Short communication(T-2)

THERMOHYDRAULIC PERFORMANCE OF SOLAR AIR COLLECTOR USING W-SHAPED ARTIFICIAL ROUGHNESS

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ABSTRACT

An experimental investigation has been carried out to study heat transfer, friction characteristics and thermo-hydraulic performance of roughened absorber plate in solar air heater by using W-shape rib roughness, the roughened wall being heated while the remaining three walls insulated. The roughened wall has relative roughness height (e/Dh) 0.018, relative roughness pitch (p/e) 10, rib height 0.8 mm, angle of attack in the range of 30^o - 60^o and duct aspect ratio (W/H) 8. The air flow rate corresponds to Reynolds number between 2300-14000. Experimental results have been compared with those for smooth duct under similar flow and thermal boundary condition. Performance comparison of ribs with different angle of attack show that W-shape ribs with angle of attack of 60^o gives best thermo-hydraulic performance.

Key Words : Solar air heater, Thermo-hydraulic performance W-shape ribs, Friction Characteristics, Neat tronsjer

INTRODUCTION

Flat plate solar air heaters deliver heated air at moderate temperatures for space heating and crop drying. Main thermal resistance to heat transfer is formation of laminar sub-layer on heat transferring surface. Efforts for enhancing heat transfer have been directed towards artificially destroying boundary layer. Artificial roughness in the form of wires and various rib arrangements have been used to create turbulence near the wall to break the laminar sub-layer[1-11]. Because of rib roughness, heat transfer coefficient enhancement is also accompanied with an enhancement in friction factor. Appropriate way to evaluate performance of solar air heaters with roughened absorber plate is to take both heat transfer and pumping power requirement into account i.e. to carry out thermo-hydraulic performance evaluation[9]. Objective of present investigation is to study experimentally effect of W-shape rib roughness provided on absorber plate in solar air heater on its thermo-hydraulic performance. Thermo-hydraulic performance comparision for different angle of attacks has been done.

MATERIAL AND METHODS

Indoor experimenttal investigation

The experimental set up is an indoor open flow loop that consists of a test duct with entrance and exit sections, a blower, control valve, orifice plate and various devices for measurement of temperature and fluid head. The test section is of 1500 mm length (33.75 D_h). The entry and exit lengths are 177 mm (2.5 $\sqrt{WH}$) and 354 mm (5 $\sqrt{WH}$) respectively[12]. The test section carries the roughened absorber plate at the top. Exit section of 354 mm length is used after the test section in order to reduce the end effect in the test section. In the exit section after 130 mm, three equally spaced baffles are provided in 87 mm length for the purpose of mixing the hot

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air coming out of solar air duct to obtain a uniform temperature of air at the outlet. An electric heater was fabricated by combining series and parallel loops of heating wire on asbestos sheet. The heat flux may be varied from 0 to 1000 W/m^2 by a variac across it. The back-side of the heater is insulated with glass wool to minimize heat losses. The outside of the entire set-up from the inlet to the orifice plate is insulated with 25 mm thick foamed polystyrene (thermocole). The heated plate is 1 mm (20 SWG) thick G. I. sheet of size 1500 mm x 200 mm having W-shaped ribs glued on its rear side by epoxy resin and this forms the top broad wall of the duct. The mass flow rate of air is measured by means of a orifice meter connected with an inclined manometer, and the flow is controlled by control valves provided in the lines. Calibrated copper- constantan 0.3 mm (24 SWG) thermocouples were used to measure the air and the heated plate temperatures at different locations. A digital micro-voltmeter is used to indicate the output of the thermocouples. Pressure drop across the test section was measured by a micro-manometer. The geometry of W-shaped rib roughness used in the experiment

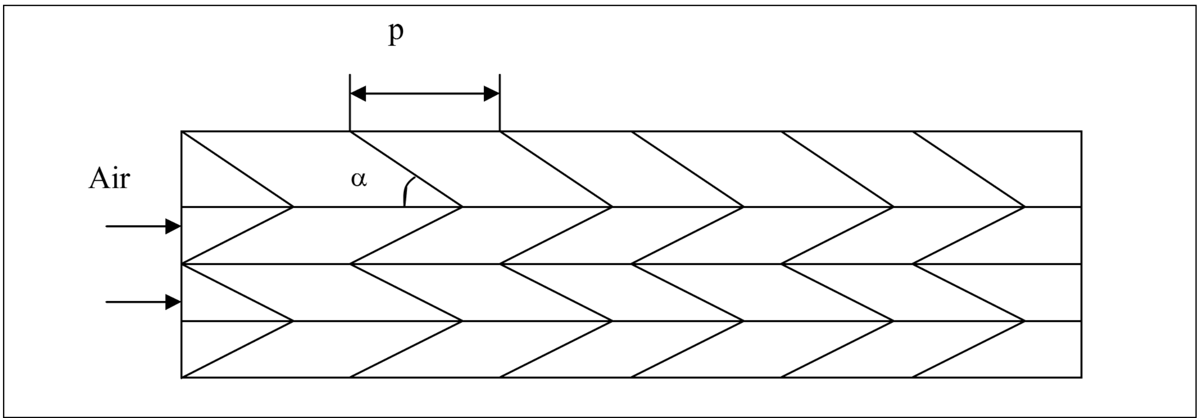

Fig. 1 : Roughness geometry

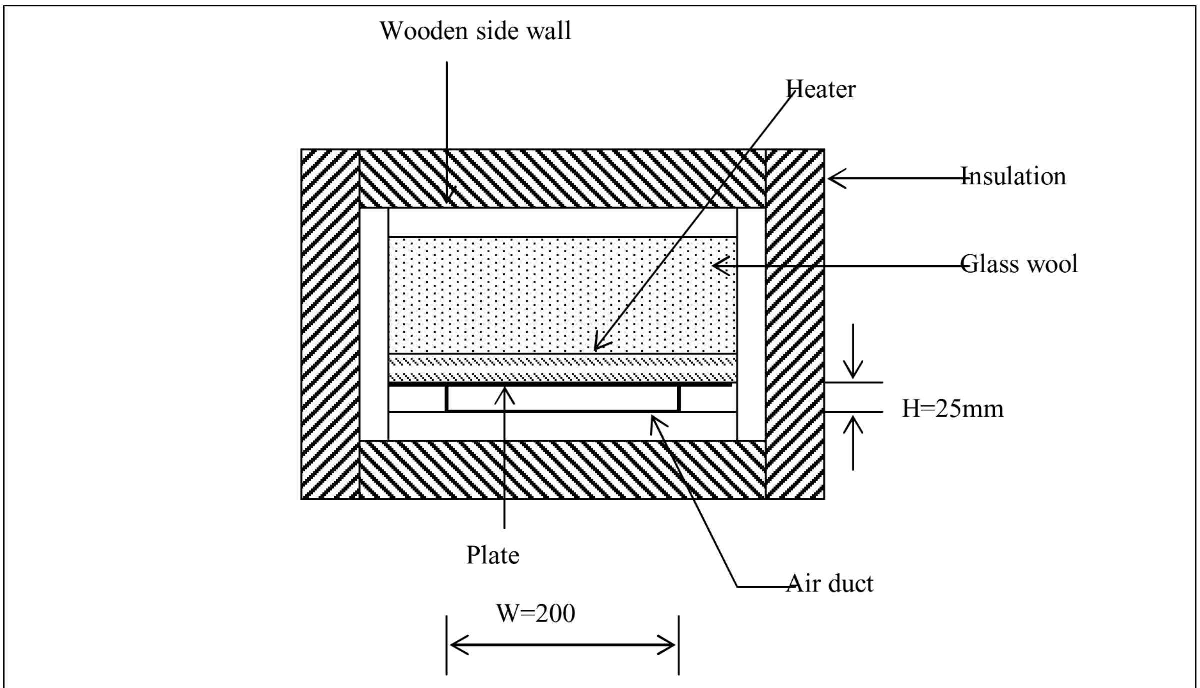

Fig. 2 : Cross-sectional view of experimental set up

is shown in **Fig. 1**. Cross-section of the experimental set up is shown in **Fig. 2**.

Experimental procedure

Blower is switched on and the flow control valve is adjusted to give a predetermined rate of airflow to the test section. The test runs to collect relevant heat transfer data were conducted under steady state conditions. For each rib configuration seven runs have been conducted at air-flow rates corresponding to the flow reynolds number between 2300 and 14000 **(Table 1).** After each change of flow rate the system is allowed to attain steady state before the data were recorded. The following parameters were measured during the experiments: 1. Pressure drop across the orifice meter 2. Inlet air temperature of collector 3. Outlet air temperature of collector 4. Temperature of absorber plate 5. Pressure drop across the test section of the duct.

Range of parameters for investigation

Parameter	Values
Reynolds Number	2300-14000
Hydraulic Diameter	44.44 mm
Rib height	0.8 mm
Relative roughness pitch	10
Relative roughness height	0.018
Aspect ratio of duct	8:1
Rib angle of attack	30^0, 45^0 and 60^0

Data Reduction

Heat transfer coefficient for the heated test section was calculated from

$$h = \frac{Q_u}{A_p (T_p - T_f)} \qquad (1)$$

where h is convective heat transfer coefficient (W/m^2K), Q_u is heat transfer rate to air (W), A_p is area of absorber plate (m^2), T_p is mean plate temperature (K) and T_f is mean air temperature (K). The mean plate temperature T_p in Eq. (1) has been calculated as weighted mean of the plate temperature values obtained experimentally. Heat transfer rate, Q_u, to the air is given by,

$$Q_u = mCp\,(T_\alpha - T_i) \qquad (2)$$

where m is mass flow rate of air (kg/s), C_p is specific heat of air at constant pressure (kJ/kgK), T_o is air outlet temperature (K) and T_i is air inlet temperature (K). Heat transfer coefficient has been used to determine Nusslet number. Friction factor (f) was determined from the measured value of pressure drop, ΔP, across the test section length, L_f, of 1.36 m (between two points at 250 mm and 1610 mm from the inlet) using the equation

$$f = \frac{2 \Delta P \rho D_h}{4 L_f G^2} \qquad (3)$$

where ΔP is pressure drop in the duct (N/m^2), ρ is density of air (kg/m^3), D_h is hydraulic diameter (m), L_f is duct length for calculation of friction factor and G is the mass velocity of air (kg/sm^2).

RESULTS AND DISCUSSION

Prior to experimentation on roughened plates, data collection on smooth rectangular duct was carried out. Friction factor results were compared with the correlation for a smooth rectangular duct given by modified blasius equation

$$f_s = 0.085\ R_e^{-025}$$

where Re is Reynolds number. Standard deviation of the present experimental friction data has been found to be ±5 % from the values predicted by equation (4). Standard deviation of the Nusselt number data was ±5 % from the values predicted by modified dittus boelter equation[13]. The good agreement between the predicted and experimental values ensures the accuracy of the experimental data collected with the present setup.

Variation of nusselt number and friction factor with Reynolds number

Fig. 3 and **Fig. 4** show the variations of Nusselt number ratio Nu_r/Nu_s, and friction factor ratio f_r/f_s, respectively, with Reynolds number, i.e. the effect of the roughness on the Nusselt number and friction factor enhancements relative to the smooth duct. Over the range of reynolds number studied, the values of Nusselt number ratio are found to be 1.32-1.92, 1.32-1.81 and 1.09-1.56

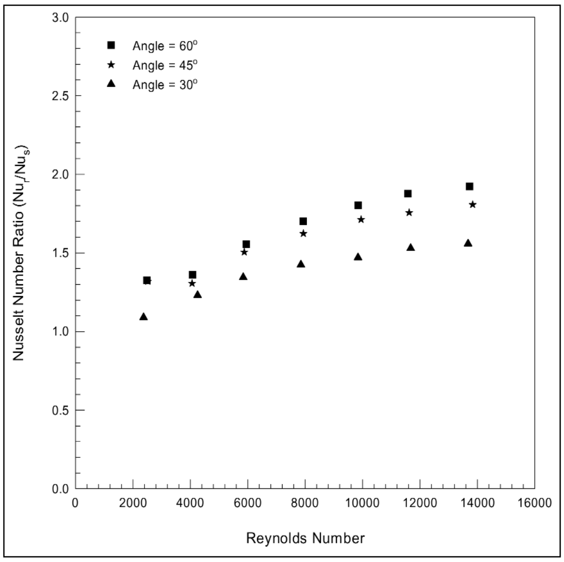

Fig. 3 : Nusselt number ratio versus Reynolds number

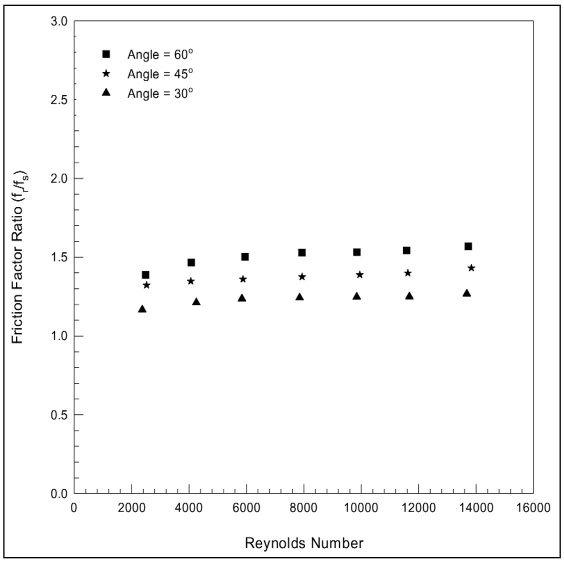

Fig. 4 : Friction factor ratio versus Reynolds Number

for 60^0, 45^0 and 30^0 angle of attack respectively. Friction factor ratios for these rib arrangements are 1.39-1.57, 1.32-1.43 and 1.17-1.27 respectively.

Thermo-Hydraulic performance

Artificial roughness on the absorber plate results in heat transfer enhancement. It is accompanied by increase in friction factor[14-15]. To select the roughness geometry it is essential that heat transfer is maximized while keeping frictional losses at minimum possible value. This requirement is fulfilled by considering heat transfer and friction characteristics simultaneously. For achieving simultaneous consideration of thermal as well as hydraulic performance, i.e., thermo-hydraulic performance, Webb et al.[16] proposed a thermo-hydraulic parameter defined as $(Nu_r/Nu_s)/(f_r/f_s)^{1/3}$ where Nu_r and Nu_s are Nusselt number of roughened and smooth plate respectively. f_r and f_s are friction factor of roughened and smooth plate respectively. This parameter is plotted in **Fig. 5.** against Reynolds number for relative roughness height of 0.018 and for different angles of attack. It is seen that thermo-hydraulic performance improves with increasing angle of attack and enhanced performance is obtained with 60° angle.

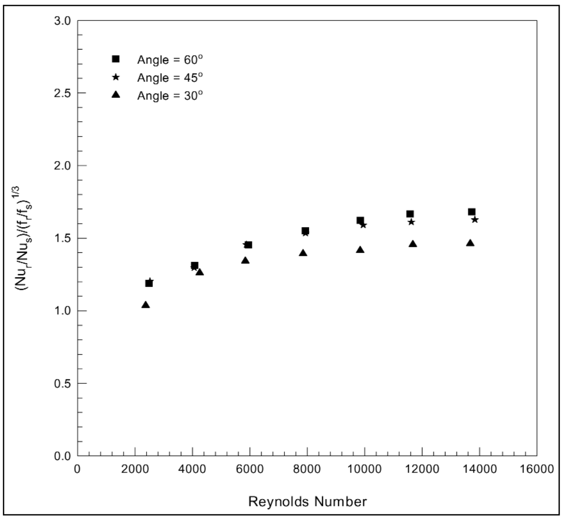

Fig. 5 : Thermo-hydraulic performance parameter versus Reynolds number

CONCLUSION

The enhancement in Nusselt number over the smooth duct is 32-92%, 31-81% and 9-56% for 60°, 45° and 30° respectively. Friction factor ratios for these arrangements are 1.39-1.57, 1.32-1.43 and 1.17-1.27 respectively. Thermo-hydraulic performance parameter improves with increasing the angle of attack of flow and best performance occurs with an angle of attack of 60°.

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