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Effect of geometrical aspects on the performance of jet plate solar air heater

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ABSTRACT

The present work deals with the experimental study of effects of flow and channel spacings, Z_1 and Z_2 on the performance of a cross – flow staggered hole jet plate solar air heater. This work is carried out with mass flow rate, $\dot{m}_1$ = 0.030–0.065 kg/s, $\dot{m}_2$ = 0.020–0.043 kg/s, Reynolds number, *Re* = 2700–6900, depth ratio, Z_2/Z_1 = 0.75–1.0, total air depth, Z = 0.14 m, jet hole diameter, D = 0.006 m, Number of jet holes, N = 1173 and tilt angle, θ = 22.6°. The experiment is performed during the month of November - December, 2013 at ISM Dhanbad, India between 9.00 AM to 3.00 PM on hourly basis in the clear sky with the help of precision instruments fitted with the setup for recording the temperature, velocity and intensity of radiation. The performance in terms of outlet temperature, collector efficiency and Nusselt no. of this solar air heater are found substantially higher at higher spacing between the jet and absorber plate (Z_2 = 0.07 m) while mass flow rate adversely affects the outlet temperature. In the present study, the non-conventional jet plate solar air heater is also compared with conventional parallel plate solar air heater and it is observed that the performance of the jet plate solar air heater is always higher than conventional solar air heater. Friction factor is not significantly changed with Z_2. Based on the experimental data, the correlations for Nusselt number and friction factor have been developed.

1. Introduction

The jet plate solar air heater is categorized under non - conventional solar air heater which could give better performance than conventional solar air heater. The principal applications in which solar air heaters are used are drying of agricultural crops and space heating (Akpinar and Kocyigit, 2010), pre heating in industries and auxiliary heating in buildings during winter season (Karsli, 2007).

In the recent past, several modifications have been made on conventional solar air heaters by providing artificial roughness obstacles, baffles in various shapes with different arrangements and longitudinal fins over and underside of the absorber plate. As a result, the heat transfer coefficients between the absorber plate and the air pass have been increased (Akpinar and Kocyigit, 2010; Karsli, 2007; Romdhane, 2007). Thombre (1991) have suggested a variation on conventional type solar air heater with longitudinal fins fitted under the lower surface of the absorber plate. Singh (2006) analytically presented the heat transfer enhancement in a continuous longitudinal fins solar air heater for different pitches. Kurtbas and Emre (2006) have studied solar air heater with free and fixed fins and found increased heat transfer coefficient and output air stream temperature in both. Adam and Yousef (2008) have theoretically investigated the effect of mass flow rate, depth of flow channel and length of air heater on thermal performance and pressure drop through the channel with and without porous medium. Singh (2013) investigated the experimental results on flow and heat transfer studies in a double – pass counter flow solar air heater. Chaudhary and Garg (1991) have done analytical work and evaluated the gain in temperature increment and performance efficiency of the inline hole cross and non - cross flow jet concept solar air heater over that of the parallel plate air heater with duct depth 10 cm and length 2.0 m is 15.5–2.5 °C and 26.5–19.0% respectively, for air flow rates in the range 50–250 kg/h m^2. Metzer and Florschuetz (1979) studied heat transfer characteristics for inline and staggered arrays of circular jets with cross - flow spent air. Xing and Sebastian (2010) have presented the experimental and numerical results on heat transfer characteristics of inline and staggered hole jet plate in cross - flow condition. Chauhan and Thakur (2013) have suggested on heat transfer and friction factor correlations for impinging jet solar air heater.

Based on above cited literatures, it is clear that ample amount of works have been done in the cross flow jet plate with inline hole solar air heater. However, very few literatures are available in the staggered hole jet plate solar air heater (Metzer and

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Nomenclature

A	surface area of absorber plate, m^2
Aj	area of jet hole, m^2
A_2	cross – sectional area of upper channel, m^2
C	sp. heat capacity of air, kJ/kg K
d	air thicness between absorber and cover plate, m
D_2	hydraulic diameter of upper channel, m $D_2 = 4WZ_2/2(W + Z_2)$
D	diameter of jet hole, m
D_h	hydraulic diameter for parallel plate air heater, m $D_h = 4WZ/2(W + Z)$
F_1	dimensionless constant
F_2	cross - flow degradation factor
f_s	friction factor
h_{cPa}	plate-to-air heat transfer coefficient in parallel plate air heater, W/m^2 K
h_{Pj}	average plate - to - jet air heat transfer coefficient, W/m^2 K
I_T	incident solar intensity, W/m^2
K_a	thermal conductivity of air flowing through duct, W/m K
l_i	glass wool thickness, m
L	length of air heater, m
m	dimensionless constant
$\dot{m}_1$	mass flow rate of air in parallel plate and bottom channel, kg/s
$\dot{m}_2$	mass flow rate of air in cross - flow, kg/s
Nu_{Pa}	Nusselt number between absorber and back plate
Nu_{ja2}	Nusselt number between absorber and jet plate
Nu	Nusselt number for parallel plate and jet plate solar air heater
Re	Reynolds number for parallel plate and jet plate solar air heater
Re_D	jet Reynolds number
Re_{ja2}	flow Reynolds number between absorber and jet plate
Re_{Pa}	flow Reynolds number between absorber and back plate
T_A	ambient temperature, °C
T_1	inlet temperature of air at bottom channel, °C
T_2	inlet temperature of air at upper channel, °C
Ta	channel air temperature in parallel plate air heater, °C
T_{a1}	air temperature at lower channel, °C
T_{a2}	air temperature at upper channel, °C
T_i	inlet air temperature above jet plate in mixing of air, °C
T_o	outlet air temperature, °C
T_{ol}	outlet air temperature at jet hole, °C
T_P	absorber plate temperature, °C
V_w	wind speed, m/s
$\bar{V}_1$	wetted mean inlet velocity of air in bottom channel, m/s
$\bar{V}_2$	wetted mean inlet velocity of air in the upper channel, m/s
V_j	jet air velocity, m/s
$\bar{V}$	average velocity of air in the upper channel, m/s
$\bar{V}_{av}$	average velocity of jet air and inlet velocity in upper channel, m/s
$\bar{V}_o$	wetted mean outlet velocity of air in the upper channel, m/s
Z	total depth of solar air heater $(Z_1 + Z_2)$, m
Z_1	spacing between jet and bottom plate, m
Z_2	spacing between jet and absorber plate, m
W	air heater width, m

Greek symbols

η_c	collector efficiency
ρ	density of air, kg/m^3
σ	standard deviation

Subscripts

a	air stream in parallel plate air heater
i	inlet air at upper channel
j	jet air/jet plate
o	outlet air at heater exit
Al	aluminium
B	bias uncertainty
ol	outlet air at jet hole
P	absorber plate
P_R	precision uncertainty
t	thickness
u	individual uncertainty
U	total uncertainty
θ	tilt angle

Florschuetz, 1979; Xing and Sebastian, 2010; Chauhan and Thakur, 2013) So, the present work is motivated by a need to experimentally investigate the behaviour of the jet plate with staggered hole solar air heater which was not experimentally analyzed by Chaudhary and Garg (1991). The present investigation is aimed to study the influence of flow and channel spacing on the thermal performance of the cross - flow staggered hole jet plate solar air heater and to compare the performance with a conventional solar air heater. In the present study, the correlations for Nusselt number and friction factor have also been developed.

2. Set UP description and procedure

2.1. Description of the experimental set up and procedure

Fig. 1 shows the schematic cross - sectional view of conventional parallel plate solar air heater having air depth Z (depth between bottom plate to absorber plate) and Fig. 2 presents cross - sectional view of a non conventional cross – flow staggered hole jet plate solar air heater with flowing of air in bottom and upper channel having depth Z_1 and Z_2 respectively. The photographic view of the same is also shown in Fig. 3. It consists of blower, black painted absorber plate, bottom plate, jet plate with staggered hole (Photographic view shown in Fig. 4), toughened glass cover plate, voltage regulator, three numbers of digital temperature display units (DTDU), thermocouples embedded on each plates. The sides and bottom of the air heater are properly insulated with glass wool.

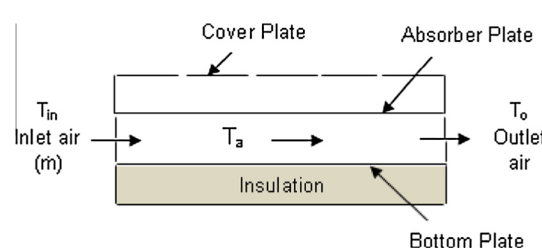

Fig. 1. Schematic cross - sectional view of conventional parallel plate solar air heater with air flow in channel.

In the present study, cross – flow staggered hole jet plate solar air heater is converted into a conventional parallel plate solar air