Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 117 (2015) 192–202

SOLAR ENERGY

www.elsevier.com/locate/solener

Numerical simulation for structural parameters of flat-plate solar collector

Zhang Jiandong [a], Tao Hanzhong [a,b,*], Chen Susu [a]

[a] The College of Energy, Nanjing Tech University, Nanjing 211816, China
[b] The Solar Corporation of SOLAREAST, LianYunGang 222000, China

Received 26 November 2014; received in revised form 28 March 2015; accepted 21 April 2015
Available online 16 May 2015

Communicated by: Associate Editor Brian Norton

Abstract

Based on finite volume method, the steady-state thermal performances of the flat-plate solar collector are studied by taking account of absorber plate thickness, collector tube spacing, collector tube length, collector tube diameter and insulating layer thickness. A physical model of gilled flat-plate solar collector is built, then the numerical simulation of the model is carried out and the numerical simulation results are compared and analyzed with experimental results. The results show that: Either increasing the absorber plate thickness or reducing the collector tube spacing can significantly improve the instantaneous efficiency of the collector. Setting the solar radiation intensity of 700 W/m^2 and the environmental speed of 4 m/s, when the absorber plate thickness increases from 0.1 mm to 2.1 mm, the collector instantaneous efficiency increases from 46.57% to 64.03%. When the collector tube spacing decreases from 170 mm to 50 mm, the collector instantaneous efficiency increases from 52.81% to 66.01%. Reducing the collector tube length and increasing collector tube diameter are both conducive to improve the instantaneous efficiency of the collector. When the collector tube length decreases from 2800 mm to 1200 mm, the collector instantaneous efficiency increases from 57.50% to 60.12%. When the collector tube diameters increases from 8 mm to 20 mm, the collector instantaneous efficiency increases from 56.18% to 63.97%. When the thickness of insulating layer is 30 mm or more, increasing its thickness has no significant effect on improving the instantaneous efficiency of the collector. The research results are helpful to optimize the design parameters of the flat-plate solar collector.

Keywords: Solar; Collector; Flat-plate; Numerical simulation

1. Introduction

With the economic and social developing and population increasing, energy demand continues to increase and global energy consumption is huge. Therefore, the future energy supply will become quite nervous. Currently, our energy supply consists mostly of coal, petroleum, natural gas and other fossil fuels. The characteristics of unrenewable and environmental polluting of fossil energy is contrary to the global sustainable development strategy. So it is an important approach to develop renewable energy and clean energy. It is considered that solar energy could replace coal, oil and natural gas as a clean energy in the future, because it is inexhaustible, clean and safe (Banos et al., 2011). The exploitation of solar energy has mainly forms of photoelectric transition and photothermal conversion, among which the photothermal conversion of solar energy heater is undoubtedly more mature. So far, many

* Corresponding author at: The College of Energy, Nanjing Tech University, Nanjing 211816, China. Tel.: +86 13776668774.
E-mail address: taohanzhong@njtech.edu.cn (T. Hanzhong).

http://dx.doi.org/10.1016/j.solener.2015.04.027
0038-092X/

Nomenclature

A	collector plate area, m^2
b	glass cover thickness, mm
c	distance glass cover to absorber plate, mm
c_μ	empirical constant, $c_\mu = 0.09$
c_1	empirical constant, $c_1 = 1.44$
c_2	empirical constant, $c_2 = 1.92$
C_b	thermal resistance of junction of tube plate, $W/(m^2\,°C)$
C_p	specific heat capacity of fluid, J/(kg K)
D	outside tube diameter, m
D_i	inside tube diameter, m
e	insulation thickness, mm
f	on-way length
f_x	mass force
$\vec{f}$	direction vector
$\vec{f}'$	scattering direction vector
F	fin efficiency
F_R	collector heat transfer factor
F'	collector efficiency factor
g	acceleration of gravity, m/s^2
$h_{f,i}$	heat transfer coefficient between heat transfer working fluid and the pipe wall, $W/(m^2\,°C)$
h_w	convective heat transfer coefficient between ambient air and the glass cover, $W/(m^2\,°C)$
I	solar radiation intensity, W/m^2
k	turbulent kinetic energy
L	collector tube length, mm
n	refraction coefficient
N	glass cover layers
m	total mass flow of the working fluid, $m = m_s \cdot z$, where m_s is the working fluid mass flow rate in the single collector tube, kg/s; z is the number of collector tube
μ	dynamic viscosity, kg/(m s)
μ_t	turbulent viscosity, kg/(m s)
ρ	density of fluid, kg/m^3
σ	Stephen–Boltzmann constant, and its value is: $5.67 \times 10^{-8}\ W/(m^2\,°C^4)$
σ_k	turbulent kinetic energy corresponding to Prandtl number, $\sigma_k = 1.0$
σ_ε	turbulent dissipation rate corresponding to Prandtl number, $\sigma_\varepsilon = 1.3$
τ	glass cover transmittance, %
ψ	instantaneous efficiency deviation, %
Φ	phase function
P	hydrostatic pressure, Pa
P_{out}	outlet pressure, $P_{out} = 0$
Q	solar radiant energy incident on the collector plate area in per unit time, W
Q_u	the working fluid absorbed useful energy in per unit time, kJ/h
$\vec{r}$	position vector
s	collector tube wall thickness, mm
S_ϕ	generalized source term
t	absorber plate thickness, mm
T	temperature, °C
T'	local temperature, °C
u	velocity of x direction, m/s
U	vector of fluid velocity
U_L	the collector total heat loss coefficient, $W/(m^2\,°C)$
U_t	top heat loss coefficient, $W(m^2\,°C)$
v	velocity of y direction, m/s
v'	ambient wind speed, m/s
w	velocity of z direction, m/s
W	collector tube spacing, m
x	cartesian coordinate system

Greek symbols

α	absorber plate absorption rate, %
α'	absorption coefficient
β	coefficient of thermal expansion
β_f	scattering coefficient
ε	turbulent dissipation rate
ε_g	transparent cover emissivity, %
ε_p	absorber plate emissivity, %
ϕ	universal variable
η	collector instantaneous efficiency
λ	thermal conductivity, W/(m k)
Γ_ϕ	generalized diffusion coefficient
Ω	solid angle of space

Subscripts, superscripts

a	ambient
f, i	work fluid inlet
p	absorber plate
o	constant
in	inlet

standards (ANSI/ASHRAE, 2003; EN 12975-2, 2006) and articles (Norton, 1992; Garg, 1985) about solar thermal application have been published.

Flat-plate and vacuum tube solar collectors are the most widely used heaters among the solar collector systems. Although vacuum tube solar collector enjoys advantages of vacuum insulation and mature technology, it is made from glass which is easy to burst of tube, fouling and unable to building integration of solar energy systems. The flat-plate solar collectors have the advantages of simple structure, high pressure bearing, durable, low maintenance rate, high heat efficiency and low production costs. It will become the main trend in the future for the high demand of building integration of solar energy systems