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A REVIEW ARTIFICIALLY ROUGHENED TRIANGULAR DUCT SOLAR AIR HEATER

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ABSTRACT
The geometry of duct is the important factor influencing heat transfer for any end use in laminar and turbulent flow. The basic requirement of industries is of high heat transfer rate and less pumping power. Since the flow of fluid in industries is turbulent in nature. Many studies are performed to understand the performance of duct in non circular(rectangular, semicircular, square, ellipse etc.) in shape. This paper present the review on the various studies performed on triangular duct. In this article natural and forced convection using newtonian fluid based experimental and numerical studies are considered. In order to improve the heat transfer through duct various geometry of roughness are embedded in the absorber plate and results obtained are used to compare the performances with smooth solar air heater and correlations are generated for different geometry. It is observed that among all other boundary conditions uniform heat flux gives optimum heat transfer.

1. INTRODUCTION

The demand of energy is increasing with the time and this demand is mainly fulfilled by fossil fuel such as coal, oil, petroleum etc. Since this fossil fuel is non renewable, so this will not lasts forever. It will going to be extinct in next 100 or 150 years. In addition to that this also give negative impact to environmentsuch as acid rain, ozone layer depletion, global climate change etc. So there is the basic need to shift our energy sources to renewable energy because it will never extinct and also it is pollution free.

The sun light is the major source of energy and can be used to heat air in solar air heater..The design of solar air heater is such that top of the metallic plate is made black colour, so that the light incident on it gets fully absorbed. While the other side is insulated and air flow takes below the absorber plate. Conduction, convection and radiation are the three modes of heat transfer takes place in solar air heater. The heat transfer occurs between the fluid near the surface and the surface is convective heat transfer. Constant flow rate at outlet is required in practical application and in order to obtain this condition external power is required. This external power is provided by pumps. So to calculate the performance of solar air heater two parameter i.e. heat transfer and pumping power both are taken in account. More the pumping power required more cost is required to maintain the flow. So the basic requirement is to increase heat transfer to maximum and reduce the pumping power to minimum.

2. EFFECT OF CROSS-SECTION OF DUCT ON HEAT TRANSFER AND FRICTION FACTOR

Satyendra singh [1] performed analytical and numerical investigations to study the effect of the geometry of duct in the thermal performance of solar air heater. The crossection of geometry considered are semicircular and triangular. Absorber plate are embedded with V down rib in bottom side. The analytical investigation is carried out to study the effect of ribs on performance of solar air heater. Ansys-Fluent software is used the analytical investigation. It is concluded that the thermal and thermohydraulic efficiencies of Semicircular duct are obtained to be 3–5% higher than that of the triangular duct and pressure drop obtained in semicircular duct is 70% higher than the triangular duct.

Cebeci and Bradshaw et. al.[2] Physical and computational aspects of convective heat transfer , Page no.130, In this study about effect of crossection of duct in the performance of solar air heater. Here different crossection shapes are taken are rectangular, square, ellipse, circular, and triangular. It is concluded that the minimum friction factor is obtained in triangular crossection.

C.W. leung et.al.[3] performed experimental analysis to study the effect of apex angle in the performance of the triangular duct solar air heater having two of its sides equal. The isosceles triangular ducts were manufactured with duralumin, and fabricated with the same length of 2.4 m and hydraulic diameter of 0.44 m. in turbulent flow conditions. Five different values of apex angles 30 º,45 º,60 º,75 º,90 º and three rib roughness values on the surfaces are considered. It is observed that the duct with apex angle of 60º have high thermal performance.

D.A. Campbell et.al.[11] performed experimental analysis to find the effect of rounding all the corners of triangular duct. It is observed that there is incremenet heat transfer value but friction factor also increase which in result increases the pumping power.

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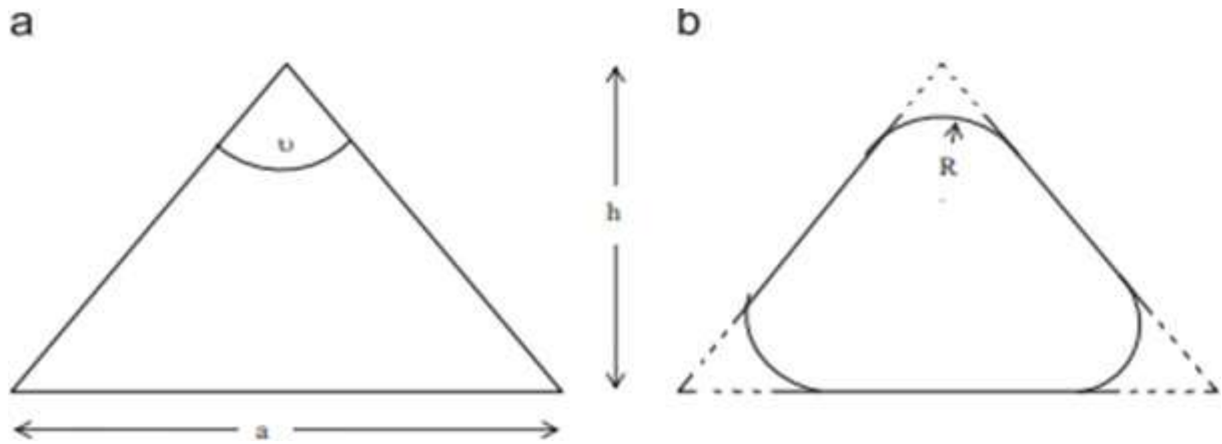
R.K. shah et.al. [18] performed numerical analysis to find the effect of geometry of duct in the performance of the solar air heater. Various geometry of duct taken are triangular, rectangular, trapezoidal, triangular duct with rounding the corners, sine, rhombic and any other arbitrary shape. This paper present wide range of results based on height to base ratio and also present the effect of rounding the corners of triangular duct. It is concluded that heat transfer increases on increasing the rounding of corners of the triangular duct.



Triangular duct with and without rounding

S. Ray et.al.[16] performed an numerical analysis to study the effect of radius of corners of roundings on the square and triangular duct. The radius of corners is varied from zero to maximum value (1 for square duct and $1/\sqrt{3}$ for triangular duct). It is concluded that variation in local hear transfer coefficient increases with increase in rounding radius. Friction factor in case of rounded triangular duct increases with rounding radius and attain maximum value at radius of 0.35 and also the effectiveness of the rounded portion increases with rounding radius and attains maximum value at 0.325.

3. EFFECT OF ARTIFICIAL ROUGHNESS

D.D.luo et.al.[4]performed the experimental study the effect square ribs embedded in triangular duct solar air heater on the forced convection and friction factor characteristics. The parameter of experiment are 0.11<relative rib height (H/D)<0.21, 3.41<relative rib to rib height (S/W)<13.93 and 4000<Reynold number(Re)<23,000. It is concluded that the value of H/D and S/W that gives optimum performance is 0.18 and 7.22 respectively. Friction factor in triangular duct increases with the height of the rib and the maximum friction factor is observed at S/W =7.22. The correlation of nusselt number and friction factor is also predicted depending upon H/D, S/W, and Re.

Nidhul Kottayat et.al. [5] performed numerical analysis to study the effect of inclination of ribs embedded on one side of the triangular duct solar air heater ($30^\circ < \alpha < 75^\circ$) on the performance with reynold number varying 5000 < Re < 17500. It is concluded that the performance of solar air heater shows maximum at $\alpha = 45^\circ$.

Rajneesh Kumar et.al.[6] performed numerical analysis to study the effect forward chemfered rectangular rib,here additional parameters of roughness is added named as rib aspect ratio (e/w) and rib chamfered height ratio (e′/e) and the effect of this roughness on the performace of solar air haeter is studied.Reynold number is varied from 4000 to 17000. This numerical study is performed in ANSYS software. The rib parameter taken are 0.24<e/w<1.5, 0.018<relative roughness height (e/D)<0.043 and 0<e′/e<1. A constant heat of $1000W/m^2$ is provided on the ribbed surface of solar air heater. The maximum value of nusselt number enhancement of 2.88 is observed at e/w = 1.5, e/D = 0.043 and e′/e = 0.75 and at Re = 17000. The maximum value of friction penalty of 3.52 is observed in case of e/D = 0.043 at Re = 4000. The correlation of nusselt number and friction factor is also predicted depending upon e/w, e/D and e′/e value

Selcuk Darici et. al.[7] performed experimental analysis to compare the performance of two solar air heaters with smooth absorber plate and trapezoidal corrugated absorber with different mass flow rates. The different mass flow rates taken are 0.022, 0.033, 0.044 kg/s. Itr is concluded that difference in inlet and outlet temperature increases with incraese in mass flow rates. For mass flow rate of 0.022kg/s difference in maximum temperature in both cases is observed is 9 °C. It is also observed that the performance of solar air heater increases with increases in mass flow rate. It is obtained that the thermal efficiency of solar air heater with trapezoidal corrugated absorber plate is 63% for 0.044kg/s.

Yadaba Mahanand et. al.[8] has performed numerical analysis to understand the effect of quarter circular ribs planted on the absorber plate on the performance of solar air heater. In this paper the effect of orientation of quarter circular ribs on the performance is studied. The ribs are aligned periodically in a transverse manner to the flow. A constant heat flux of 1000 W/m^2 iis supplied to the absorber plate of solar air heater. Input parameter varied in the range are 3800<Reynolds number< 18000, whereas the 7.14<relative roughness pitch <17.86, and the value of relative roughness height is constant, i.e., 0.042. It is found that maximum thermal enhancement of 1.88 is obtained at relative roughness pitch 7.14.

Anil Kumar et. al.[9] performed experimental investigation the effect of multi v shaped rib embedded in rectangular duct solar air heater with reynold number varying from 2000 to 20000. Maximum increment of nusselt number of 6.74 and friction factor of 6.37 compared to smooth duct is obtained. It has also been concluded that the value of Nusselt number and friction factor is more in multi v shaped with gap than continuous multi v shaped rib.

Anil Singh yadav et.al.[10] performed numerical analysis to study the effect of semicircular rib on the performance of solar air heater. The software used for this numerical analysis is ANSYS Fluent 16 software. Reynold number is varied from 3800 to 18000. The RNG k-ε model is used for the simulation purpose. Here different pitch values are taken for different investigation, pitch P = 10, 15, 20, 25mm. The main focus of the paper is to study the effect of ribs and the pitch of ribs on the performance of solar air heater. It is concluded that at pitch value of 15mm, The maximum performance is shown by solar air heater.

Leung et al.[12] has performed experimental study to study heat transfer and friction factor characteristics of equilateral horizontal duct solar air heater having their surface as groove roughened. This grooves are equally spaced, parallel and have same apex angle. This apex angle is varied from 0° to 150° and the depth of groovr taken is 1mm. Grooves are equally spaced i.e. 34mm and Reynold number is varied from 2800 to 9500. At Re = 6150, maximum heat transfer takes place at 17.5°, while the maximum friction factor is obtained at 110°. So the maximum use of grooves having apex angle of 17.5° is used.

Ahn and Son [13] studied the effect of Pitch to height of rib P/e on the performance of solar air heater by performing experimental analysis. The parameter are varied such as Reynold number is varied from 10000 to 70000, height to hydraulic diameter is taken as 0.046 and Pitch to height of rib P/e values are 4, 8 and 16mm. It is concluded that solar air heater shows maximum result at P/e = 8 in the entire range of Reynold number.

Amro et al. [14] This experiment focuses towards the cooling of turbine blades especially first stage turbine blade as large amount of heat load is present here. In order to increase cooling rate this paper takes trigular duct with 3D ribs attached with the surfaces. Reynold number is varied from 50000 to 200000. It is obtained that the maximum increase in heat transfer takes place at 60° inclination but it is also seen that maximum friction factor is obatined. When two parameter such as heat transfer and friction factor are taken together, then the maximum performance is shown at 45° inclination.

Braga and Saboya [15] performed the experimental analysis to study the effect pin fin effect of pin fin roughened internal walls on the heat transfer and friction factor.Extra length is taken both inside and outside the duct in order to attain fully developed flow about 30 times of hydraulic diameter.Thermodynamic conditions of two walls are isothermal and the third one is adiabatic. It is observed that at a constant Reynold number heat transfer increases about 200%.

Kumar et. al.[17] performed complete literature review to study the effect of various heights artificial roughness on the thermal perfomance of solar air heater. Various artificial geometries of such as ribs, dimple, baffles, wire mesh, delta etc. have considered during the literature survey. With the addition of roughness on absorber plate heat transfer increases and the friction penalty also increases. It is observed that maximum enhancement in heat transfer is obtained is for dimple embedded solar air heater about 7.58 followed by multi v shaped with gap of 6.74 and multi v shaped without gap of 6. It is concluded that the friction factor of dimple embedded solar air heater is 4.68 while the friction factor of multi v shaped with gap is 6.37 and without gap is 5. Thermohydraulic performance lies between 1.38 to 2.45.

Tong-miing liou et. al.[19] experimental analysis is conducted to study the effect of presence of various shaped ridges embedded on the two opposite wall of the duct, The geometries of ridges taken are semicircular, triangular, and square crosssection. Reynold number is varies from 7800 to 50000. It has been concluded that square ridge beat heat transfer of all the ridges taken.

Authors	Shape of the roughness/Parameter	Results/correlation
D.D. Luo[4]	Square $\{4000<Re_D<23000\}$	$Nu_D = 0.0058\, Re_D^{0.5924} \left(\frac{H}{D}\right)^{-2.7515} \left(\frac{S}{W}\right)^{1.8414}$
	$\{0.11 < \frac{H}{D} < 0.21\}$	$* \, e^{-0.7772\left(\ln\left(\frac{H}{D}\right)\right)^2} * \, e^{-0.4684\left(\ln\left(\frac{S}{W}\right)\right)^2}$
	$\{3.41 < \frac{S}{W} < 13.93\}$	$f = 5.04 Re_D^{-0.2897} \left(\frac{H}{D}\right)^{1.6224} \left(\frac{S}{W}\right)^{1.7842} e^{-0.4407\left(\ln\left(\frac{S}{W}\right)\right)^2}$

Yadaba Mahanand [8]	Quarter circle {4000<ReD<23000} → $\{4000<Re_D<23000\}$ $\{7.14 < \frac{P}{e} < 17.86\}$.	$Nu_r = 0.0341\, Re_D^{0.884} \left(\frac{P}{e}\right)^{-0.1293}$ $f_r = 0.5953\, Re_D^{-0.3194} \left(\frac{P}{e}\right)^{-0.0985}$
Anil Kumar [9]	Multi v shaped $\{2000<Re<20000\}$ $\{6 < \frac{P}{e} < 12\}$ $\{0.5 < \frac{g}{e} < 1.5\}$ $\{1 < \frac{W}{w} < 10\}$ $\{0.24 < \frac{G_d}{L_v} < 0.80\}$ $\{0.5 < \frac{\alpha}{60} < 1.25\}$	$Nu_r = 0.008532\, Re^{0.932}\left(\frac{e}{D}\right)^{0.175}\left(\frac{W}{w}\right)^{0.506} * e^{-0.0753(\ln(\frac{W}{w}))^2} * \left(\frac{G_d}{L_v}\right)^{-0.0348} * e^{-0.0653(\ln(\frac{G_d}{L_v}))^2} * e^{-0.223(\ln(\frac{g}{e}))^2} * \left(\frac{g}{e}\right)^{-0.0708} * e^{-0.0653(\ln(\frac{\alpha}{60}))^2} * e^{-0.223(\ln(\frac{P}{e}))^2} * \left(\frac{\alpha}{60}\right)^{-0.0239} * \left(\frac{P}{e}\right)^{1.196}$ $f_r = 3.1934\, Re^{0.932}\left(\frac{e}{D}\right)^{0.268}\left(\frac{W}{w}\right)^{0.1132} * e^{0.0974(\ln(\frac{W}{w}))^2} * \left(\frac{G_d}{L_v}\right)^{0.0610} * e^{-0.1065(\ln(\frac{G_d}{L_v}))^2} * e^{-0.6349(\ln(\frac{g}{e}))^2} * \left(\frac{g}{e}\right)^{-0.1769} * e^{-0.1527(\ln(\frac{\alpha}{60}))^2} * e^{0.1486(\ln(\frac{P}{e}))^2} * \left(\frac{\alpha}{60}\right)^{0.1553} * \left(\frac{P}{e}\right)^{-0.7941}$
Nidhul Kottayat [5]	Inclined Rectangular ribs $\{30° < \alpha < 75°\}$ $\{5000<Re<17500\}$	Performance of triangilar duct SAH increases with maximum value at $\alpha = 45°$
Rajneesh Kumar [8]	Rectangular and forward Chemfered rib $\{4000<Re<17000\}$ $\{0 < \frac{e'}{e} < 1\}$ $\{0.24 < \frac{e}{w} < 1.5\}$ e	Best Performance is observed in forward chemefered rib $Nu_r = 0.066\, Re^{0.858}\left(\frac{e'}{e}\right)^{0.022}\left(\frac{e}{w}\right)^{0.112}\left(\frac{e}{D}\right)^{0.241} * e^{0.039(\ln(\frac{e'}{e}))^2}$ $f_r = 11.79\, Re^{-0.58}\left(\frac{e'}{e}\right)^{0.169}\left(\frac{e}{w}\right)^{0.131}\left(\frac{e}{D}\right)^{0.0.318}$ e' 2

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	$\{0.018 < \frac{}{D} < 0.043\}$	$* \, e^{0.203(\ln(\frac{}{e}))}$
Selcuk Darici [7]	Trapezoidal Corrugated Rib	Best thermal efficiency of the solar air Darici collector with trapezoidal absorber plate is 63% for 0.044 kg/s
Anil Singh yadav [10]	Semicircular rib {3800<Re<18000}	Maximum nusselt number enhancement obtained is 2.08 at P= 10mm at Re=15000 and friction factor of 2.01 at P=10mm at Re=3800.
C.W. Leung [12]	V grooved roughess rib depth: 1 mm 30 º <θ<90 º P = 34mm 2800<Re<9500	For smooth surface $Nu_D = 0.014Re_D^{0:83}$, $f = 0:33Re_D^{-0.38}5$ For groove angle, θ= 30º $Nu_D = 0.036Re_D^{0:77}$, $f = 0:43Re_D^{-0.40}5$ For groove angle, θ= 60º $Nu_D = 0.031Re_D^{0:77}$, $f = 0.45Re_D^{-0.40}5$ For groove angle, θ= 60º $Nu_D = 0.029Re_D^{0:77}$, $f = 0.47Re_D^{-0.40}$
Ahn and Son [13]	6 Aluminum square ribs 10000 <Re<70,000 $\{4 < \frac{P}{e} < 16\}$ Rib height,h = 2mm	$\frac{P}{e} = 8$ perform better in entire reynold number

CONCLUSION

After going through the literature reviews following conclusions are drawn:-

- Duct with triangular geometry has the least friction factor when compared to other geometry.
- On rounding the corners of triangular duct nusselt number increases and also friction factor also increase. This increases in friction factor results in more pumping power.
- On increasing rounding radius friction factor increases and also increase in effectiveness is also observed. The maximum increament observed in rounding radius of 0.35
- Adding roughness element to the surface of solar air heater, results increase in heat transfer and also pumping power.
- In case of triangular duct, apex angle plays an important role in heat transfer. The maximum heat transfer occurs at apex angle of 60 º.

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