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Collector efficiency improvement of recyclic double-pass sheet-and-tube solar water heaters with internal fins attached

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Abstract

The sheet-and-tube solar water heater is a convenient and common heater to be used as domestic hot water heating. This paper investigates the effects on collector efficiency of a double-pass sheet-and-tube solar water heater with fins attached under various arrayed density. In addition, the number of pair ducts and total mass flow rate are taken into account during the calculation procedure. The theoretical prediction shows that the higher collector efficiency is obtained under the suitable designing and operating parameters. Considerable improvement in collector performance is obtained by employing a recyclic operation with fins attached and under various arrayed density, instead of employing a single-pass flat-plate device. The effect of the recycle ratio, arrayed density and number of fins attached on the collector efficiency enhancement as well as the power consumption increment has also delineated.

Keywords: Solar water heater; Finned tube; Tube distances

1. Introduction

Topic on the research of solar energy has become a matter of great concern due to energy crisis all over the world. The direct applications of solar energy (i.e. thermal application of solar energy) are simpler and more feasible application compared to indirect applications (i.e. photoelectric application) to transform to electricity by using solar radiation. Flat-plate solar collectors are the devices which absorb the solar radiation, transform it into heat, and to heat passing media (usually air, water, or oil). Flat-plate solar collectors are mechanically simpler than concentrating collectors to be used in domestic and industrial needs, which are constructed with the blackened absorber to transfer the absorbed energy to the flowing medium, transparent cover to reduce convection and radiation losses to atmosphere, and back and side insulation to reduce conduction losses. There are wide applications with solar collector, solar refrigerators [1] and solar cooker [2,3], desalination [4], crop drying [5], domestic hot water [6] and hybrid photovoltaic/thermal system [7] for higher temperature and middle to low temperature using. In order to achieve higher performance on solar collectors, coil spring [8], twisted tape [9], helical ribs [10] and longitudinal fins [11,12], these are well-known strategies to be used in creating fluid turbulence (convective heat-transfer coefficient) and/or extending heat transfer area (residence time) in flat-plate solar collectors.

A more popular method to extend heat transfer rate and promote the fluid turbulence is attaching longitudinal fins. The application of attaching fins concept to the solar air heater in rectangular channels to enhance the heat transfer rate has been studied theoretically. Besides, the recycle-effect concept was used in designing recyclic devices with external recycle at the end [13,14] to increase the convective heat-transfer coefficient. The improvements of device performance in solar air heaters with consideration of attaching fins concept and recycle-effect concept have been studied theoretically and experimentally, as confirmed from our previous papers [15–19].

In addition, previous studies had no consideration of influences of arrayed density (i.e. distance between tubes, W) on collector efficiency improvement under fixed collector area. The work of the present paper investigates theoretically a device with internal fins attached in a

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Nomenclature

A_c surface area of the collector, $2nW\ell$ (m^2)
A_{tf} cross area of fins (m^2)
C_b conductance of bond ($kJ\,s^{-1}\,m^{-1}\,K^{-1}$)
C_p specific heat of water at constant pressure ($kJ\,kg^{-1}\,K^{-1}$)
D outside diameter of tube (m)
D_i inside diameter of tube (m)
$D_{h,1}$, $D_{h,2}$ equivalent hydraulic diameter of tubes with/without fins attached (m)
F sheet standard efficiency, defined by Eq. (3)
F'_{fin} collector efficiency factor of solar collector with fins attached, defined by Eq. (2)
f_F Fanning friction factor
H_{fin} height of internal fins (m)
H_0 hydraulic dissipated energy of single- and double-pass device with/without
H_R recyclic operation and fins attached, respectively (hp)
$h_{f,i}$ convective heat-transfer coefficient inside tube ($kJ\,s^{-1}\,m^{-2}\,K^{-1}$)
h_w convective heat-transfer coefficient for air flowing over the outside surface of glass cover ($kJ\,s^{-1}\,m^{-2}\,K^{-1}$)
I_0 incident solar radiation ($kJ\,m^{-2}\,s^{-1}$)
I_R improvement of collector performance, defined by Eq. (27)
k thermal conductivity of fins ($kJ\,s^{-1}\,m^{-1}\,K^{-1}$)
k_f thermal conductivity of water ($kJ\,s^{-1}\,m^{-1}\,K^{-1}$)
k_{fl} thermal conductivity of flat ($kJ\,s^{-1}\,m^{-1}\,K^{-1}$)
k_s thermal conductivity of insulator ($kJ\,s^{-1}\,m^{-1}\,K^{-1}$)
L total length of tubes, $n\ell$ (m)
ℓ length for each tube (m)
ℓ_s thickness of the insulator (m)
$\ell w_{f,i}$ friction loss of single- and double-pass ($kJ\,kg^{-1}$)
M quantity defined by Eq. (4) (m^{-1})
M_0, M_1, M_2 the mass flow rate of single- and double-pass conduits, respectively ($kg\,min^{-1}$)
m the total water mass flow rate ($kg\,min^{-1}$)
N number of glass cover
N_f number of fins attached
Nu_i Nusselt number of single- and double-pass
n number of pair ducts
P the perimeter of fins (m)
Pr Prandtl number
Q_u total useful gain of energy carried away by fluid per unit time ($kJ\,s^{-1}$)
$q'_{u,fin}$ useful energy gain with fins attached per unit length in the flow direction ($kJ\,s^{-1}\,m^{-1}$)
R recycle ratio
Re_0, Re_1, Re_2 Reynolds number of single- and double-pass conduits, respectively
S useful energy of absorbing plate from the sun ($kJ\,m^{-2}\,s^{-1}$)
T_a ambient temperature (K)
T_b wall temperature of tube (K)
$T_{f,0}$ inlet temperature of water (K)
$T_{f,i}(z)$ fluid temperature in i tube (K)
$T_{p,m}$ mean absorbing plate temperature (K)
t_f thickness of fins (m)
U_B loss coefficient from the bottom of the solar collector to the ambient ($kJ\,s^{-1}\,m^{-2}\,K^{-1}$)
U_E loss coefficient from the surface of edge to the ambient ($kJ\,s^{-1}\,m^{-2}\,K^{-1}$)
U_L overall loss coefficient ($kJ\,s^{-1}\,m^{-2}\,K^{-1}$)
U_T loss coefficient from the absorbing plate of the solar collector to the ambient ($kJ\,s^{-1}\,m^{-2}\,K^{-1}$)
v_0, v_1, v_2 fluid velocity of single- and double-pass devices, respectively ($m\,s^{-1}$)
V wind velocity ($m\,s^{-1}$)
W distance between tubes (m)
Z axial coordinate along the flow direction (m)

Greek symbols

α_p absorptivity of the absorbing plate
β collector tilt (deg)
ε tolerance
ε_g,ε_p emissivity of the glass cover, absorbing plate
δ thickness of plate (m)
η collector efficiency
η_D collector efficiency in a single-pass sheet and tube solar water heater
η_f fin efficiency defined by Eq. (5)
η_R collector efficiency in a double-pass sheet-and-tube solar water heater
θ_b temperature difference between tube wall and fluid (K)
τ_g transmittance of the glass cover
ρ fluid density ($kg\,m^{-3}$)
μ fluid viscosity ($kg\,m^{-1}\,s^{-1}$)
σ Stefan–Boltzmann constant $= 5.67 \times 10^{-11}$ ($kJ\,s^{-1}\,m^{-2}\,K^{-4}$)

double-pass sheet-and-tube solar water heater under recyclic operation with various arrayed density as a parameter. There are two purposes in the present study: firstly, to design a new recycle type in sheet-and-tube solar water heaters with internal fins attached under various arrayed density; secondly, to study the effect of number of pair ducts, incident solar radiation, inlet water temperature, arrayed density and mass flow rate of water on collector efficiency. The increment of hydraulic dissipated energy due to the recyclic device with internal fins attached and various arrayed density has been also discussed.