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ScienceDirect

Solar Energy 105 (2014) 479–493

SOLAR ENERGY

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Effect of artificial roughness on heat transfer and friction characteristics having multiple arc shaped roughness element on the absorber plate

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Received 16 December 2013; received in revised form 16 February 2014; accepted 10 April 2014
Available online 8 May 2014

Communicated by: Associate Editor P. Gandhidasan

Abstract

In this present experimental investigation the effect of geometrical parameters of multiple arc shaped roughness element on heat transfer and friction characteristics of rectangular duct solar air heater having roughness on the underside of the absorber plate have been studied. The parameters were selected on the basis of practical considerations and operating conditions of solar air heaters. The experiments carried out encompasses Reynolds number (Re) in the range of 2200–22,000, relative roughness height (e/D) range of 0.018–0.045, relative roughness width (W/w) ranges from 1 to 7, relative roughness pitch (p/e) range of 4–16 andarc angle (α) ranges from 30 to 75°. The thermo-hydraulic performance parameter was found to be best for relative roughness width (W/w) of 5.

Keywords: Nusselt number; Friction factor; Multiple arc shaped; Roughness element

1. Introduction

Solar energy is available freely, omnipresent and an indigenous source of energy that provides clean environment. The easiest methodology for making the proper use of solar energy is its conversion to thermal energy using solar collector. These solar collectors are the part of solar air heater and solar water heater which are used for heating air and water respectively. Solar air heater has been employed to deliver heated air at low to moderate temperatures for space heating, crop drying and several industrial applications (Kumar et al., 2012). Thermal efficiency of smooth plate solar air heater is significantly low because of low convective heat transfer coefficient between the absorber plate and fluid (air). This also leads to increase the absorber plate temperature and high amount of heat losses to the atmosphere. In order to make solar air heater efficient it is necessary to enhance the heat transfer rate. In a smooth plate solar air heater a thin viscous sub layer develops adjacent to the wall in turbulent boundary layers where the velocity is relatively low. In this region heat transfer is predominated by conduction and beyond this heat transfer process is dominated by convection (Kumar et al., 2013).

The easiest method used for the enhancement of heat transfer is to provide artificial roughness on the underside of plate. Artificial roughness provides the turbulence to the flow which leads to increase the heat transfer between the air and the heated wall but it also increases the pumping power penalty. For that purpose roughness should be created in such a region that the only laminar sub layer

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http://dx.doi.org/10.1016/j.solener.2014.04.007
0038-092X/

Nomenclature

A_p	surface area of absorber plate (m^2)
A_o	area of orifice meter (m^2)
C_P	specific heat of air (J/kg-K)
C_d	coefficient of discharge
D	hydraulic diameter (m)
e	rib height (m)
e/D	relative roughness height
f	friction factor for roughened duct
H	height of duct (m)
h	heat transfer coefficient (W/m^2-K)
In	turbulence intensity
k	thermal conductivity (W/m-K)
L	length of test section in duct (m)
m	mass flow rate of air (kg/s)
Nu	Nusselt number
ΔP_o	pressure drop across orifice plate (Pa)
ΔP_D	pressure drop across test section (Pa)
p	pitch (m)
p/e	relative roughness height
Pr	Prandtl number
Q_u	useful heat gain (W)
Re	Reynolds number
St	Stanton number
T_o	air outlet temperature (K)
T_i	air inlet temperature (K)
T_{pm}	average temperature of absorber plate (K)
T_{fm}	average temperature of air (K)
v	mean flow velocity in duct (m/s)
W	width of duct (m)
W/w	relative roughness width
W/H	aspect ratio of duct

Greek symbols

α	arc angle (°)
ρ	density (kg/m^3)
β	ratio of orifice diameter to pipe diameter

Sub-scripts

m	manometric
s	smooth

may get disturb. There are various methods to provide roughness on the surface (absorber plate) such as casting, sand blasting, forming, machining, and welding. Various experimental investigations have been carried out involving different shapes and size of artificial roughness. Shape, size and orientation of roughness elements have its influence on the performance of solar air heater. A detailed review has been carried out on the rectangular duct having roughness on the absorber plate (Bhushan and Singh, 2010; Hans et al., 2009; Varun et al., 2007).

Prasad and Saini (1988) had experimentally investigated the effect of e/D and p/e on Nusselt number and friction factor. The maximum enhancement in Nusselt number and friction factor were found to be 2.38 and 4.25 times respectively. Gupta et al. (1993) had experimentally investigated the effect of e/D and angle of attack on Nusselt number and friction factor using inclined ribs as a roughness element. The maximum heat transfer and friction factor were found at an angle of attack of 60° and 70° respectively. Inclined wire enhance heat transfer more as compared with transverse wire due to generation of secondary flow in addition to breaking of laminar sub layer. Taslim and Krecher (1996) had investigated the heat transfer and friction characteristics of a channel roughened with angled and v-shaped ribs. V-shaping of ribs can further enhance heat transfer due to generation of two high heat transfer regions. Momin et al. (2002) had experimentally investigated the effect of geometrical parameters of v-shaped ribs on heat transfer and friction factor. The maximum enhancement of Nusselt number and friction factor were found to be 2.30 and 2.83 times respectively over smooth duct. Saini and Saini (2008) had experimentally investigated arc-shaped ribs in rectangular channel and reported an enhancement in Nusselt number and friction factor of order 3.6 and 1.75 times respectively as compared to smooth one. Hans et al. (2010) used multiple v-shaped ribs on the heated plate having rectangular passage. The maximum enhancement in Nusselt number and friction factor were found in the order of 6 and 5 times respectively as compared with smooth one. Sethi et al. (2012) has carried out experimental investigation on dimple shaped element arranged in angular fashion (arc) as roughness element and reported an enhancement in Nusselt number and friction factor of the order of 2.46 and 3.08 times respectively as compared to smooth. Yadav et al. (2013) has experimentally investigated effect of heat transfer and friction characteristics of turbulent flow of air passing through rectangular duct which is roughened by circular protrusions arranged in angular arc fashion. The maximum enhancement in Nusselt number and friction factor is 2.89 and 2.93 respectively as compared to smooth duct.

In view of the above, it can be stated that angling of wire leads to increase the heat transfer significantly but less increase in friction factor takes place. In this present study, multiple arc shaped roughness elements were selected for the experimental investigation of heat transfer and friction characteristics in a rectangular channel solar air heater.

1.1. Roughness geometry

Multiple arc-shaped roughness elements (Fig. 1) were chosen for the experimental investigation of roughened