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Performance of a double pass solar air collector

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Abstract

Double pass counter flow solar air collector with porous material in the second air passage is one of the important and attractive design improvement that has been proposed to improve the thermal performance. This paper presents theoretical and experimental analysis of double pass solar air collector with and without porous material. A mathematical model has been developed based on volumetric heat transfer coefficient. Effects of various parameters on the thermal performance and pressure drop characteristics have been discussed. Comparison of results reveals that the thermal efficiency of double pass solar air collector with porous absorbing material is 20–25% and 30–35% higher than that of double pass solar air collector without porous absorbing material and single pass collector respectively.

Keywords: Solar air collector; Double pass; Porous absorbing material; Thermal performance; Effective thermal efficiency

1. Introduction

Solar energy collector is a special type of heat exchanger that transforms solar radiation energy into internal energy of the transport medium. Basically, there are two types of flat-plate solar heating collectors; water heating collectors and air heating collectors. The pace of development of air heating collector is slow compared to water heating collector mainly due to lower thermal efficiency. Solar air collectors are widely used for low to moderate temperature applications like space heating, crop drying, timber seasoning and other industrial applications. Conventional solar air collectors have poor thermal efficiency principally due to high heat losses and low convective heat transfer coefficient between the absorber plate and flowing air stream. Attempts have been made to improve the thermal performance of conventional solar air collectors by employing various design and flow arrangements. Wao et al. (2000) used the sine wave absorber in place of plane absorber plate and numerically studied the natural convection inside the channel between cover and the sine wave absorber for single pass flat-plate solar air collector. Garg et al. (1989) used an absorber with fins attached in order to improve the thermal performance of the single pass solar air collector. Yeh (2000) studied the effect of parallel barriers on the collector efficiency of single pass flat-plate solar air collector. Sodha et al. (1982a,b) presented the performance of solar air heater with matrix. Ahmad et al. (1995) investigated the effect of absorber matrix, mass flow rates and solar energy flux on a packed bed single pass solar air collector. Metwally et al. (1997) experimentally investigated the thermal performance of corrugated-duct solar air collector. Dhiman and Tiwari (1984) studied performance of a two channel suspended flat-plate solar air heater. Sahu and Bhagoria (2005) reported the augmentation of heat transfer coefficient by using transverse ribs on absorber plate of solar air collector. Karwa et al. (2001) presented the performance of solar air heaters having integral chamfered rib roughness on absorber plate. Mohamad (1997) analyzed the performance of counter flow solar air heater

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Nomenclature

A_c	collector area, m^2
a	surface area density, m^2/m^3
c_p	specific heat of air, J/kg K
D	depth of solar collector duct, m
D_h, D_e	equivalent diameter of duct, m
d	wire diameter, m
f	friction factor
h	heat transfer coefficient, W/m^2 K
k	thermal conductivity, W/m K
L	length of solar collector duct, m
m	mass flow rate of air, kg/s
m'	mass flow rate per unit width, kg/s m
n	number of layers
Nu	Nusselt number (hD_h/k)
p	porosity (Void vol/total vol.)
p_t	pitch of wire mesh, m
P	power, W
Pr	Prandtl number ($\rho C_p/\mu$)
Δp	pressure drop, N/m^2
Q_u	useful heat gain, W
Re	Reynolds number ($G_o D_h/\mu$)
T	temperature, K
V	volume, m^3
V_∞	wind velocity, m/s

Greek symbols

α	absorptivity
ε	emissivity
β	extinction coefficient, 1/m
θ_i	incidence angle, degree
ρ	density, kg/m^3
τ	transmittivity
μ	viscocity, kg/m s
η	thermal efficiency ($Q_u/A_c I$)
I	intensity of solar radiation, W/m^2

Subscript

1	first
2	second
a	ambient, air
b	bed
f	fluid, flow
fi	fluid inlet
fo	fluid outlet
g	glass
i	inlet
m	matrix
o	out, void
p	plate, packed
r	radiation
s	solid, smooth
t	total
$thmp$	thermohydraulic
v	volumetric
w	wire, wind

with a porous matrix. Naphon and Kongtragool (2003) applied the mathematical models for predicting heat transfer characteristics and performance of the various configurations of flat-plate solar air collector. The thermal performance of a packed bed double pass solar air heater was presented by Ramadan et al. (2007). Sopain (2000) carried out the simulation study and the thermal performance of double pass solar air heater with and without porous media. Naphon (2005) numerically studied the thermal performance characteristics of double pass flat-plate solar air heater with and without porous media. The double pass counter flow arrangement with porous material in the second air passage is one of the effective alternative to improve its thermal performance. The major reason of interest in porous material includes high effective heat transfer area per unit volume resulting in high heat transfer capability. Also solar radiations are absorbed gradually by layers of porous matrix, resulting in effective heat transfer between the porous material and the flowing air. In addition to this, the concept of double pass arrangement reduces the top heat loss coefficient considerably which, improves the thermal efficiency. Additionally, this kind of solar air collectors can be fabricated with a little additional expenditure over the conventional air collectors. In view of the above, the double pass counter flow solar air collector with and without porous matrix in the lower passage (between the lower glass cover and absorber plate) is an attractive choice for improving the thermal performance of conventional solar air collector.

The use of porous/packing material for improving the performance of solar air collector has been proposed by many investigators including Bharadwaj et al. (1981), Shoemaker (1961), Mishra and Sharma (1981), Choudhuri and Garg (1993), Chau and Henderson (1977), Fahmy and Labib (1991), Sharma et al. (1991), Sodha et al. (1982a,b), Chiou et al. (1965) and Kolb et al. (1999). Some pioneer research work regarding heat transfer on wire mesh screens as packing elements was due to Tong and London (1957), Kays and London (1964) and Hamid and Beckman (1971). Varshney and Saini (1998) and Thakur et al. (2003) investigated this kind of arrangement for single pass solar air collectors. No experimental investigation has been reported for heat transfer in double pass solar air collector for this type of flow arrangement.