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Experimental analysis of geometrical parameters on the performance of an inline jet plate solar air heater

Akhilesh Soni, S.N. Singh *

Department of Mechanical Engineering, IIT(ISM), Dhanbad 826004, India

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ABSTRACT

An experimental investigation has been carried out to study flow and heat transfer in solar air heater for inline holes inserted between absorber and back plate. The analysis has been carried out for cross flow conditions. The effect of flow and geometrical parameters, especially jet diameter and hydraulic diameter has been studied. Mass flow rate for the study is varied corresponding to the Reynolds number range of 4600–12,000. The jet diameter, streamwise pitch, and spanwise pitch, each normalized by hydraulic diameter, i.e. D_j/D_h, X/D_h, and Y/D_h, are in the range: 0.053–0.084, 0.53–0.63, and 0.53–0.63 respectively. Performance is studied in terms of Temperature Rise Parameter (TRP), collector efficiency, and Nusselt number. Hourly variations of solar intensity have also been shown. Collector efficiency increases and Temperature Rise Parameter decreases with increase in mass flow rate for all geometrical configurations. All the above-listed performance parameters are found to be maximum at jet diameter to hydraulic diameter ratio of 0.07. A correlation for Nusselt number in terms of Reynolds number, jet diameter, and hydraulic diameter has also been developed.

1. Introduction

Recent studies by Belusko et al. (2008) and Yunfei et al. (2010) have shown jet impingement concept in solar air heaters to be of extreme importance in improving the performance of Solar Air Heater. Impinging air jets have been identified as an effective method of achieving high heat transfer rates and have been widely used (Han, 2004; Martin, 1977; Jambunathan et al., 1992). Various experimental and analytical studies have been conducted on heat transfer and cooling of impinging jets in single and array jets. Turbine and electronic equipment's cooling, and cooling of stock materials during the metal forming process are some of the widespread areas where jet impingement concept has been employed. Impinging jets have thus evidenced their supremacy in heat transfer enhancement. Using air jets impingement concept in solar air heater is not a new concept. Perry (1954) demonstrated that air jets impingement enhanced the surface heat transfer coefficients better than any other conventional method (Duffie, 1978; Kreith and Kreider, 1980; Tonui and Tripanagnostopoulos, 2007; Gao et al., 2007; Mohamad, 1997).

Choudhury and Garg (1991) calculated the gain in temperature increment and performance efficiency of the jet concept air heater over that of the parallel plate air heater. Singh (2006) analytically presented the heat transfer enhancement in a continuous longitudinal fins solar air heater for different pitches. Metzger et al. (1979) investigated heat transfer characteristics for inline and staggered arrays of circular jets with cross - flow spent air. Florschuetz et al. (1981) studied heat transfer characteristics of impinging jets with cross – flow. Kercher and Tabakoff (1970) and Chance (1974) demonstrated heat transfer characteristics measured on a target surface beneath a two-dimensional array of impinging jets indicating that in-line arrangement of jets provides better heat transfer than staggered arrangements. Nayak and Singh (2015) proved that collector efficiency is higher in cross - flow inline hole than non – cross flow inline hole jet plate solar air heater at fixed mass flow rate and jet hole diameter. Karthikeyan et al. (2015) computationally studied the influence of span wise pitch on Local Heat Transfer Distribution for the inline array in cross flow. Sun et al. (2010) studied the influence of channel depth on the performance of solar air heaters. Nayak and Singh (2016) studied the geometrical aspects of performance of jet plate solar air heater for the staggered hole configuration in cross flow conditions.

Based on the above literature, it is well established that Solar Air Heaters with inline jet holes arrangement in cross flow conditions gives the best performance than any other arrangement. To the best of the author's knowledge, no experimental work on the optimization of geometrical parameters for the performance of SAH with inline jet hole arrangement in cross flow conditions

* Corresponding author.
E-mail addresses: akhileshsoni95@mece.ism.ac.in (A. Soni), singh.sn.memme@ismdhanbad.ac.in (S.N. Singh).

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Nomenclature

A	surface area of absorber plate, m^2
A_2	inlet cross sectional area of upper channel, m^2
A_j	area of N jet holes, m^2
C_p	specific heat of air, kJ/kg K
D_{h1}	hydraulic diameter of bottom channel, m $D_{h1} = 4\,W\,Z_1/2\,(W + Z_1)$
D_h	hydraulic diameter of upper channel, m $D_h = 4\,W\,Z_2/2\,(W + Z_2)$
D_j	diameter of jet hole, m
F_R	heat removal factor
h_{pj}	heat transfer coefficient in the upper channel, W/m^2 K
I	incident solar flux (W/m^2)
K	thermal conductivity of air flowing through duct, W/mK
L	collector length, m
m_1	mass flow rate of air through bottom channel, kg/s
m_2	mass flow rate of cross – flow air through upper channel, kg/s
N	total number of holes on jet plate
Nu_{pj}	Nusselt number at upper channel
Pr	Prandtl number
Q_u	useful heat gain, W
Re_{ja2}	flow Reynolds number between absorber and jet plate
T_A	ambient temperature, °C
T_{a1}	inlet air temperature at lower channel, °C
T_{a2}	inlet air temperature at upper channel, °C
T_{fi}	mean inlet air temperature in upper channel, °C
T_{fo}	outlet air temperature, °C
T_{o1}	outlet air temperature from jet holes, °C
T_{fm}	bulk mean temperature in upper channel, °C
T_{pm}	absorber plate temperature, °C
U_L	overall heat loss coefficient, W/m^2 K
V	bulk velocity in upper channel, m/s
V_j	jet velocity, m/s
V_o	outlet velocity, m/s
V_1	inlet velocity in lower channel, m/s
V_2	inlet velocity in upper channel, m/s
V_{av}	average velocity of inlet and jet air in upper channel, m/s
X	streamwise pitch, m
Y	span wise pitch, m
Z_1	distance between jet plate and back plate, m
Z_2	distance between jet plate and absorber plate, m

Greek letters

α	solar absorptivity of absorber plate
η_c	collector efficiency
θ	tilt angle
τ	transmissivity of glass cover plate
μ	dynamic viscosity of air, N s/m^2

has been done. Thus the objective of this paper is focused on the study of geometrical parameters on the performance of Jet plate solar air heater for the inline hole arrangement in cross flow conditions.

2. Experiment and procedure

Fig. 1 shows that the schematic cross – sectional view of jet concept solar air heater with air flow in cross flow conditions. Fig 2 gives a pictorial view of the experimental setup. It comprises a blower, black paint coated absorber plate, bottom plate, a jet plate with inline holes, toughened glass cover plate, voltage regulator, 3 numbers of digital temperature display units (DTDU), thermocouples embedded on each plate, two flow channels of depth Z_1 and Z_2 and bottom insulation. The entire structure is supported on a movable steel frame. The graphic interpretation of the hole alignment in the jet plate is shown in Fig. 3.

The air with mass flows rate $\dot{m}_1$ impinges out of the holes, impacts on the absorber plate and mixes with $\dot{m}_2$ and exits from the upper channel. Digital hot wire anemometer (DHWA) is inserted through the drilled holes at the inlet of both, bottom and upper channel and at the exit of upper channel. The inlet velocity (V_1), inlet temperature (T_{a1}) of air at the inlet side of bottom channel, outlet velocity (V_o), outlet temperature (T_{fo}) of air at exit side of upper channel for cross flow conditions, inlet velocity (V_2) and inlet air temperature (T_{a2}) of air at inlet side of upper channel for cross – flow condition are measured with the help of DHWA. The temperatures of absorber plate at 10 points, jet plate at 10 points and bottom plate at 3 points are measured by thermocouples connected with separate digital temperature display unit (DTDU). Ambient temperature (T_A) is measured by DHWA. The solar intensity is recorded by a Digital Solar Pyranometer. The range of geometrical parameters and details of experimental setup are listed in Table 1 and 2 respectively.

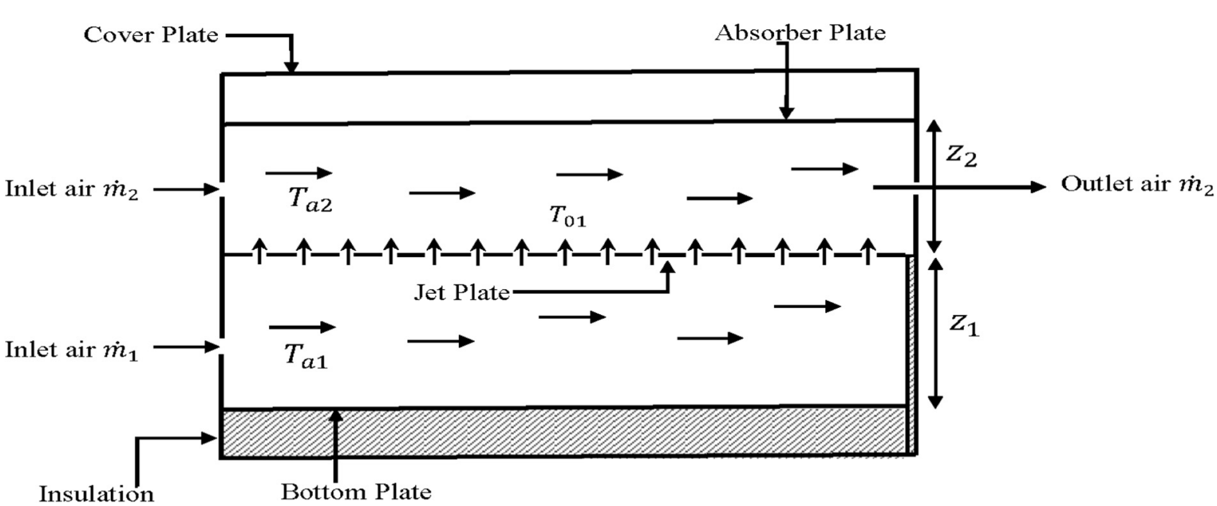

Fig. 1. Schematic cross sectional view of inline jet plate solar air heater in cross flow conditions.