Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 114 (2015) 114–133

SOLAR ENERGY

www.elsevier.com/locate/solener

Dynamic model and experimental validation of an indirect thermosyphon solar water heater coupled with a parallel circular tube rings type heat exchange coil

Ka-Kui Tse *, Tin-Tai Chow

Building Energy and Environmental Technology Research Unit, Division of Building Science and Technology, City University of Hong Kong, Kowloon, Hong Kong, China

Received 3 May 2014; received in revised form 19 December 2014; accepted 25 January 2015

Communicated by: Associate Editor Ursula Eicker

Abstract

This article introduces the design of an indirect thermosyphon solar water heating system coupled with a parallel circular tube rings type heat exchanger. The proposed heat exchange coil set is able to provide similarly of heat exchange areas of a comparable size helical coil but reduces the friction loss of the thermosyphon fluid flow. The design can also maintain the thermal stratification along the vertical height of the storage water tank. Hence, the thermal efficiency of the solar water heater is improved as compared with a same system but coupled with a comparable size helical coil and shell type storage water tank. Detailed mathematical model development from individual components to the integration of whole system are described. The transient system model is simulated by a self-developed FORTRAN program. The experimental and simulations results of the solar thermal system are fully presented in this paper. Comparison of both results shows good agreements and convinces the accuracy of the entire system models as well as the suitability of the computational method. The effectiveness of the proposed heat exchange coil set is evaluated by its *NTU* value which is computed by program simulation. The *NTU* value reveals that the overall efficiency of the solar thermal system can be improved by further physical design optimization. Simulation results analyses also consolidate the enhancement of the thermosyphon flow rate (in other words, the efficiency) of the proposed design over the helical coil design as expected.

Keywords: Solar water heater; Thermosyphon flow; Heat exchanger; Dynamic model

1. Introduction and background

Thermosyphon solar water heating system is a kind of passive solar technology that utilizes solar energy in the absence of external electrical and mechanical energy input. It functions by the principle of natural circulation. Without any mechanical moving parts (i.e water circulating pumps), the costs of operation and maintenance can be significantly saved.

Solar water heating (SWH) has shown a great potential to be applied in Hong Kong. According to the study by the Electrical and Mechanical Services Department (EMSD) of the Hong Kong SAR government, the annual energy saving relative to a conventional in-line electric water heater by using flat plat solar water heater are predicted to be large, which is in the range from 65.6% to 74.7% (EMSD, 2002).

* Corresponding author.
E-mail address: kakuitse.ca@gmail.com (K.-K. Tse).

http://dx.doi.org/10.1016/j.solener.2015.01.032
0038-092X/

Nomenclature

A	area, m^2
A_f	area ratio
A_J	total cross section area of water tubes, m^2
a	radius of curved pipe, m
BP	buoyant pressure, Pa
C	specific heat capacity, J/kg °C
De	dean number, –
d	diameter, m
f	friction factor, –
g	gravitational constant, ms^{-2}
G	solar irradiation, W/m^2
H	internal diameter of the water tank, m
h	heat transfer coefficient, $W/(m^2K)$
i	inclination angle of collector, °
k	singular pressure drop coefficient, –
k	thermal conductivity, W/(mK)
L	length, m
l	wet perimeter, m
$\dot{m}$	mass flow rate, kg/s
N	Number of risers in the collector array, –
Nu	Nusselt number, –
P	pressure, pa
$\dot{Q}$	heat transfer rate, W
$\dot{q}$	heat transfer rate per unit area, W/m^2
R	thermal resistance, m^2K/W
R	radius of curvature of coil, m
Re_s	Reynolds number of laminar flow in straight pipe, –
T	temperature, K
t	time, s
U	overall heat transfer coefficient, $W/(m^2K)$
u	fluid flow velocity, m/s
$\overline{U}$	centerline velocity of flow in pipe, m/s
(UA)	overall heat transfer*area constant, W/K
V	volume, m^3
W	width, m
x	distance, m

Greeks

α	absorptivity, –
β'	coefficient of thermal expansion, 1/K
δ	curvature ratio, –
δ	thickness, m
υ	kinematic viscosity, m^2/s
ρ	density, m^2/s
φ	pressure difference ratio, –

Subscripts

a	ambient air
ab	thermal absorber
ave	appropriate average difference
c	heat exchange coil set
cl	collector
ct	connecting tubes
e	exit
ex	heat exchanger coil
f	fluid in thermosyphon loop
fi	fluid in "i"th position, $i = 0$ to 5
g	front glass
i	incoming
in	inlet of collector array
in	inlet of heat exchange coil
in	insulation material
L	loss
ln	logarithmic mean
m	mean
out	outlet of collector array
p	potable water
$p,in1$	potable water inlet at position 1
$p,in2$	potable water inlet at position 2
$p,out1$	potable water outlet at position 1
$p,out2$	potable water outlet at position 2
r	radiation
s	surface
t	tube
tk	tank
tki	"i" th water layer of the tank
$tki(n)$	"i" th water layer of the tank at night
w	wall
$wind$	heat transfer due to wind
x	position x
$x–y$	between object "x" to object "y"

Superscripts

k	at time step k
n	at time step n
t	at time step t

Conventionally, flat-plate type and evacuated tube type solar water heaters are generally recommended in Hong Kong. Chow et al. (2011) had compared the energy performance and the cost payback period of two common types of evacuated tube solar water heaters for domestic application in Hong Kong. A typical flat-plate type thermosyphon (SWH) system can be either direct or indirect. Direct thermosyphon (SWH) system means the water heated up by the thermal collector array is directly consumed by the users. Indirect thermosyphon (SWH) system heats up the consumable water by the hot thermosyphon loop via a heat exchanger. An internal heat exchange coil is coupled inside the insulated storage water tank to separate the thermosyphon flow circuit and the potable water circuit. The