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Validated mathematical models of a solar water heater system with thermosyphon evacuated tube collectors

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ABSTRACT

An evacuated tube solar water heater system using thermosyphon heat exchange was experimentally and theoretically investigated. Solar radiation and ambient temperature data from Chiang Mai Province were used as the modeling system by an Explicit Finite Difference Method (EFDM). The experimental setup consisted of 8 evacuated tube collectors (ETCs) with thermosyphon diameters of 15.88 mm for the evaporator and 22.22 mm for the condenser. Lengths of the evaporator, adiabatic, and condenser sections were 1700 mm, 150 mm and 100 mm, respectively. Mathematical model results of both thermal resistance method and EFDM were validated by experimental results. Theoretical results for temperature and thermal efficiency concurred with experimental results and previous research. Experimental result, thermal resistance method and EFDM results indicated that maximum temperature of hot water occurred at 4:00 p.m. as 65.25 °C, 71.19 °C, and 69.46 °C, respectively. Thermal efficiency of the solar water heater system was 58.28% of the experimental result, 55.97% of the thermal resistance method and 57.60% of the EFDM result. EFDM provided better accuracy than the thermal resistance method by 2.97%.

1. Introduction

Renewable energy sources have now become high priority with an ever-increasing global power demand and rapid decline in fossil fuels. Solar power is an environmentally friendly energy resource which can be harnessed to produce hot water. Evacuated tube collectors are widely used for solar thermal conversion in hot water applications; their high absorption surface coating and vacuum insulation prevents heat loss to outside ambient temperature. Three types of evacuated tube collector (ETC) can be classified according to their working fluid type as (a) Water-in-glass evacuated tube collector [1–3], (b) U-type or single phase thermosyphon evacuated tube collector [4–6], and (c) Two-phase closed thermosyphon evacuated tube collector [3,7–14]. A two-phase closed thermosyphon is a highly efficient device for heat transfer [15]. Previous studies investigated how working fluid, filling ratio and size of thermosyphon affected the performance of solar collectors both theoretically and experimentally compared to conventional solar collectors.

Most researchers designed and calculated thermosyphon heat transfer by thermal resistance methods [3,9–14,16,21,22]. Azad [12] focused on a flat plate solar collector model utilizing heat pipes which showed good concurrence between measured and theoretical results and was able to predict the optimum ratio of thermosyphon tube for experimental configurations. Charoensawan and Wannagosit [13] analyzed the thermal performance of an evacuated tube solar water heater with thermosyphon for each season in Thailand. They found that maximum daily temperature and average thermal efficiency of the system was achieved during the

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Nomenclature

A	Surface area, (m^2)
c_p	Specific heat capacity, (J/(kg-K))
I_G	Solar intensity, (W/m^2)
k	Thermal conductivity, (W/(m-K))
M	Water mass, (kg)
$\dot{m}$	Mass flow rate, (kg/s)
Nu	Nusselt number
$\dot{Q}$	Heat rate, (W)
T	Temperature, (°C)
Δt	Time interval, (s)
Z	Thermal resistance, (K/W)

Greek letters

α	Thermal diffusivity, (m^2/s)
α_{evac}	Absorptivity of the ETC absorber surface
ε	Emissivity of glass
η	Thermal efficiency
θ	θ-direction
σ	Stefan–Boltzmann constant
τ_{evac}	Transmittance of ETC

Subscript

am	Ambient air
cond	Condenser
evac	Evacuated glass tube
evap	Evaporator
fin	Collector fin
i	Inner/inlet
iar	Inside annular ring
loss	heat loss
m	Manifold
o	Outer/outlet
oar	outside annular ring
r	r-direction/another annular ring
ST	Energy storage
tank	Storage tank
w	Water
z	z-direction

summer. Zambolin and Del Col [14] evaluated two different types of solar collectors as a flat plate and evacuated tube under the same operating conditions and determined that the evacuated collector had higher efficiency. However, to maximize thermal efficiency of a solar water heater system, heat transfer by thermosyphon is also interesting and very important.

As mentioned above, previous researchers studied and developed the theory for solar water heating system design depending on heat transfer by thermosyphon. Consequently, this study aimed to improve the accuracy of the mathematical model for an evacuated tube solar water heater using thermosyphon and Explicit Finite Difference Method (EFDM). Mathematical model results were validated under the same operating conditions.

2. Experimental setup

The outer and inner diameters of the ETC were 58 mm and 47 mm with 1800 mm of total length. The thermosyphon was made of a copper tube with 15.60 mm of both evaporator and adiabatic diameter while the condenser diameter was 22.25 mm. Lengths of evaporator, adiabatic, and condenser were 1700 mm, 150 mm and 100 mm, respectively. The working fluid within thermosyphon was R141 and its filling ratio at 70% of the evaporator volume. Other components of the solar water heater system consisted of a

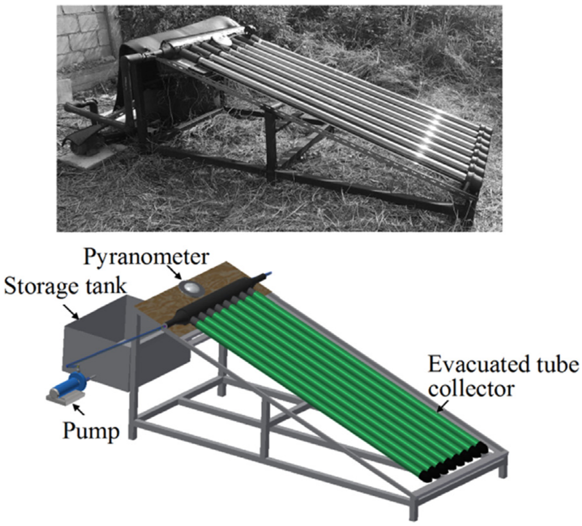

Fig. 1. Solar water heater system setup.