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Performance study of solar water heater comprised of the separate loops flow boiling in the mini tubes

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ABSTRACT

Boiling is generally characterized by a high heat transfer coefficient, so that a large heat flux can be sustained at a fairly low temperature difference between the heat transfer surface and the boiling fluid. In literature, the most works for loop two-phase closed thermosyphon types of the solar collectors have common condenser with one downcomer tube. In present study, we have simulated the wickless heat pipes type of a solar collector comprised of the separate loops flow boiling in the mini tubes. In this study, it is assumed that each mini tubes have constant diameter as 0.005 m. Because of the flow boiling process into the riser, vapor leaves evaporator surface quickly and allows a quick liquid be replenished to the evaporator through the downcomer. In this design, each loop is evaluated separately. In this work, the optimum values of the collector components have been calculated using temporary modeling of the risers flow boiling processes in EES software. In the case of one mini loop, both the experimental and present numerical model showed the collector thermal efficiency about 11%. But, simulation results show that, in the case of the four mini loops, this collector thermal efficiency can reach near to 60%.

1. Introduction

There are two types of thermosyphon solar water heaters. These are single-phase and two-phase of working fluid. Computer simulation on performance of a two-phase thermosyphon solar water heater showed that the performance of two-phase system was higher than that of single-phase system [1]. The two-phase closed thermosyphan (TPCT) is a closed container filled with a small amount of working fluid. It is the high performance heat transfer device which is used to transfer a large amount of heat at a high rate with a small temperature difference. It was applied to many application fields such as solar water heating systems [2–8]. The TPCT is a single tube or double tubes (loop type) heat exchanger. Hussein [7] investigated theoretically and experimentally of single tube type of a TPCT solar water heater, as shown schematically in Fig. 1. The collector in this form is simplest in manufacturing and has less material cost. In his experimental work, the fourteen wickless heat pipes were used. Inner diameters of each tube were 0.0117 m. Also working fluid was distilled water. The experimental and theoretical results indicated that there was an optimum number of wickless heat pipes to be used in designing the wickless heat pipes flat plate solar collectors with cross flow heat exchanger. This optimum number was about 12 pipes. In a single tube type of a TPCT, thermal performance is restricted by entrainment and flooding phenomena. Furthermore, it is difficult to maintain a uniform liquid film which causes the heat transfer performance to deteriorate [9]. In one of our prior works [10], combination of the thermal net work analysis and the lumped capacity were used in order to simulate thermal characteristics of a TPCT operation. The results showed that the condenser section has the high exergy destruction rate in comparison with the other TPCT system components.

In the loop type of a TPCT the boiling process may be occurred in the evaporator section include the pool or the flow boiling processes. For pool boiling process in the evaporator, Chien et al. [4] indicated that the most works for a two-phase thermosyphon solar water heater have shared design under different operating modes, include the charge and discharge cycles, as shown in Fig. 2. In the case of charge cycle the vapor is produced, as shown in Fig. 2(a). Then it flows through the check valves and releases heat to the energy storage material. Finally, the condensed working fluid goes into the collector tubes to complete the charge cycle. In the case of discharge cycle, the heat is transferred from the energy storage material to the entered cold water from the internal tube of the double-pipe heat exchanger, as shown in Fig. 2(b). They declared that a theoretical model needs to be developed for further studies. For their works the thermal resistance-capacitor model was developed to analyze the two-phase thermosyphon solar water heater.

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Nomenclature

A_c	collector area, m^2
A_r	riser cross section area, m^2
A_{sr}	riser lateral area, m^2
Bo	boiling number
C_f	specific heat of the water of tank, J/Kg K
Co	convection number
d_r	riser diameter, m
f	friction factor
f_{12}	single phase friction factor
F_{Fl}	friction factor
F	standard fin efficiency for straight fins with rectangular profile
g	gravitational acceleration, m/s^2
h_1	downcomer inner enthalpy, J/kg
h_2	riser inner enthalpy, J/kg
h_3	riser outer enthalpy, J/kg
h_{Lo}	single-phase, all-liquid-flow heat transfer coefficient, W/m^2 K
h_{tp}	two-phase heat transfer coefficient, W/m^2 K
$I(t)$	total solar intensity radiation on the collector, W/m^2
K_p	conductivity of the aluminum absorber plate, W/m K
L_r	riser length, m
M_f	water mass inside the storage tank, kg
$\dot{m}_r$	riser mass flow rate, kg/s
N	numbers of the loop tubes
p_1	downcomer inner pressure, Pa
p_2	riser inner pressure, Pa
p_3	riser inner pressure, Pa
Pr	liquid dimensionless Prandtl number
$q_{f,in}$	net energy entered to the energy storage tank, W
$q_{f,loss}$	heat loss from wall of the energy storage tank to the ambient, W
q_u	useful energy entered to a riser, W
Re_{Lo}	single-phase, all-liquid-flow dimensionless Reynolds number
T_{23}	two-phase flow temperature, K
T_{amb}	ambient temperature, K
T_f	tank water temperature, K
T_f^t	tank water temperature at time of $\tau = t$, K
T_f^0	initial value of the tank water temperature at time of $\tau = 0$ K
T_p	absorber plate mean temperature, K
T_{sc}	condenser surface temperature, K
U_L	sum of the heat losses from the outer cover glass and the collector box to ambient, W/m^2
W	distance between two loops, m
x_r	vapor quality of a riser

Greek symbols

β	tilt angle of the solar water heater (here, $\beta = 40$), (°)
δ_p	absorber plate thickness (here, aluminum with $\delta_p = 0.002$), m
ε	surface roughness of the riser tube (here, $\varepsilon = 0.005$), m
ρ_1	downcomer inner density, kg/m^3
ρ_2	riser inner density, kg/m^3
ρ_{23}	riser density, kg/m^3
ρ_3	riser outer density, kg/m^3
ρ_{gr}	riser vapor density, kg/m^3
ρ_{lr}	riser liquid density, kg/m^3
Δp_{f12}	pressure drop for a downcomer, *Pa*
Δp_{f23}	pressure drop for a riser, *Pa*
$\tau\alpha$	product of effective absorptivity and transmittivity (here, $\tau\alpha = 0.72$)

In the flow boiling arrangement, the heat producing component is arranged non horizontally in a relatively conventional tube to allow vapor leave boiling zone (boiler) surface quickly and to allow a quick liquid replenish to the boiler. Also, the flow boiling process offers the profit of increasing the critical heat flux (CHF) when compared to the same device in a pool boiling configuration. CHF is an important condition that defines the upper limit of safe operation of heat transfer equipment employing boiling heat transfer in heat flux controlled systems [11–13]. Performance investigation of a flow boiling solar water heater has been numerically conducted, by Aung and Songjing [3]. Fig. 3 shows schematically design of their collector. As shown in this figure, the flow boiling processes occur in the eight riser tubes. The riser tube size is varied from 0.0125 m to 0.025 m with inclination range 2–75°. The risers have the common vapor out put. The summed vapor releases heat to the energy storage material through the coiled heat exchanger (condenser). Finally, the condensed working fluid drops to the fluid storage tank, and then goes into the downcomer tube to complete the cycle. Their results showed that the collector efficiency in a two-phase thermosyphon loop sharply increases with increasing of collector inclination until optimum condition. Then, it shows a flat trend beyond optimum inclination. The maximum collector

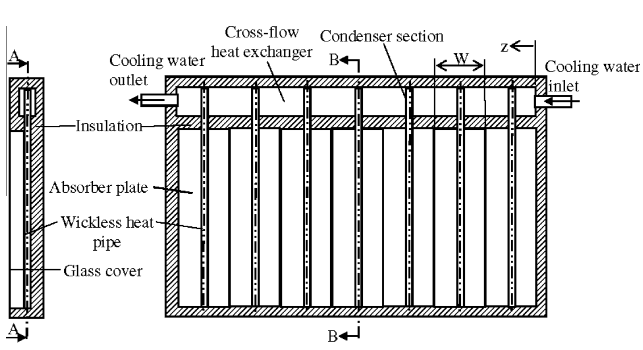

Fig. 1. Schematically presentation of a solar water heater consists of single-tubes of the TPCT units, Adopted from Hussein work [7].

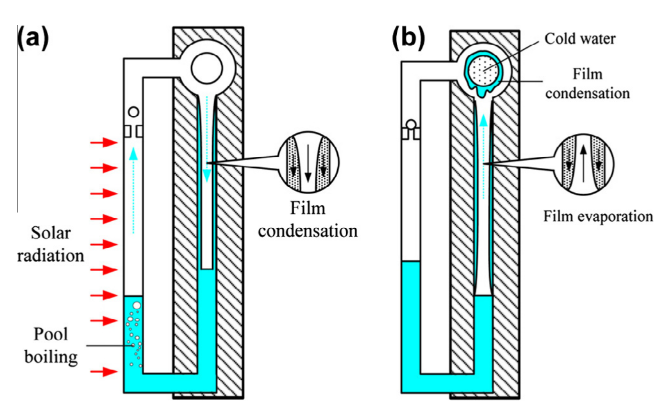

Fig. 2. Schematically presentation of a solar water heater consists of double-tubes of the TPCT units; (a) charge mode, and (b) discharge mode, Adopted from Chein et al. works [4].