

Investigating The Parameters For The Performance Enhancement Of A Solar Air Heater Having Different Artificially Roughened Geometries

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Abstract: The use of an artificial roughness on a surface of absorber plate is an effective technique to enhance the rate of heat transfer to fluid flow in the duct of a solar air heater. This paper presents a comparison of parameters that enhance the heat transfer coefficient thus efficiency of a solar air heater for different artificially roughened geometries for the Reynolds number from 2500 -18000. The V-rib gives better results in whole range of Reynolds number than wedge shaped rib. While the arc shaped rib gives better performance in whole range of Reynolds number. However, smooth duct found suitable than the wedge and V shaped ribs for the lower range of Reynolds number.

Key words: Artificial roughness, Fluid flow, solar air heaters.

1. Introduction

Solar air heaters because of their inherent simplicity are cheap and widely used as collection devices of solar energy and useful for room heating and crop drying. Solar air heater have low efficiency because of low heat transfer coefficient between the air and absorber plate which leads to higher temperature of absorber plate which causes more thermal losses to the environment [1]. It was found that the main resistance to the convective heat transfer coefficient is due to the formation of the boundary layer on the heat transferring surface. Attempt has to be made to disturb this layer by using artificially roughened surfaces. Artificial roughness in the forms of wires and in various arrangements has been used to create the turbulence across the laminar sub layer [2]. Thus the artificial roughness can be used for the enhancement of heat transfer coefficient between the absorber plate and air, improving the thermal performance of solar air heater. Contrary to this by providing more disturbance across the layer will cause more pumping power required which increase the friction which results in reduction of effective efficiency. Sufficient information is available in the literature about heat transfer and friction characteristics for the flow in roughened circular tubes and channels in turbulent flow. The roughness wire orientation and geometry, i.e. pitch and relative roughness height affects the flow structure [3-5]

2. Types of artificial roughness

Nikuradse [6] investigated the effect of roughness on the friction factor and velocity distribution in pipes roughened by sand blasting. Nunner [7] and Dippery and Sebersky [8] developed a friction similarity law and a heat momentum transfer analogy for flow in sand grain roughened tubes. In case of solar air heaters, rib type roughness has been investigated mostly.

The ribs can be continuous or discrete depending on the arrangement i.e. staggered or some other arrangements were used. The orientation of the ribs can be transverse, inclined and V shaped. Han and Zhang [9] found that ribs inclined at angle of 45° results in better heat transfer coefficient when compare to transverse ribs. Lau et al. [10] and Taslim et al [11] investigated the effect of V shaped ribs and found that it result better compare to inclined and transverse ribs. Ichimiya et al [12] experimentally investigated the effect of porous type roughness on the heat transfer and friction characteristics in parallel plate duct. The rib roughness can also be recognized in accordance with the shape of the cross section of the ribs such as square, rectangular, triangular, circular, semicircular and trapezoidal ribs. Ravigururanjan and Bergles [13] used four types of roughness i.e. semicircular, circular, rectangular and triangular ribs to develop the general statistical correlations for heat transfer and pressure drop for single phase turbulent flow in internally ribbed surface. Liou and Hwang [14] tested three shapes square, triangular and semicircular to study the effect of rib shapes on turbulent heat transfer and friction in a rectangular channel with two opposite ribbed walls.

3. Effect of roughness parameters on heat transfer and friction factor in solar air heaters

Table 1 Typical values of system and operating parameters

Parameters	Values
Length, L (mm)	1000
Width, W (mm)	200
Height, H (mm)	20
Insolation, I (W/m^2)	1000
Overall loss coefficient, UI	5
Transmittance-absorbance, ($\tau\alpha$)	0.85
Relative roughness height, e/D	0.02–0.04
Relative roughness pitch, p/e	10
Reynolds number, Re	2000–24 000

A number of investigators investigated heat transfer and friction for roughened duct of solar air heaters. Momin et al [15] experimentally investigated the effect of geometrical parameters of V shaped ribs on heat transfer and fluid flow

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characteristic of rectangular duct. The investigation covered a Reynolds number range from 2500-18000, relative roughness height from 0.02-0.04 and angle of attack of flow from 30°-90° at fixed relative pitch of 10. Bhagoria et al [1] performed experiment to determine the effect of relative roughness pitch, relative roughness height and wedge angle on the heat transfer and friction factor. Saini and Saini [16] investigated the effect of expanded metal mesh geometry (i.e. relative long way length of mesh (l/e) and relative short way length of mesh (s/e)) on heat transfer and friction factor. Saini and Saini [17] studied the effect of arc shaped ribs on the heat transfer and friction factor of rectangular duct. The correlations for heat transfer and friction factor developed by these investigators for different geometries of roughness element is given in Table 2.

Nomenclature:

A	smooth absorber plate area = WL , m^2
C_p	specific heat of air, J/kg K
D_h	hydraulic diameter of duct = $4WH/\{2(W+H)\}$, m
E	rib height, mm
e^+	roughness Reynolds number
e/D_h	relative roughness height
f	friction factor
FR	heat removal factor
g	heat transfer function
G	mass flow per unit area of plate = $M/(WL)$, $kg/m^2 s$
h	heat transfer coefficient from absorber plate to air, $W/m^2 K$
H	air flow duct depth, m
I	solar radiation on the collector plane, W/m^2
K	thermal conductivity of air, $W/m K$
L	length of test section, m
m	mass velocity of air = $M/(WH)$, $kg/m^2 s$
M	mass flow rate, kg/s
N	number of glass covers
Nu	Nusselt number = hD_h/k
p	rib pitch, mm

P	pumping power, W
p/e	relative roughness pitch
Pr	Prandtl number
Q_u	useful heat collection, W
Q_L	heat loss from the collector, W
R	roughness function
Re	Reynolds number
St	Stanton number
T_a	ambient temperature, °C
T_i	inlet air temperature, °C
T_m	mean air temperature, $(T_o+T_i)/2$, °C
T_o	outlet air temperature, °C
T_p	mean plate temperature, °C
UL	overall loss coefficient, $W/m^2 K$
v	velocity of air in the duct, m/s
w	width of rib, mm
W	width of the duct
W/H	duct aspect ratio

Greek symbols

dp	pressure drop, Pa
\emptyset	rib chamfer angle, degree
η	thermal efficiency
η_e	efficiency of electric motor
η_{fan}	efficiency of blower or fan
η_{th}	efficiency of thermal-electric conversion process
η_{eff}	effective thermal efficiency
τ_a	transmittance-absorptance product

Subscript

s	smooth duct
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4. Results and discussion

An investigation of the performance of solar air heaters with different artificially roughened surface on the airflow side of the absorber plates has been carried out. Fig. 1 shows the variation of nusselt with Reynolds number at different set of operating parameters

Table 2
Correlations used for heat transfer coefficient and friction factor for different roughness geometries

Author	Type of Roughness	Range of Parameters	Nusselt Number correlation	Friction Factor correlation
Momin et al. [15] 0.093	V- Shaped rib	e/D : 0.02-0.04 p/e : 10 α : 30° to 90° Re: 2500-18000	$Nu_s=0.067Re^{0.888} (e/D)^{0.424}$ $(\alpha/60)^{-0.077} \exp [-0.782\{\ln (\alpha/60)\}^2]$	$f_s=6.266Re^{-0.425}(e/D)^{0.565}(\alpha/60)^{-1}$ $\exp [-0.719\{\ln (\alpha/60)\}^2]$
Bhagoria et al [1] ($\phi/10$) ^{0.49}	Wedge Shaped rib	e/D : 0.015- 0.033 p/e : 60 $\phi^{-1.0264} < p/e < 12.12$ Φ : 8,10,12,15 Re: 3000-18000	$Nu_s=1.89 \times 10^{-4} Re^{1.21} (e/D)^{0.426} (p/e)^{2.94}$ $\exp [-0.71\{\ln (p/e)\}^2] (\phi/10)^{-0.018}$ $\exp [-1.5\{\ln (\phi/10)\}^2]$	$f_s=12.44Re^{-0.18}(e/D)^{0.99}(p/e)^{-0.52}$
Saini and Saini [16] 0.19	Expanded Metal Mesh	e/D : 0.12-0.039 L/e: 25-71.87 S/e: 15.62-46.87 Re: 1900-13000	$Nu_s=4 \times 10^{-4} Re^{1.22} (e/D)^{0.625} (s/10e)^{2.22}$ $\exp [-1.25\{\ln (s/10e)\}^2] (l/10e)^{2.66}$ $\exp [-0.824\{\ln (l/10e)\}^2]$	$f_s=0.815Re^{-0.361}(l/e)^{0.266}(s/10e)^{-1}$ $(10e/D)^{0.591}$
Saini and Saini [17]	Arc Shaped rib	Re: 3000-18000 p/e : 10 e/D : 0.021-0.042	$Nu_s=0.001047Re^{1.3186} (e/D)^{0.3772}$ $(\alpha/90)^{-0.1198}$	$f_s=0.14408Re^{-0.17103}(e/D)^{0.1765}$ $(\alpha/90)^{0.1185}$
Dittus- Boelter	Smooth Duct		$Nu_s=0.024 Re^{0.8} Pr^{0.4}$	$f_s=0.085Re^{-0.25}$

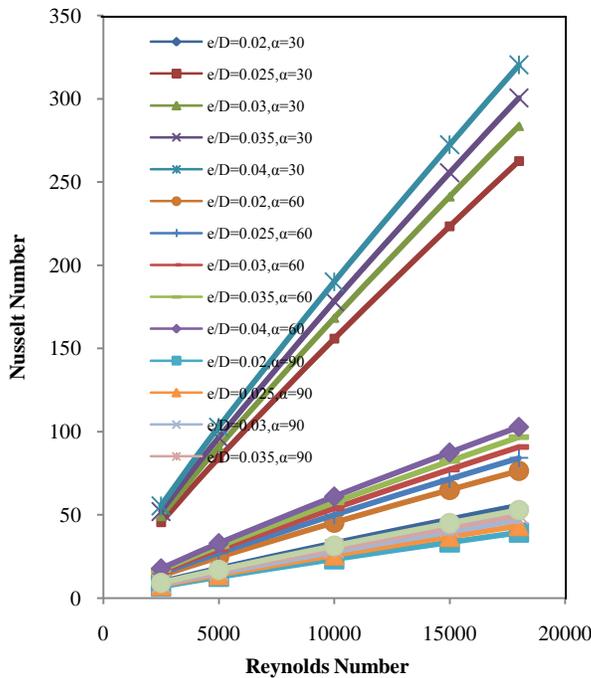


Fig. 1 shows the variation of Nusselt Number with the Reynolds number at different set of operating parameters for Momin [15]

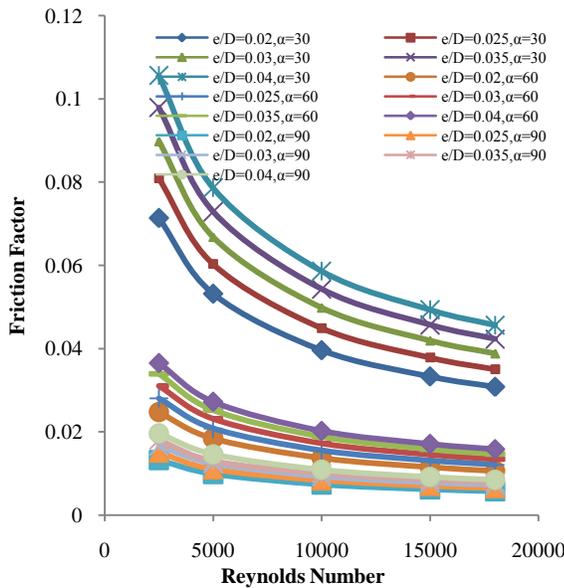


Fig. 2 shows the variation of Friction Factor with the Reynolds number at different set of operating parameters for Momin [15]

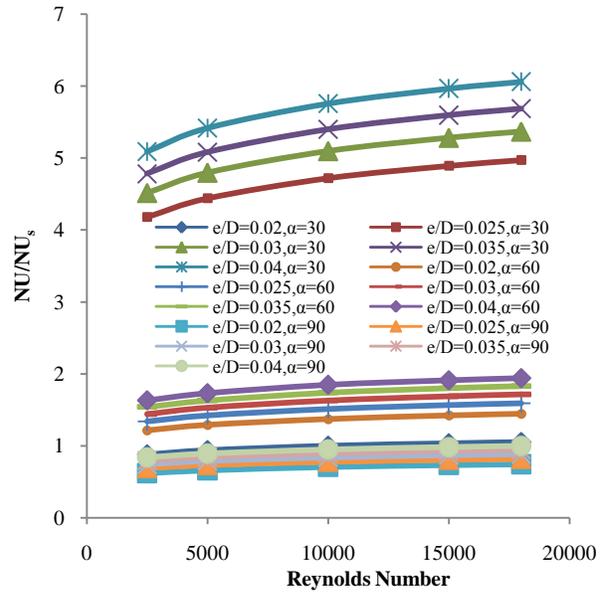


Fig. 3 shows the variation of Nusselt number ratio with the Reynolds number at different set of operating parameters for Momin [15]

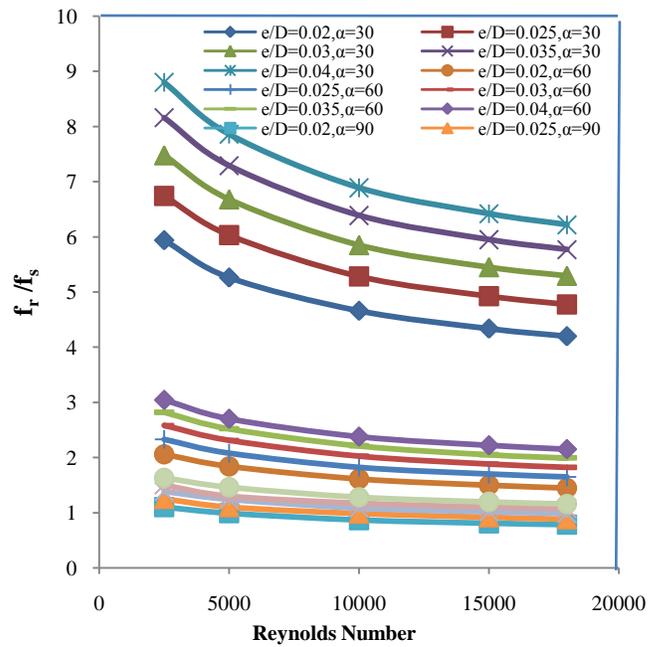


Fig. 4 shows the variation of Friction Factor ratio with the Reynolds number at different set of operating parameters for Momin [15]

It is found from fig 1 and fig 2 that rate of increase of nusselt number was observed to be lower than the rate of increase of friction factor with an increase in Reynolds number. The maximum enhancement of nusselt number and friction factor as a result of providing artificial roughness had been found to be 2.3 to 2.83 times respectively over smooth duct for an angle of attack of 60°. It was reported that for relative roughness height (e/D) value of 0.034 and angle of attack of 60° gives the best results. It is found that at angle of attack of 30° it gives

normally same results as that for smooth duct. Fig 3 and Fig 4 shows the variation of nusselt number and friction factor ratio with Reynolds number and it is seen that the enhancement of nusselt number is up to 120-150% for the angle of attack of 60° and up to 400-500% for the angle of attack of 30° for the higher

values relative roughness height but this tends to higher increase in friction losses. Thus it is found to be compensatory at (e/D) of 0.034 and for attack angle of 60°.

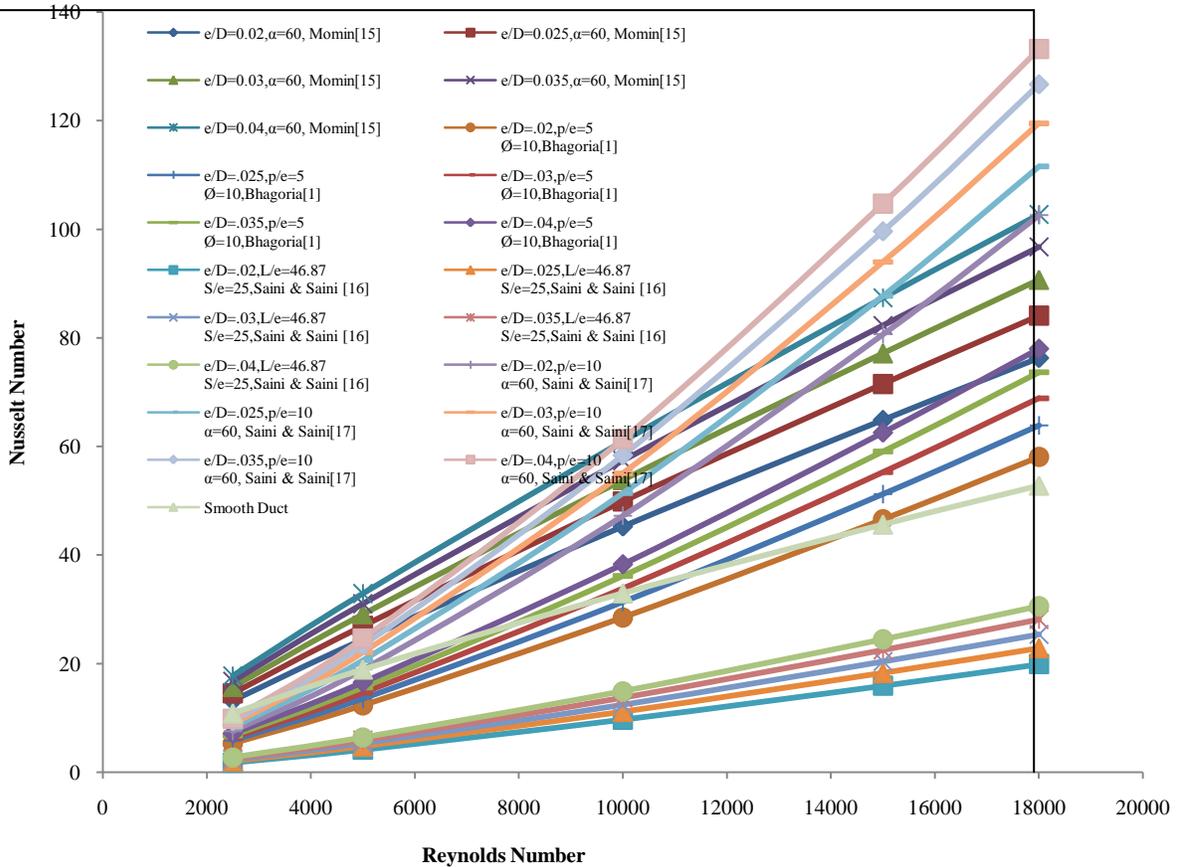


Fig. 5 shows the variation of Nusselt Number with the Reynolds number at different set of operating parameters for Momin [15], Bhagoria [1], Saini&Saini [16], Saini&Saini [17]

From Fig. 5 It was found that for higher range of Reynolds number the arc shaped rib gives better performance compare to V rib and wedge shaped rib. Whereas for the lower range of Reynolds number V ribs gives better performance compare to other geometries. For the whole range of Reynolds number V ribs gives better performance than wedge shaped rib. While the smooth duct gives better performance than wedge and V ribs for lower range of Reynolds number.

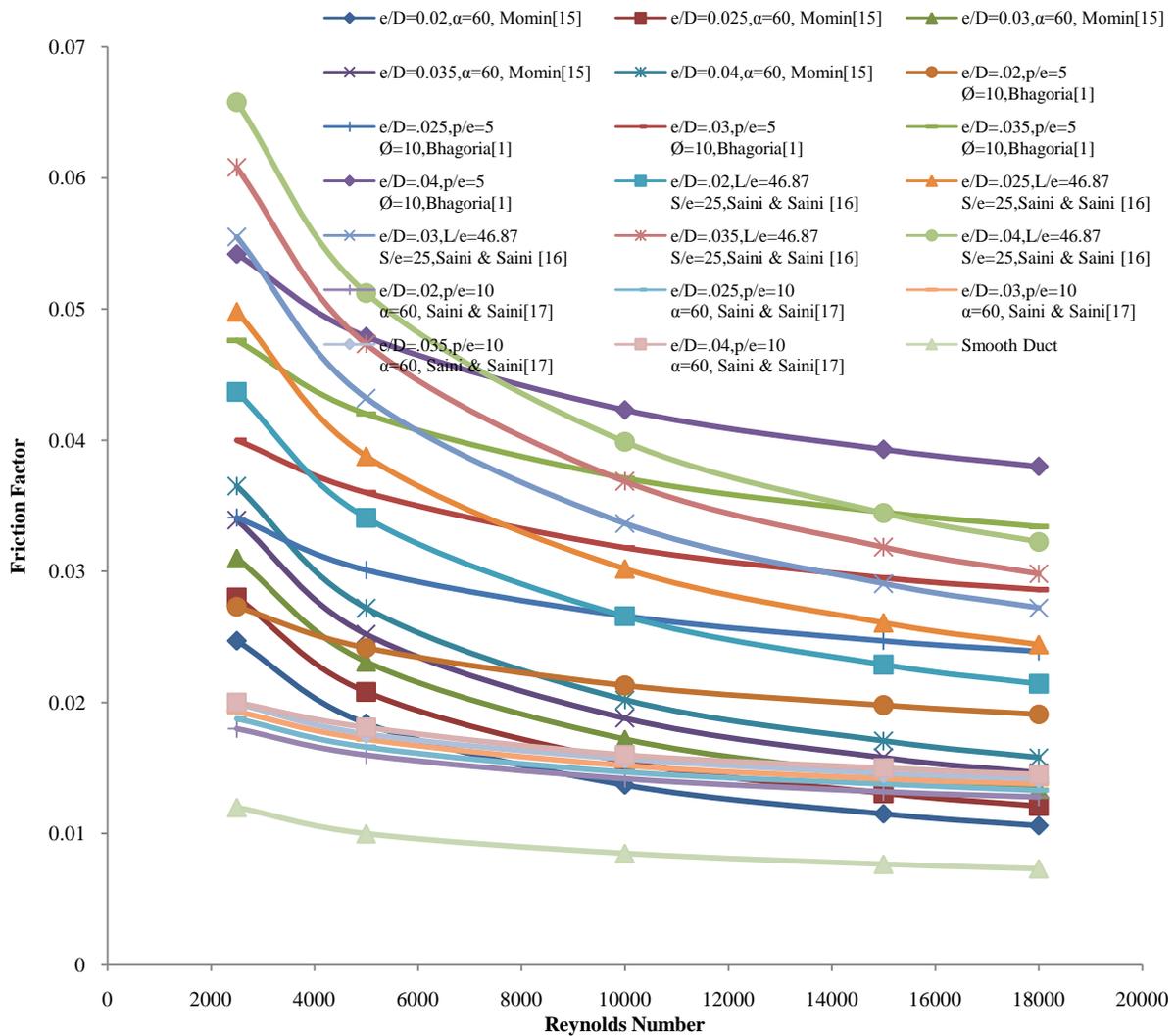


Fig. 6 Shows the variation of Friction Factor with the Reynolds number at different set of operating parameters for Momin [15], Bhagoria [1], Saini & Saini [16], Saini & Saini [17]

From fig. 6 it is seen that the friction factor is high in arc shaped rib compare to smooth duct but contrary to this it has high value of nusselt number. Thus from Fig 5 and Fig 6 it is seen that the arc shaped wires ribs gives best performance compare to the other geometries i.e. V-shaped rib, Wedge shaped rib, Metal mesh geometry.

5. Conclusion

There is a considerable enhancement in the heat transfer coefficient of solar air heaters having roughened duct provided with different types of roughness elements. The arc shaped rib found suitable for whole range of Reynolds number over other geometries contrary considering with effect friction factor.

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