0.026	0.024	0.022	0.021
5000	0.011	0.021	0.021	0.023	0.022	0.02	0.019
8000	0.0095	0.0195	0.018	0.022	0.021	0.019	0.017
11000	0.009	0.0186	0.017	0.02	0.019	0.018	0.016
14000	0.0083	0.0175	0.016	0.019	0.018	0.017	0.016
16000	0.008	0.0165	0.016	0.018	0.017	0.016	0.015

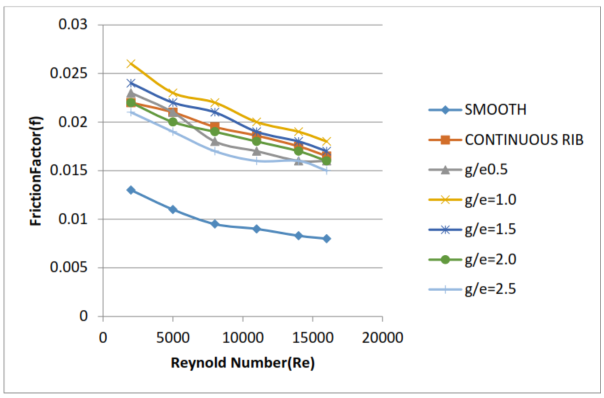


Fig. 7 Comparison between Friction factor and Reynolds number at different gap width(g/e)

The fluid friction phenomenon can be observed and described by the contour of pressure for rectangular rib. The contour plot of pressure is shown in Fig. 8 (a, b, c and d).

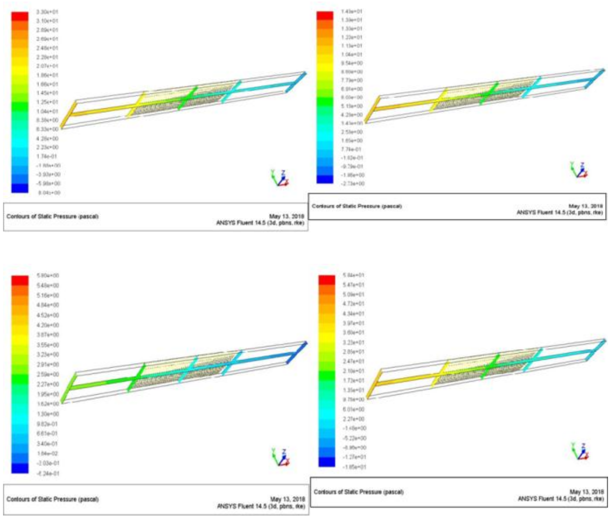


Fig 8 Contour plot of pressure for (a) Re=4000 (b) Re=8000 (c) Re=12000 (d) Re=16000

B. Enhancement of Friction Factor (f/fs)

Table 4 shows the values of enhancement of friction factor across the duct generated from CFD for different values of relative gap width and Reynolds number at a fixed value of roughness pitch in broken double arc ribs.

Table 4 Values of enhanced value of friction factor from CFD at different relative gap width(g/e).

REYNOLD NUMBER (Re)	Friction factor Enhancement(f/f_s)						
	SMOOTH	CONTINUOUS ARC	g/e=0.5	g/e=1.0	g/e=1.5	g/e=2.0	g/e=2.5
2000	1.692308	1.85	2	1.97	1.87	2	1.79
5000	1.909091	2.02	2.090909	2.06	2.045	2.090909	1.973
8000	2.1	2.23	2.315789	2.285	2.281	2.315789	2.2
11000	2.06	2.223	2.304	2.278	2.27	2.304	2.2
14000	2.04	2.13	2.289157	2.24	2.198	2.289157	2.11
16000	1.98	2.12	2.25	2.19	2.15	2.25	2.05

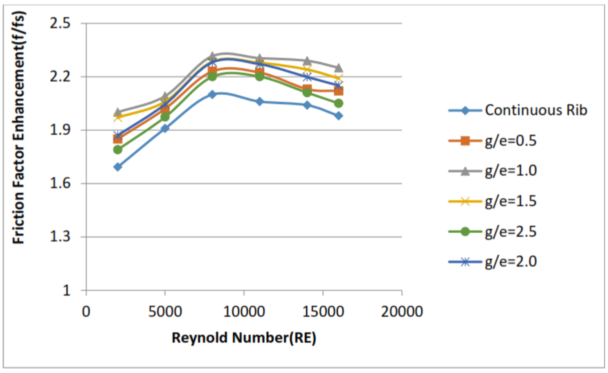


Fig. 9 Variation of friction factor ratio with Reynolds number as a function of relative gap width (g/e)

C. Thermo-Hydraulic Performance

It has conjointly been determined from Figures 10 and 11 that the most values of Nusselt no. and friction issue correspond to relative gap breadth of 1.0, thereby, which means that associate sweetening in heat transfer is in the midst of friction power penalty because of a corresponding increase within the friction factor.

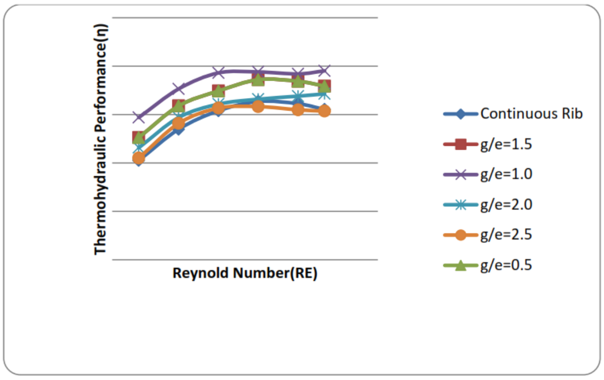


Fig. 10 Thermo-hydraulic performance parameter as a function of Reynolds Number for different relative gap width (g/e)

VI. CONCLUSION

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

A 2-dimensional CFD analysis has been administrated to review heat transfer and fluid flow behavior in an exceedingly rectangular duct of a star air heater with one rough wall having broken double arc-rib roughness. The result of Reynolds number and relative gap breadth (g/e) on the heat transfer constant and friction issue are studied. So as to validate this numerical model, results are compared with on the market results below similar flow conditions. CFD Investigation has been administrated in medium Reynolds number flow (Re = 2000–16,000). The subsequent conclusions square measure drawn from gift analysis:

1. The Renormalization-group (RNG) k-ε turbulence model predicted very close results to the experimental results, that yields confidence within the predictions done by CFD analysis within the present study

2. RNG k-ε turbulence model has been valid for swish duct and grid independence take a look at has additionally been conducted to check the variation with increasing variety of cells.

3. The roughened duct having broken double arc shaped rib with relative gap width of 1.0 provides the highest Nusselt number at a Reynolds number of 16000.

4. For broken double arc rib the maximum increase of average Nusselt number is found to be 2.67 times sof smooth duct for relative gap width (g/e) of 1.0 at a Reynolds number of 11000.

5. The roughened duct having broken double arc- rib with relative gap width of 1.0 provides the highest friction factor at a Reynolds number of 3500.

6. For broken double arc-rib the maximum enhancement of average friction factor is found to be 3.67 times that of smooth duct for relative gap width of 1.0 at a Reynolds number of 3800.

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

VII. WORK FOR FUTURE SCOPE

1. There is lot of possibility in the analysis of a solar air heater by using Computational fluid Dynamics software.

2. The rib shape can be changed to semi rectangular, triangular, etc.

3. The method can be applied for different, more complex geometries such as broken double arc with stagger.

4. The work can be extended for varying solar radiations instead of constant solar radiation.

5. The work can be extended for varying relative roughness pitch instead of constant relative gap position.

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