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Performance improvement of wire mesh packed double-pass solar air heaters with external recycle

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ABSTRACT

The device performance of the new design of wire mesh packed double-pass solar air heaters with attaching wire mesh under external recycle was investigated experimentally and theoretically. The improvement of device performance of wire mesh packed solar air heaters with different flow patterns is represented graphically and compared, including the single-pass, flat-plate double-pass with recycle and wire mesh packed double-pass with recycle. Heat transfer improvement is considerably obtained by employing such a recyclic double-pass with wire mesh packed, instead of using the flat-plate single-pass operation. The wire mesh packed double-pass device introduced in this study was proposed for aiming to strengthen the convective heat transfer coefficient for air flowing through the wire mesh packed bed, and to determine the optimal design on an economic consideration in terms of both heat transfer efficiency improvement and power consumption increment. The effect of recycle ratio on the heat transfer efficiency enhancement as well as the power consumption increment has been also delineated.

1. Introduction

Solar air collectors in low temperature energy technology have attracted a great deal of interest in recent years and are widely used in space heating [1], drying agricultural products [2,3] and some industrial applications [4,5]. The low convective heat transfer coefficient between the absorber and flowing air in the solar air collector results in a higher temperature of the absorber plate and leads to higher heat losses to surroundings. The effects of forced convection [6], extended heat transfer area [7], free convection [8,9], air turbulence [10] and packing materials [11,12] play significant roles in improving solar air heater collector performance, as reported by several investigators. Moreover, numerous heat and mass transfer problems with internal and external recycle at ends have been developed such as loop reactors [13], air-lift reactors [14], draft-tube bubble columns [15] and thermal diffusion column [16], resulting in improved device performance. The strength of forced heat convection by using recycle effects should be improved in designing and modifying the construction of solar air heaters. The double-pass solar air heater is indicated experimentally numerically that can enhance the thermal performance by increase the heat transfer surface of the flowing air duct [17–19].

In this work, a new design of double-pass solar air heaters is proposed and studied theoretically and experimentally with the use of wire mesh as packing material in lower channel under recycling operation. The influence of wire mesh buffer in the duct of solar air heater was investigated in enhancing the thermal performance of the solar air heater by several literatures [20–23]. Meanwhile, Kolb et al. [24] found that the wire mesh in solar air heater not only yields an improvement of heat transfer rates but also provide smaller friction losses compared to traditional design [25]. The purposes of the present study are: (a) to compare both theoretical predictions and experimental results in wire mesh packed double-pass solar air heater; and (b) to discuss the effects of the recycle ratio and air mass flow rate on both heat transfer efficiency improvement and power consumption increment in making the economic consideration.

2. Theory

The new configuration of recyclic double-pass solar air heater uses the absorbing plate to divide the air flowing conduit into two subchannels with wire mesh attached in the bottom subchannel. The wire mesh screen matrices were welded to the absorber plate by silver solder. Heat transfer by conduction will occur across the solder joints which are mounted between the absorber plate and wire mesh. In steady-state operation, the temperature of wire mesh will reach a specific value in heating the flowing air by convective

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Nomenclature

A_c	surface area of the collector = LW (m^2)
B_i	coefficients defined in Eqs. (A17)–(A22)
C_P	specific heat of air at constant pressure (J/kg K)
d_W	wire diameter of screen (m)
D	depth of the bed
$D_{e,0}$	equivalent diameter of downward-type single-pass device (m)
$D_{e,a}$	equivalent diameter of lower subchannel of double-pass device (m)
$D_{e,b}$	equivalent diameter of upper subchannel of double-pass device (m)
E	deviation of the experimental measurements from theoretical predictions, defined in Eq. (36)
E_f	further improvement in collector efficiency
f_F	Fanning friction factor
F_i	coefficients defined in Eqs. (A34)–(A36)
G_i	coefficients defined in Eqs. (A23)–(A29)
H	height of both upper and lower subchannels (m)
h_a	convection coefficient between the bottom and lower subchannel (W/m^2 K)
h_a'	convection coefficient between the absorber plate and lower subchannel (W/m^2 K)
h_b	convection coefficient between the absorber plate and upper subchannel (W/m^2 K)
h_b'	convection coefficient between the inner glass cover and upper subchannel (W/m^2 K)
h_{c1-c2}	convection coefficient between the inner glass cover and outer glass cover (W/m^2 K)
$h_{r,c1-c2}$	radiation heat transfer coefficient between two covers, defined in Eq. (25) (W/m^2 K)
$h_{r,c2-s}$	radiation heat transfer coefficient from cover 2 to the ambient, defined in Eq. (26) (W/m^2 K)
$h_{r,p-c1}$	radiation heat transfer coefficient between cover 1 and absorber plate, defined in Eq. (23) (W/m^2 K)
$h_{r,p-R}$	radiation heat transfer coefficient between absorber plate and bottom plate, defined in Eq. (24) (W/m^2 K)
h_w	convective heat transfer coefficient for air flowing over the outside surface of glass cover (W/m^2 K)
I_0	incident solar radiation (W/m^2)
I_i	coefficients defined in Eqs. (47) and (48)
I_D	percentage of collector efficiency improvement in flat-plate air heater, defined in Eq. (37)
I_P	percentage of power consumption increment, defined in Eq. (47)
I_W	percentage of collector efficiency improvement in wire mesh air heater, defined in Eq. (38)
k	thermal conductivity of the stainless steel plate (W/m K)
k_i	coefficients defined in Eqs. (A32) and (A33)
k_s	thermal conductivity of insulator (W/m K)
L	channel length (m)
l	the maximum length of the mesh (m)
l_s	thickness of insulator (m)
$\ell w_{f,a}$	lower subchannel friction loss of double-pass device (J/kg)
$\ell w_{f,b}$	upper subchannel friction loss of double-pass device (J/kg)
$\ell w_{f,S}$	friction loss of downward-type single-pass device (J/kg)
M_a	parameter defined in Eq. (3) (W/K m^2)
M_b	parameter defined in Eq. (4) (W/K m^2)
$\dot{m}$	total air mass flow rate (kg/s)
N	number of glass cover
$N_{\exp}$	the number of the experimental measurements
$N_{u,i}$	Nusselt number
n	number of screens in a matrix
P	porosity of mesh
$P_{c,i}$	power consumption defined in Eqs. (42) and (43) (W)
P_t	pitch of wire mesh (m)
Q_u	useful energy gained by air (W)
r_h	hydraulic radius (m)
R	recycle ratio
Re_0	Reynolds Number defined in Eq. (13)
Re_a	Reynolds Number defined in Eq. (13)
Re_b	Reynolds Number defined in Eq. (13)
$S_{\eta exp}$	the precision index of an individual measurement
$S_{\overline{\eta}_{\exp}}$	the mean value of $S_{\eta_{\exp}}$
$T_a(\xi)$	axial fluid temperature distribution in the lower subchannel (K)
$T_b(\xi)$	axial fluid temperature distribution in the upper subchannel (K)
$T_{a,o}$	the temperature of the subchannel a at outlet (K)
$T^0_{a,0}$	the mixing temperature of the subchannel a at $x = 0$ (K)
$T_{b,0}$	the temperature of the subchannel b at $x = 0$ (K)
$T_{a,L}$	the temperature of the subchannel a at $x = L$ (K)
$T_{b,L}$	the temperature of the subchannel b at $x = L$ (K)
$T_{a,m}$	the mean temperature of the lower subchannel (K)
$T_{b,m}$	the mean temperature of the upper subchannel (K)
T_{c1}	temperature of inner glass cover (K)
T_{c2}	temperature of outer glass cover (K)
$T_{c1,m}$	mean temperature of inner glass cover (K)
$T_{c2,m}$	mean temperature of outer glass cover (K)
T_{in}	inlet air temperature (K)
T_p	temperature of absorbing plate (K)
$T_{p,m}$	mean temperature of absorbing plate (K)
T_R	temperature of bottom plate (K)
T_s	ambient temperature (K)
U_B	loss coefficient from the bottom of solar air heater to the ambient environment (W/m^2 K)
U_{B-s}	loss coefficient from the surfaces of edges and the bottom of the solar collector to the ambient environment (W/m^2 K)
U_{c1-s}	loss coefficient from the inner cover to the ambient environment (W/m^2 K)
U_L	overall loss coefficient (W/m^2 K)
U_T	loss coefficient from the top of solar air heater to the ambient environment (W/m^2 K)
V	wind velocity (m/s)
v_a	the velocity of the lower subchannel (m/s)
v_b	the velocity of the upper subchannel (m/s)
Y_i	coefficient defined in Eqs. (A30) and (A31)

Greek letters

α_p	absorptivity of the absorbing plate
η_D	collector efficiency of the double-pass device
η_S	collector efficiency of the downward-type single-pass device
$\eta_{\exp,i}$	experimental data of collector efficiency
$\eta_{theo,i}$	theoretical prediction of collector efficiency
η_W	collector efficiency of wire mesh solar air heater
τ_g	transmittance of glass cover
ε_g	emissivity of glass cover
ε_R	emissivity of bottom plate