International Journal For Technological Research In Engineering
Volume 7, Issue 4, December-2019 ISSN (Online): 2347 - 4718

PERFORMANCE ENHANCEMENT OF HOT AIR DUCTS BY USING LONGITUDINAL STRIPES MOUNTED ON THE HEAT PANEL

MD Mojahid[1], Deepesh Bhavsar[2]
[1]MTech scholar, [2]Asst. Professor
Department of Mechanical Engineering, 1RNTU, Bhopal, India

ABSTRACT: In this paper the effect of longitudinal stripes mounted on the heat panel of hot air duct was discussed. The review is concentrated on the geometry of the stripes and its location on the heat panel of hot air duct. Both numerical and Computational Fluid Dynamics (CFD) analysis was considered for discussion with dry air and Nano fluids as a working fluid. The trial has been conducted on the heat transfer and friction factor, for a heat panel of hot air duct mounted longitudinal stripes without symmetrical gaps. The common facts observed from this analysis is that the implementation of artificial roughness on the heat panel results in a considerable increase in the rate of heat transfer without increasing the flow resistance in the ducts. Further, it is observed that when the desired heat transfer was carried with smooth and rough stripes with symmetrical gaps it was found that;

- ***The smooth stripes could not transfer the desired heat due to absence of friction; so, they are not preferred practically.***
- ***The rough stripes were efficient enough to transfer the desired heat, but they are not economical and are very complex in design and construction.***

Whereas, the longitudinal Square stripes without symmetrical gaps, when compared with the smooth and rough stripes with symmetrical gaps, it was concluded that the related Nusselt Number and Friction Factor for longitudinal Square stripes without symmetrical gaps was more efficient as well as economical, than that of smooth and rough stripes with symmetrical gaps for flow. This investigation was carried out on a Reynolds Number ranging in between 4000-18000.
Keywords: CFD analysis, Reynolds Number, Heat Panel, Hot Air Duct, Friction factor and Nusselt number.

I. INTRODUCTION

Now a days energy is the most important part of our life. So the use of energy effectively and reduce the wastage of energy. The energy mostly used in the form of heat and solar energy is abundantly available worldwide. Solar energy is an important alternative resource of energy, Which is used in domestic and industrial applications like solar air heaters, solar lights, solar pumps, photovoltaic applications, and many more, to meet the energy demand. The best and also the most effective way to utilize solar energy are to convert it into thermal energy for heating applications by the help of solar collectors and solar air heaters duct. The ducts are employed in heating, ventilation, and air conditioning (HVAC) to deliver and remove air. The required air movements include, for instance supply air, reoccurrence air, and exhaust air. When the air is flow from long duct most of heat energy are waste in terms of radiation. So for reducing this wastage energy by placing a heat panel in the duct which get the energy from heater generally solar air heaters are used. To increase the rate of thermal efficiency in a fluid, an artificial roughness is created closer to the surface, which results in recirculation of the fluid to create turbulence. The techniques implementing passive techniques in heat panel by using irregular forms like stripes, grooves, baffles, winglets, and twisted tapes, increases the heat transfer enhancement in hot air duct [1–3]. Numerous authors [4–7] have conducted analytical and experimental investigations implementing passive techniques in heat panel that resulted in heat transfer enhancement. The performance of hot air duct is enhanced by using longitudinal square stripes without symmetrical gap is more efficient as well as economical.

II. LITERATURE SURVEY

1) Lei Luo, et al. [1] conducted a simulation investigation of various shapes, such as triangular grooves and perturbation triangular ribs, with additional shapes like semi-cylinder grooves and perturbation semi-cylinder ribs with delta-Winglet Vortex, including a consideration of Reynolds number range from 4000 to 40,000. Lei Luo, et al. [1] revealed that perturbation semi-cylinder ribs result in the best thermal enhancement due to strong rotation formation and the semi-cylinder grooves-shaped rib, together with DWVGs, show the maximum thermal enhancement.

2) L. Varshney, et al. [2] numerically examined 12 different types of tapered shape of rectangular rib considering taper angle of 1.6_, 2.3_, and 3.2_ for a pitch distance of 10, 15, 20, and 25 mm. The authors used the Renormalization Group method in the k–e turbulence model with the selection of a wall enhanced function in the range of Reynolds number 3800 to 18,000. Their result reveals that the angle of 1.6_ shows the maximum enhancement with index increases from 1.31 to 1.91. A Relative roughness pitch, P/e = 10.7 with Re no ranges 12,000 displays the best performance in heat transfer.

3) Ali Najah Al-Shamani, et al. [3] conducted simulation work for four different rib-groove shapes in a channel using nano particles with different volume fractions in the Reynolds number, which varied from 10,000 to 40,000. The report revealed that a new novel Trapezoidal groove shape shows the best heat transfer rate with a decent Nusselt number.

4) S.C. Lau, R.T Kukreja And R.D Mc Millin [4], In this study the turbulent Heat transfer and friction factor effects were analyzed by optimizing an angle of attack and it was recognized that in square channel with two opposite walls the analysis was done on five different types of angle of attack i.e. 40°, 60°, 90°, 120°, 135° and predicted that 60° angle gives an better heat transfer and less friction factor.
5) J.C. Han and Y.M Zhang [5] the investigation was done on the effect of broken rib profiles on the local heat transfer distributions. The pressure drop in a square channel by considering two opposite inline ribbed wall was analyzed for Reynolds number 15000 to 90000 and the result obtained was so that the optimization of 60° broken stripe with P/e=10 provides more heat transfer.
6) Tabish Alam, R.P.Saini, J.S.Saini [6] in this study the analysis was done to predict the effect of variable shaped perforation holes in terms of V-shaped roughness in form of walls fabricated to a heat wall of square shaped duct of solar air heater. Five kinds of holes ranging from i.e. circular to square and rectangular in the circularity range of 0.6-1.0 has been considered with optimizing relative pitch of 4-12. The relative roughness height was 0.4-1.0, and open area ratio was 5-25%, and angle of attack was 30°-75° with variable Reynolds number of flow was considered i.e. 2000-20000. It was also analyzed that the Nusselt number value was in the ratio of 1.13 when circular perforation holes were replaced by rectangular holes of circularity of 0.69.
7) Rajendra Karwa [7] the experimental investigation was done in this study to recognize heat transfer and friction factor in a square duct with stripe on one long wall in a transverse inclined in V-discrete pattern. The duct has width to the height ratio of 7.19-7.75, P/e=10 and height of roughness 0.050 and angle of attack 60°, Reynolds n umber ranging between 2800-15000. The roughened wall of the duct was continuously heated while the three walls are insulated and it was predicted that V-down discrete arrangement gives best heat transfer performance.
8) Smith Eiamsa-ard, et al. [8] using three types of rib-groove arrangement with the parameters of W/H equal to 20, height of the duct H equal to 9 mm, rib height set as e equal to 3 mm, and three different pitch ratios P/e of 6.6, 10, and 13.3. The results support the idea that using a Triangular-Rib with a Triangular-Groove-shaped rib shows that thermal enhancement obtained the highest values for all pitch ratios at a constant pumping power.

9) Atul Lanjewar, et al. [9] experimentally investigated thermal performances and friction factor (f) with novel ‘W’-shaped ribs placed in a rectangular duct on its underneath on one side of the wall prepared at a 60 inclination admiration to the fluid flow direction. The study considered a duct hydraulic diameter ratio equal to 8.0, a relative roughness height (e/Dh) fixed in the range from 0.018 to 0.03375, a relative roughness pitch (p/e) of the rib equal to 10, and an attack angle from 30_ to
75 The Reynolds number used ranged from 2300 to 14,000. They declared that the ‘W’ shape of the rib at a 60 attack angle gave the best thermal performance and friction factor when related with the smooth duct.

10) Anil Singh Yadav and Bhagoria J.L. [10] simulated a CFD code for a repeated transverse square sectioned rib. The authors examined 12 dissimilar position of a square sectioned rib with the following parameters: relative roughness height ranging from (e/D) 0.021 to 0.042, relative roughness pitch (P/e) ranging from 7.14 to 35.71, and Re no ranging from 3800 to 18,000. They concluded that Re 12000 produced a good thermo-hydraulic performance (THPP) equal to 1.88 and the best rib roughness shows an (e/D) value of 0.042 and (P/e) equivalent to 10.71.

11) Anil Kumar and Man-Hoe Kim.[11] examined the influence of the roughness width ratio by the CFD technique by using the RNG-k–e model and they analyzed the typical friction factor, Nusselt number, and overall thermal performance. The result of this case shows that the discrete multi V-rib using a staggered rib shape is 6% advanced when associated with further rib shapes. Anil Kumar and Man-Hoe found that the highest significance of the relative width ratio was 6.0.

12) R Karwa, S.C solanki, J.S Saini [12] in this experimental investigation of heat transfer and friction factor for the flow of air in a square shaped duct with chamfered stripe with roughness on one wide wall. The aspect ratios and the Square duct used are 4.8, 6.1, 7.8, 9.66, and 12. Only roughened wall was applied by heat flux and rest of three walls were insulated; and the boundary condition were applied in solar air heaters. The range of parameters analyzed in Reynolds numbers is from 3000 to 20000. The relative roughness height is from 0.0141 to 0.0328 and the relative roughness pitch are 4.5, 5.8, 7, & 8.5 and Rib chamfer angles are 0°, 5°, 10° ,15° and 18°. In roughness the Reynolds number corresponding to these parameters range from 5 to 60 & was found to have high heat transfer and also the highest friction factor formed 15° chamfered stripe. The heat transfer function is increased with the increase in aspect ratio from 4.65 to 9.65.
13) P.R. Chandra, C.R Alexandra, J.C.Han [13] in this study an experimental study of surface heat transfer and friction characteristics of a totally developed turbulent air flown over a square channel with transversal stripe by one, two, three, and four walls. The tests were performed by Reynolds numbers that are starting from ten thousand to 80000. The pitch of rib height magnitude relation, P=e, was unbroken at eight and rib height of channel hydraulic with the diameter magnitude relation, e=DH that was unbroken at zero.0625. L/DH was twenty. the warmth transfer increased the rise within the variety of ribbed channel walls from a pair of.16 from one ribbed walls case to a pair of.57 to four ribbed walls case (Re = 30000). The channel with 2 opposite ribbed walls shows a rise in heat transfer from the one ribbed walls case by 6 June 1944. The 3 ribbed walls case shows a rise over 2 ribbed walls case by five-hitter. within the four ribbed walls case it shows a rise over the 3 ribbed walls case by seven-membered. The Friction issue magnitude relation will increase with increase in Reynolds variety, for this experiment. For Re=30000, the experiments reveals a 214%

increase just in case B as compared to Case A, a seventy two increase just in case C as compared to Case B, and a thirty fifth increase just in case D as compared to Case C, and additionally half-hour increase of Case E as compared to Case D. Heat transfer performance decreases with increase in painter variety and with every further ribbed wall.

14) J.L. Bhagoria, J.S.Saini, S.C. Solanki, [14] the experimental investigation was performed by an experiment to gather heat transfer and friction knowledge for forced convection flow of air during a star air heater with rectangular duct on one broad wall unsmooth by the wedge formed transversal integral stripe. This experiment thought of the Reynolds variety starting from 3000 to 18000 with wedge height zero.015 to 0.033. The relative roughness pitch area unit sixty.17, 1.0264, P/e=12.12, and Rib wedge angles were 8°, 10 °, 12°, and 15°were compared with the sleek duct. within the presence of stripe, yields Nusselt variety is up to a pair of.4 times, whereas the friction issue rises up to five.3 times the vary of Parameters is then investigated. Therefore, most heat transfer happens during a relative roughness pitch was concerning seven.57 whereas the friction issue keeps on decreasing because the relative roughness pitch will increase. As most improvement of warmth transfer happens at wedge angle of concerning 10; whereas, on either facet of the wedge angle, Nusselt variety decreases however the friction issue will increase wedge angle also will increase. This applied mathematics correlations for Nusselt variety and friction issue has been developed because the functions of rib spacing employed in, rib height, rib wedge angle, and painter variety.

15) Abdul-Malik Ebrahim Momin, J.S. Saini, S.C. Solanki [15] in this study the experimental investigation that creates a control of geometrical parameters on formed stripe and on heat transfer and fluid flow characteristics with rectangular duct of star air heater with absorbent plate having formed stripe on that bottom are mentioned. The vary of parameters employed in this study has been selected the premise of sensible concerns for system and in operation conditions. The investigation lined the painter variety (Re) vary of2500–18000 with relative roughness height of (e/DH) of zero.02–0.034 and angle of attack of flow 30°–90° f or a hard and fast relative pitch of ten. owing to the most improvement of Nusselt variety and friction factor, as a result it provides artificial roughness that has been supported with relevance a pair of.30 and 2.83times that of sleek duct for associate angle of attack with 60°. The thermo-hydraulic performance parameters will increase the associate angle of attack of flow and relative roughness height and this maxima happens with an angle of attack of 60°. it absolutely was found that for the relative roughness height of zero.034 and for the angle of attack of 60°, the formed stripe ensures the values of Nusselt variety by one.14and 2.30 times over inclined stripe with sleek plate just in case of painter variety of 17034.

16) Sahu, J.L. Bhagoria [16] in this study an experimental investigation; it's been discovered to verify and study the warmth transfer constant by victimization 90°, and therefore the broken transversal stripe is on absorbent plate used for star air heater. The unsmooth wall was been heated whereas the remaining 3 walls were been insulated. The provided unsmooth walls have roughness pitch (P), starting from 10–30 millimeter, height o f this rib was one.5 millimeter and duct ratio provided was eight. The air flow corresponds to Reynolds variety in between 3000–12000. Within the entire vary of Reynolds variety it absolutely was found that the Nusselt variety will increase, and attains a most roughness for pitch of 20 mm and reduces with a rise in roughness pitch. The most sweetening of the warmth transfer constant happens at pitch of concerning 20 mm whereas on each facet of this pitch the Nusselt variety decreases. The experimental values of the thermal potency of a 3 unsmooth absorbent plates that were tested has been compared with the sleek plates employed in the experiment. A plate of roughness 20 mm had the very best potency of eighty three.5%. Unsmooth absorbent plates additionally inflated the warmth transfer constant one.25–1.4 times as compared to the sleek rectangular duct underneath similar in operation conditions at the next Reynolds number.

III. NUMERICAL SIMULATION

In the present analysis The geometry used for heat panel of hot air duct have the dimension 1100mm*300mm*2mm (L*W*T) is considered where,

L=Length, W=width, T=thickness

In the present study only test section is considered for the analysis, although conventional SAH is having diverging and converging sections at its ends. Fig. 1 shows the line diagram of the four different profiles shapes of the stripes are as

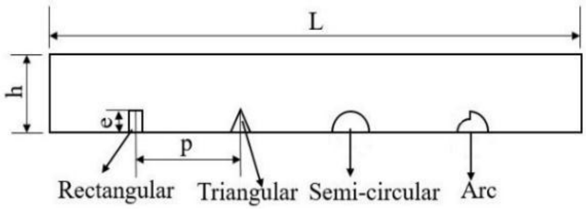

Fig. 1 Stripes profiles section shape

Material for the SAH duct and working fluid passing through the SAH are aluminum and air respectively. Properties of material, working fluid and parametric variables considered for the analysis are given in Table I.

Table I Properties of Aluminum and Air Parameter

Parameter	Aluminum	Air
Density	2.719	1..225kg/m^3
Inlet temperature	-	300K
Specific heat	871	1005J/kg-k
Thermal Conductivity	202.39	0.0242W/m-k
Dynamic viscosity	-	0.00001983 kg/m-s
Reynolds Number	4000 TO 18000	4000 TO 18000

A. Governing equations

The experimental data for plate and air at various locations in the duct were recorded under steady state conditions for given heat flux and mass flow rate of air. The data was used to compute the heat transfer rate of air flowing in the duct. Following equations have been used to determine heat transfer coefficient 'h', Nusselt number 'Nu', Reynolds number 'Re', friction factor 'f'.

$h= Q_u/A_p(T_p-T_f)$………………………..(1)

Where, the rate of heat gained by the air 'Qu' is given by,

$Qu=m*C_p*(T_o- T_i)$……………………..(2)

M=Mass flow rate.

Heat transfer coefficient has been used to determine the Nusselt Number using the equation:

$Nu = h\ D_h/k$………………………..(3)

Friction factor was determined from the flow velocity 'V' and the Pressure drop (ΔP) measured across the test section length of 1.1 m using the Darcy–Wiesbach equation as,

$f=(2*\Delta P*D_h)/ (4*\rho*L*V^2)$…………(4)

Thermo-Hydraulic performance for a given geometry is calculated from the formula,

For square stripe, =(Nuss/Nus)/(FFss/FFs)^(0.33)

For Circular stripe, =(Nuc/Nus)/(FFc/FFs)^(0.33)

Where, Nu_{ss} Nusselt number for square stripe

Where, Nu_c Nusselt number for circular stripe

Where, Nu_s Nusselt number for smooth plate

Where, FFss friction factor for square stripe

Where, FFc friction factor for circular stripe

Where, FFs friction factor for smooth plate

Since Nu is calculated by using the Dittus–Bolter equation as;

$Nu = 0.0233 X Re\ 0.8X\ Pr^{0.4}$

FF for a rectangular duct is given by the Modified Blasius equation as;

$FF = 0.085\ X\ Re^{0.25}$

The same formula is also used for obtaining the result but data require for the given formula is calculated from the contours of pressure & temperature. In order to calculate the Nusselt no. for different Reynolds number, temperature contour of air at outlet of duct and contour of plate temperature at Reynolds number 4000 to 18000 is used.

B. Geometric modeling and mesh generation

The geometry of duct with longitudinal Square stripes heat panel is made and meshed on GAMBIT. Then after putting the boundary conditions this meshed file is run on FLUENT 6.3 and the result obtained from fluent are used for validation of the result with the base paper.

The geometry used for duct with longitudinal square stripes heat panel have the dimension 1100mm*300mm*2mm (L*W*T) where,

L=Length, W=width, T=thickness

Duct dimension, Height=25mm, Width=300mm, Length of duct=2395mm, Inlet section=740mm, Test section =1100mm, Outlet section =555mm.

Type of meshing: - map

Type of element: - quadrilateral

No. of element: - 118443 No of face: - 240346

No of nodes: -121904 Interval Size: - 1

IV. RESULT ANALYSIS & DISCUSSION

4.1 Comparison between nu number of square stripe & experimental nu number for circular geometry

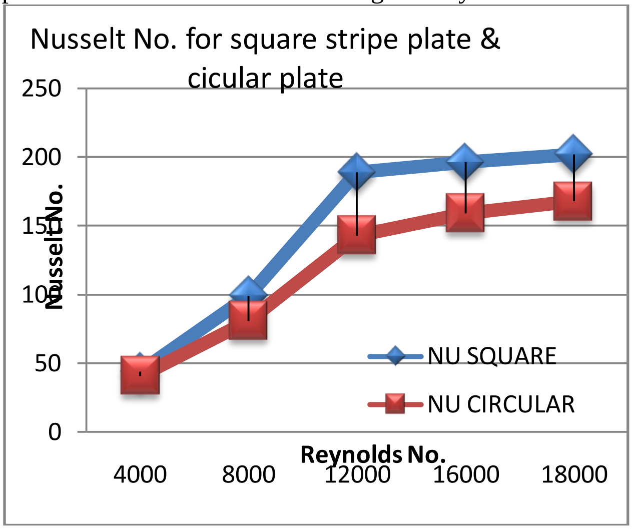

Figure 4.1 Graph of Nusselt Number versus Reynolds Number

This graph shows that Nu number obtained from CFD Follows the path of Nu Obtained by Author Experimentally, the average variation of Nu number in between CFD & Experimentally obtained is 17.01%

4.2 Comparison between friction factor of square stripe & experimental friction factor for circular geometry

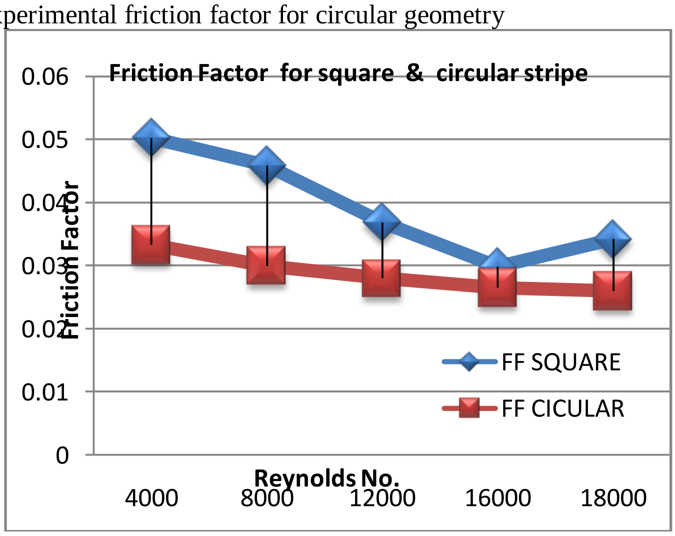

Figure 4.2 Graph of Friction factor versus Reynolds Number

This graph shows that Friction factor number obtained from CFD follows the path of Friction factor Obtained by Authors Experiment. The average variation of Friction factor number between CFD & Experimentally obtained value is 20.15 % more as compared with the result of the author.

4.2 Comparison between Thermo-Hydraulic performances for square stripe and circular

Thermo-Hydraulic performance for Reynolds number 4000, 8000, 12000, 16000, 18000 is calculated by putting the values of Nusselt number & Friction factor for square & smooth plate in the given formula above. Thermo-Hydraulic performance for different Reynolds number is tabulated as below:

Re	NU_S	NU_{SS}	FF_S	FF_{SS}	THERMO-HYDRAULIC PERFORMANCE
4000	16.41622	43.86	0.0106	0.0502668	1.824939
8000	28.58231	99.17	0.009	0.045872	2.32616
12000	39.53396	188.88	0.0081	0.036892	3.159923
16000	49.76469	196.43	0.0076	0.029835	2.604093
18000	54.68186	202.16	0.0073	0.034235	2.421878

Similarly, Thermo-hydraulic performance for Reynolds number 4000, 8000, 12000, 16000, 18000 is calculated by putting the value of Nusselt number & Friction factor for circular geometry & smooth plate in the given formula above. Thermo-Hydraulic performance for different Reynolds number is tabulated as below:

RE	NU_S	NU_C	FF_S	FF_C	THERMO-HYDRAULIC PERFORMANCE
4000	16.41622	41	0.0106	0.0333	1.705939
8000	28.58231	81	0.009	0.0300	1.897882
12000	39.53396	143	0.0081	0.0280	2.393248
16000	49.76469	159	0.0076	0.0265	2.10788
18000	54.68186	168	0.0073	0.0260	2.012641

4.3 Thermo-Hydraulic performance comparison for square stripe and circular geometry

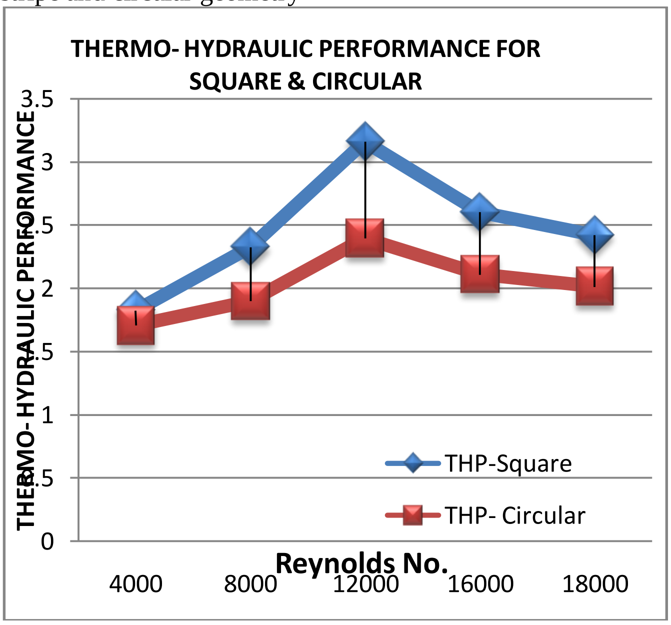

Figure 4.3 Graph of Thermo-Hydraulic performances for square stripe and circular geometry at different Reynolds number

V. CONCLUSION

Average deviation of result obtained from CFD for smooth & circular geometry for Nu number & Friction factor lies within the range, average Nu Number is deviate 3.76% for smooth plate and Average Friction factor is deviate 3.91% for smooth plate as compared to experimental work of the Author. Average deviation of results obtained for square stripe from CFD in Nu Number is deviated by 17.01 % i.e., Nu Number increases for circular geometry at each Reynolds number taken for analysis. Average deviation of result obtained for square stripe from CFD in Friction factor is deviated by 20.15% i.e., Friction factor increases for circular geometry at each Reynolds number taken for analysis.

Thermo-Hydraulic performance increases at Reynolds number 4000 for square stripe by 6.7%; and for Reynolds number 8000, 12000, 16000, 18000 it increases by 18.63%, 24.12%, and 19.35%, 16. 97% respectively.

This CFD analysis clearly indicates that square stripe roughness increases the turbulence in the air; and at the contact, the heat transferring area of air is increased which results in the increase in Nu Number and Friction factor as compared to circular geometry.

REFERENCES

[1] Luo, L.; Wen, F.; Wang, L.; Sundén, B.; Wang, S. Thermal enhancement by using grooves and ribs combined with delta-winglet vortex generator in a solar receiver heat exchanger. Appl. Energy 2016, 183, 1317–1332.

[2] Gupta, A.D.; Varshney, L. Performance prediction for solar air heater having rectangular sectioned tapered rib roughness using CFD. Therm. Sci. Eng. Prog. 2017, 4, 122–132.

[3] Al-Shamani, A.N.; Sopian, K.; Mohammed, H.A.; Mat, S.; Ruslan, M.H.; Abed, A.M. Enhancement heat transfer characteristics in the channel with Trapezoidal rib–groove using nanofluids. Case Stud. Therm. Eng. 2015, 5, 48–58.

[4] S.C. Lau, R.T. Kukreja, R.D. Mcmillin, "Effects of V-shaped rib arrays on turbulent heat transfer and friction of fully developed flow in a square channel" Int. J.Heat Mass Transfer. Vol. 34, No. 7 .pp 1605-1616, 1 991

[5] J.C. Han and Y.M Zhang "High performance heat transfer ducts with parallel broken and V-shaped broken stripe" Int. J.Heat Mass Transfer. Vol. 35, No . 2 .pp 513-523, 1992

[6] Tabish Alam, R.P.Saini, J.S.Saini "Effect of circularity of perforation holes in V-shaped blockages on heat transfer and friction characteristics of rectangular solar air heater duct" Energy Conversion and Management 86 (2014) 952–963

[7] Rajendra Karwa "Experimentally investigated that heat transfer and friction factor in rectangular duct with rectangular cross-section rib on one broad wall in transverse inclined V-continues and V-discrete pattern" Int. Comm. Heat Mass Transfer Vo.30,No.2,p p.241-250,2003

[8] Eiamsa-Ard, S.; Promvonge, P. Thermal characteristics of turbulent rib-grooved channel flows. Int. Commun. Heat Mass Transf. 2009, 36, 705–711.
[9] Lanjewar, A.; Bhagoria, J.L.; Sarviya, R.M. Heat transfer and friction in solar air heater duct with W-shaped rib roughness on absorber plate. Energy 2011, 36, 531–4541.
[10] Yadav, A.S.; Bhagoria, J.L. A numerical investigation of square sectioned transverse rib roughened solar air heater. Int. J. Therm. Sci. 2014, 79, 111–131.
[11] Anil, K.; Man-Hoe, K. Effect of roughness width ratios in discrete multi V-rib with staggered rib roughness on overall thermal performance of solar air channel. Sol. Energy 2015, 119, 399–414.
[12] R. Karwa, S.C Solanki ,J.S Saini “Heat transfer coefficient and friction factor correlations for the transitional flow regime in rib roughened rectangular ducts” International Journal of Heat and Mass Transfer 42 (1999) 1597-1615
[13] P.R. Chandra, C.R Alexandra, J.C. Han “Heat transfer and friction behaviors in rectangular channels with varying number of ribbed walls” International Journal of Heat and Mass Transfer 46 (2003) 481–495
[14] J.L. Bhagoria, J.S. Saini, S.C. Solanki “Heat transfer coefficient and friction fact correlations for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate Renewable Energy 25 (2002) 341–369
[15] Abdul-Malik Ebrahim Momin, J.S. Saini S.C. Solanki “Heat transfer and friction in solar air heater duct with V-shaped rib roughness on absorber plate” International Journal of Heat and Mass Transfer 45 (2002) 3383–3396
[16] M.M. Sahua, J.L. Bhagoria “Augmentation of heat transfer coefficient by using 90degree broken transverse stripe on absorber plate Of solar air heater” Renewable Energy 30 (2005) 2057–2073

