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Heat Transfer and Friction Factor Characteristics of Double Pass Solar Air Heater Using W-Shaped Artificial Roughness Ribs

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Abstract: *This paper represents the effect of artificial roughness with W-shaped geometry on heat transfer and friction factor of Double Pass Solar Heater having rectangular duct. Aspect ratio (W/H) of the duct is 10. Reynolds number for experiment varies from 6900 to 14000. W-shaped ribs attached on both sides of absorber plate at fixed inclination angle (α) 45^0, relative roughness height(e/D_h) is fixed0.044 and relative roughness pitch (p/e) is varies from 5 to 20. It has been observed that at relative roughness pitch (p/e) of 10 maximum heat transfer and friction factor occurs. The enhancement in the heat transfer is found to be 1.4 times of the smooth plate.*

Keywords: *Nusselt number, Friction factor, Reynolds number, W-shaped ribs, double pass solar air heater.*

I. INTRODUCTION

Solar air heater is the simplest device for converting the solar energy into heat energy. Firstly *the solar energy collected over an absorber plate then this heat is used to warm the air. Space heating, wood* seasoning, food dehydration and drying of crops are some major applications of air heater.[1]

The main problem of using solar air heater is low heat transfer to air because viscous laminar sub layer is present in turbulent boundary layer adjacent to the absorber plate. So all the heat is not able to reaches the absorber plate. Laminar sub layer should be destroyed to increase the heat transfer. Viscous laminar sublayer can be destroyed by roughening the surface.In order to roughening the surface different configuration of artificial roughness in the form of ribs has been used but due to increase in friction factor power required also increases. So for selecting the particular ribs geometry both increase in heat transfer and power penalty must be considered.

Prasad et al. [2] studied the effectof relative roughness pitch (p/e), relative roughness height (e/D_h), and Reynolds number on heat transfer andfriction factor.They found thatfriction factor and Nusselt number are2.38 and 4.25 times that of smooth duct respectively. At relative roughness pitch of 10 and relative roughness height of 0.033 they found the maximum heat transfer. Singh et al. [3] performed experiment on solar air heater having rectangular duct with periodic discrete V-down ribs. It was reported that Nusselt number and friction factor increases by 3.04 and 3.11 times as compared to smooth duct. Lanjewar et al. [4] performed experiment on single pass solar air heater having W-shaped ribs at different orientation on absorber plate to found effect of artificial roughness on heat transfer and friction factor. They found maximum thermo hydraulic performance to be 1.98 for W-down ribs and 1.81 for W-up ribs.

Satcunanathan et al.[5] introduced the concept of counter flow double pass air heater. They proved that double pass air heaters are 10-15 % more effective than single pass air heater. Wijeysundera et al. [6] investigated the thermal performance parameter of double pass solar air heater. They found that it is an economical method for improving the collector efficiency up to 10-15 % by providing two covers in conventional solar air heater in double pass mode.H.M. Yehet al. [7] investigated both experimentally as well as analytically the collector efficiency of double pass solar air heater with fins attached on both side of absorbing plate. It was reported that the collector efficiency is unity i.e. the optimal fraction of airflow rate r, is 0.5. The thermal performance decreases when r, as well as (1-r), more than 0.5. The collector efficiency of double pass solar air heater is 70.5% at the value of r is 0.5.

Sudhanshu et al. [8] investigated the impact of artificial roughness on heat transfer and friction factor characteristics of double pass solar air heater having rectangular duct and transverse ribs attached to the absorber plate as roughness element. It was reported that at relative roughness pitch (p/e) of 10 maximum heat transfer and friction factor occurs.

Avdhesh et al. [9]investigated the effect of V- shaped roughness element attached to absorber plate on both sides of double pass solar air heater having rectangular duct on heat transfer and friction factor. It was reported that at relative roughness pitch of 10, inclination angle of $60^0$and relative roughness height of 0.033 heat transfer and friction factor are maximum.

The main aim of present study is to show the effect of W-shaped artificial roughness element in the form of ribs on heat transfer and friction factor of double pass solar air heater having rectangular duct and ribs attached on both sides of absorber plate.

II. EXPERIMENTAL SETUP

The schematic and pictorial view of experimental setup is shown in “Fig.1” and “Fig.2” respectively. Size of rectangular duct is 2070mm×250mm×25mm. According to ASHARAE standard [10] the entry length is designed as 400mm. length of test section is 1600mm and a space of 70mm is left at the end for the movement of air towards upper section.

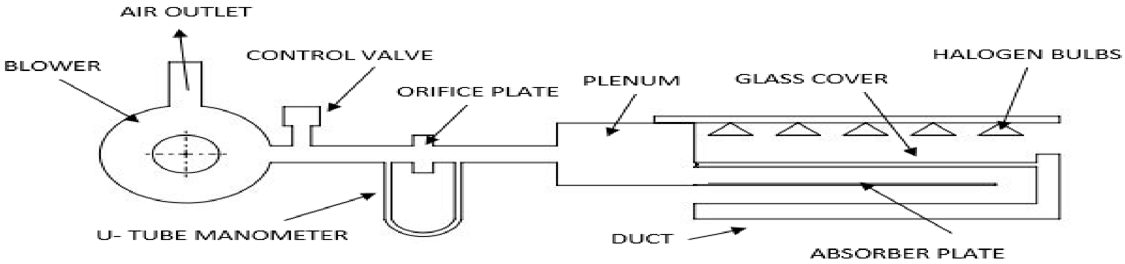

Fig. 1. Cad model of experimental set up

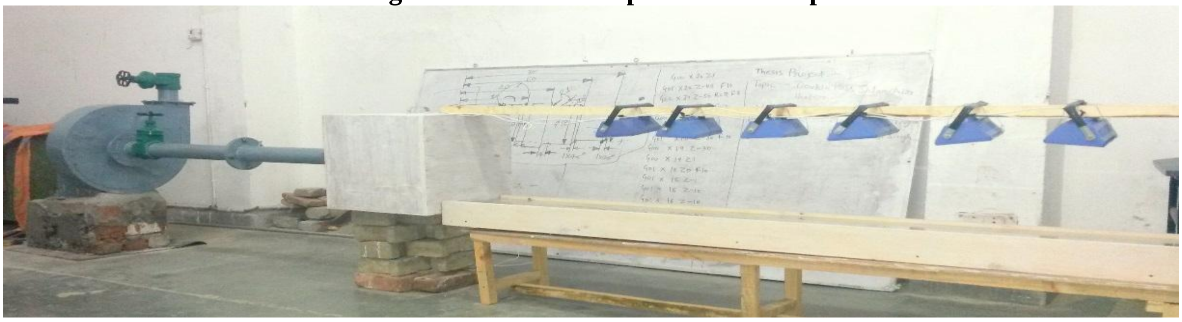

Fig. 2. Complete experimental setup

The required intensity of heat fluxfor experiment is 900w/m^2 so we use 6 halogen lights of 500W each and these lights fixed on a board at height of 1meter above from the duct. This heating source act as a solar simulator and the intensity of flux is measured by pyrometer. For providing passage to air a glass sheet of 4mm is placed over the duct and also it helps to lights directly falls over the absorber plate.GI sheet of 0.8mm thickness is used as absorber plate. Aluminum wire of 2mm diameter is used as roughness element and this wire is attached on both side of plate.The absorber plate is shown in “Figure.3”.

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Fig.3. Pictorial view of absorber plate

A calibrated orifice meter is used for measuring the mass flow rate of air through duct which is fitted in circular pipe. Flow of air is controlled by control valve provided in blower. Blower is attached to pipe for sucking the air from duct. For measuring the air and absorber plate temperature at different location 10K ohm thermistor is used. Micro manometer is used to measure pressure drop across test section.

III. EXPERIMENTAL PROCEDURE

Before starting the experiment all the joints of pipe, inlet and outlet section of duct should be check for leakage. When the setup attains steady state process, then at different mass flow rates the following data was recorded to calculate heat transfer and friction factor.

1. Air temperature at inlet and outlet of duct.
2. Temperatures at 12 different locations on absorber plate.
3. Pressure measurement across orifice meter and pressure drop across test section.
4. Mass flow rate with the help of orifice meter.

IV. DATA REDUCTION

The different formulae which is used for calculation is shown in Table 1.

Table 1. Data reduction formulae

Parameters	**Explanation**	**Formulae Used**
Mean plate Temperature (T_p)	It is calculated by taking average of temperatures recorded at 12 different locations of absorber plate.	$T_P = \frac{T_1+T_2+T_3+\cdots+T_{12}}{12}$(1)
Air Temperature (T_f)	Bulk mean temperature of air is mean of air temperature at inlet and outlet of test section.	$T_f = \frac{T_I+T_e}{2}$ (2)
Mass Flow Rate of Air (m)	Mass flow rate of air is calculated by measured pressure drop across the orifice meter.	$m = C_d A_0 \sqrt{\frac{2\rho\Delta P_0}{1-\beta^4}}$(3)
Velocity of air through duct (V)	The velocity of air is calculated by mass flow rate and area of flow (area of duct).	$V = \frac{m}{\rho WH}$(4)
Reynolds Number (Re)	The Reynolds number of airflow is calculated by knowing velocity, density, hydraulic diameter of duct and viscosity.	$Re = \frac{\rho V D_h}{\mu}$(5)
Friction factor (f)	Darcy Wiesbach equation is using to calculate friction factor by measuring pressure drop across test section.	$f = \frac{2(\Delta P)D_h}{4\rho L V^2}$(6)
Heat transfer rate (Q_u)	Heat transfer rate (Qu) to the air is calculated by using inlet and outlet temperature of air.	$Q_u = mC_p(T_o - T_i)$(7)
Heat transfer coefficient (h)	The heat transfer coefficient (h) is calculated by knowing the plate temperature and area of heating surface.	$h = \frac{Q_u}{A_p(T_p - T_f)}$(8)

V. VALIDITY TEST

The experimental setup is validated by comparing the Nusselt number and friction factor value for smooth plate calculated from experimental data with actual value defined from Dittus-Boelter equation and modified Blasius equation respectively.

Dittus-Boelter equation: $Nu_s = 2 \times .024 Re^{0.8} \mathrm{Pr}^{0.4}$ (9)

Modified Blasius equation: $f_s = 2 \times 0.085 Re^{-0.25}$ (10)

It is the case of double pass solar air heater so the Dittus-Boelter equation [10] and modified Blasius equations [11] are two times of original value. “Fig. 4” and “Fig. 5” shows the comparison of predicted value of Nusselt number and friction factor with experimental value respectively for smooth plate in order to validate the setup.

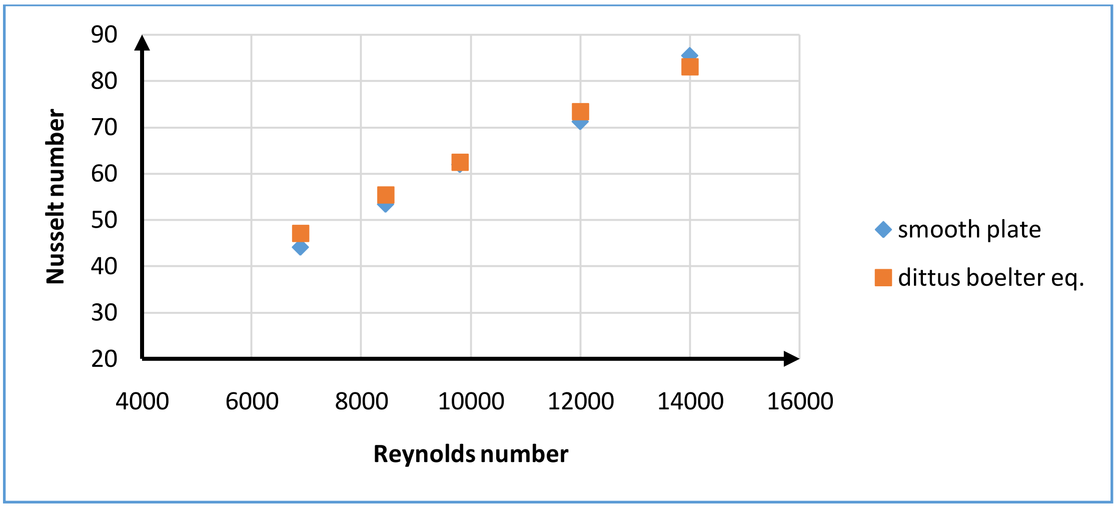

Fig. 4. Comparison of actual Nusselt number (predicted value) with experimentally calculated Nusselt number for smooth plate

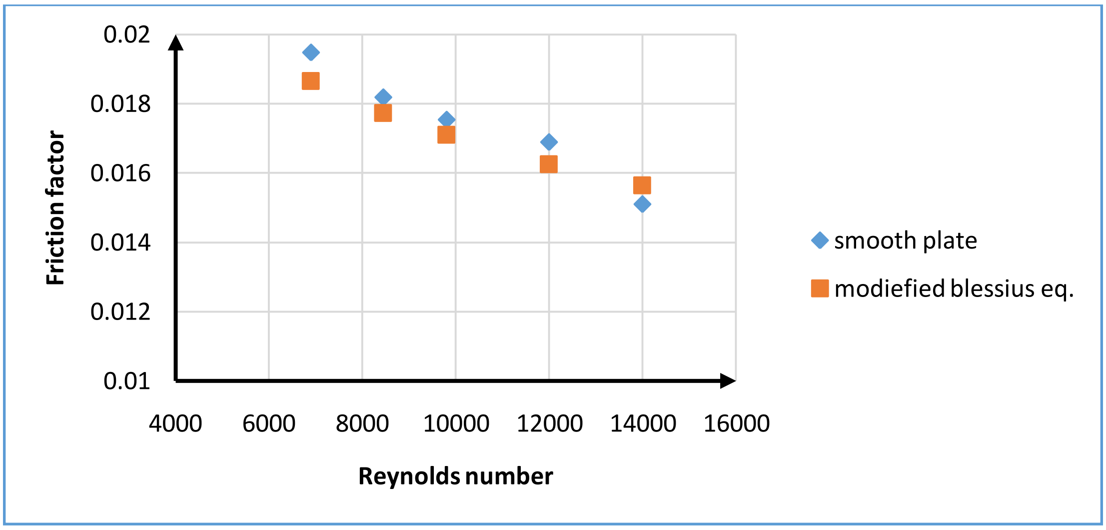

Fig. 5. Comparison of actual Friction factor (predicted value) with experimentally calculated friction factor for smooth plate

VI. RESULT AND DISCUSSION

The impact of relative roughness pitch (p/e) on Nusselt number and friction factor is discussed in this section. The variation of Nusselt number and friction factor with Reynolds number is shown in “fig.6” and “fig.7” respectively for fixed inclination angle (α) of 45^0, fixed relative roughness height (e/D_h) as 0.044 and different relative roughness pitch (p/e) as 5, 10 and 20.

“Fig.6” shows that as Reynolds number increases Nusselt number also increases continuously. The maximum enhancement in Nusselt number as well as in heat transfer occurs at relative roughness pitch of 10 because maximum reattachment point occurs at this p/e ratio hence heat transfer also get enhanced.

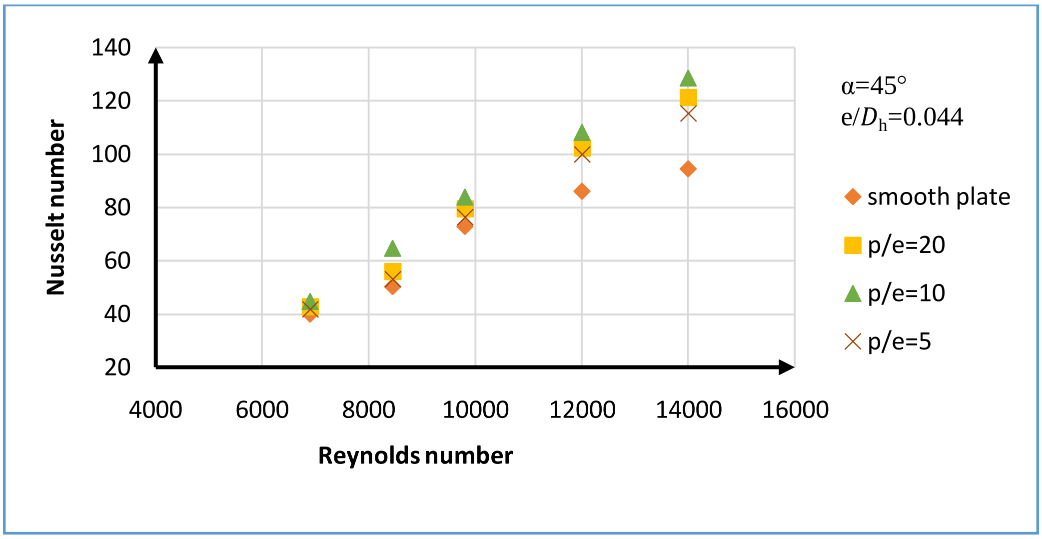

Fig. 6. Nusselt number variation with the Reynolds number

"Fig.7" shows that friction factor continuously decreases with increase in Reynolds number and the maximum friction factor occurs at relative roughness pitch (p/e) of 10.

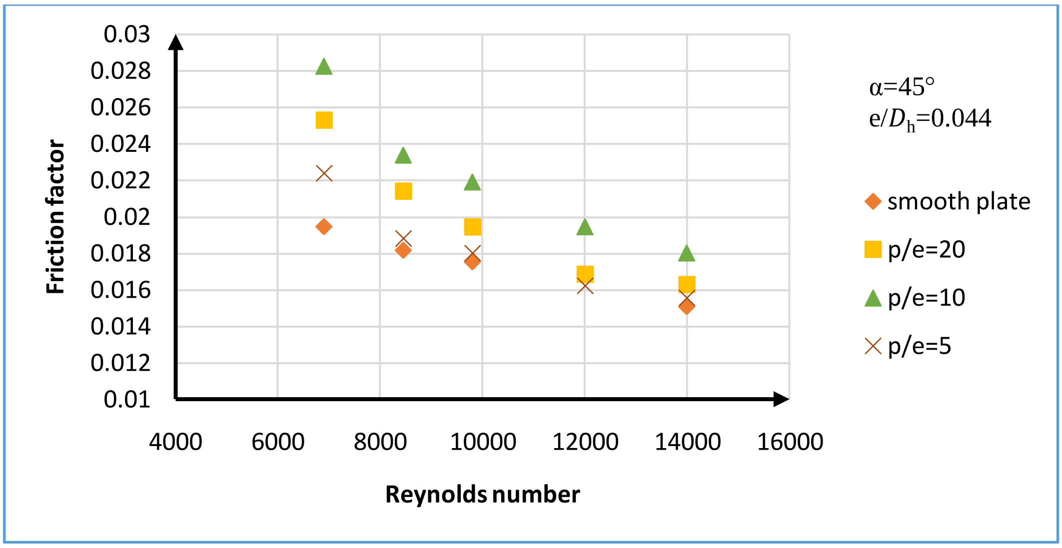

Fig. 7. Friction factor variation with the Reynolds number

VII. CONCLUSION

An experimental investigation has been carried out to show the effect of relative roughness pitch on heat transfer and friction factor of double pass solar air heater having W-shaped artificial roughness on both sides of absorber plate. On the basis of experimental investigation it is found that by providing artificial roughness on both sides of absorber plate both heat transfer and friction factor enhanced. It has been seen that Nusselt number increases continuously with increase in Reynolds number whereas friction factor continuously decreases with increase in Reynolds number. At relative roughness pitch (p/e) of 10 maximum heat transfer and friction factor occurs. Nusselt number enhanced 1.4 times as compare to smooth duct. By using this concept the highly efficient solar air heater can be design.

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