Solar Energy 170 (2018) 234–251

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Experimental study and CFD thermal assessment of horizontal hot water storage tank integrating Evacuated Tube Collectors with heat pipes

Saïf ed-Dîn Fertahi[a,b,*], T. Bouhal[a,b], T. Kousksou[b], A. Jamil[a], A. Benbassou[a]

[a] Université Sidi Mohamed Ben Abdellah (USMBA), École Supérieure de Technologie de Fès, Route d'Imouzzer BP 2427, Morocco
[b] Univ Pau & Pays Adour/E2S UPPA Laboratoire des Sciences Appliquees a la Mecanique et au Geni Electrique-fédération IPRA, EA4581, 64000 Pau, France

ARTICLE INFO

Keywords:
Experimental study
CFD thermal assessment
Horizontal storage tank
Energy performance
Numerical optimization

ABSTRACT

This paper presents an experimental study and a set of CFD simulations applied to a horizontal tank storing hot water. Hence, the main purpose of this work is to suggest a new and optimal design of the studied horizontal tank which is considered as the main device in individual solar water heaters integrating Evacuated Tube Collectors (ETC) with heat pipes. An experimental study was carried out to measure the maximum temperature of the heat pipes using a thermal camera. Subsequently, CFD simulations were performed using the previously recorded experimental results. The numerical studies aimed to assess the effect of the heat pipe's number, integrated on the lateral internal shell of the tank, on its energetic performances such as the discharging efficiency. In fact, four cases were studied according to the number of the used heat pipes (n). Several performance indicators were defined to identify the optimal configuration, such as the heat transfer coefficient assessed at the heat pipe, temperature contours and streamlines, temperature evolution according to specific paths defined inside the storage tank and the discharging efficiency…It was found that the average temperature of the horizontal tank is increased by the rise in the heat pipe's number. On the other hand, the laminar structure of the flow field is disturbed and the outlet temperature of the hot loaded water is also affected. Otherwise, the HTC calculated for the heat pipe close to the outlet of the storage tank for n = 6 achieved 212.5 W/K m^2, while it is 300 W/K m^2 and 230 W/K m^2 for n = 8 and n = 10, respectively. Moreover, the discharging efficiency of the horizontal storage tank depends mainly on the instantaneous variation of the water's temperature.

1. Introduction

1.1. Background

Hot water consumption is increasing in many countries, especially in Middle East and North Africa (MENA) (ed Dîn Fertahi et al., 2018) regions that have, collectively, the world's largest supplies of oil and gas (Hunt, 2011). This explains why individual solar water heaters have become a reliable and efficient solution to ensure the production of hot water (Mohamed et al., 2015), while contributing to the reduction of the electric bill (Al-Madani, 2006). For example in Brazil, on average, over 73% of Brazilian households use these 3–8 kW electrical resistance showerheads to provide hot water for domestic consumption which contributes to a load curve that peaks in the early evening, imposing a considerable burden to generation, transmission, and distribution utilities (Naspolini et al., 2010). The literature presents several works in which the energetic performances of thermosyphon solar water heaters have been studied (Tang et al., 2011). For instance, the performance of water-in-glass ETC solar water heaters has been assessed using experimental measurements to depict its optical and heat loss characteristics for domestic water heating in Sydney (Budihardjo and Morrison, 2009). However, the thermal assessment of solar water heaters using Evacuated Tube Collectors (ETC) with absorbing fins, where heat pipes are integrated is still considered as a new issue. Hence, it has to be analyzed and enhanced further, in order to achieve heating necessities. Therefore, particular attention must be paid to the sensitive storage part in the horizontal storage tank such an important device in solar hot water systems (Fig. 1). We have already worked on the improvement of the thermo mechanical strength of this type of horizontal storage tank (ed Dîn Fertahi et al., 2017) by conducting a parametric study which aimed to optimize three essential indicators namely, the thickness of the manufacturing shell, the material and finally the curvature radius which connects the cylindrical part of the tank to its two flat dished bottoms.

We believe that this study is original because first it belongs to a national Moroccan project entitled "*SOL'R SHEMSY*" (iresen), which aims to design and commercialize the first SWH made in Morocco funded by IRESEN. Second, it helps to understand heat transfer

* Corresponding author at: Université Sidi Mohamed Ben Abdellah (USMBA), École Supérieure de Technologie de Fès, Route d'Imouzzer BP 2427, Morocco.
E-mail address: fertahi.sayfdin@gmail.com (S.e.-D. Fertahi).

https://doi.org/10.1016/j.solener.2018.05.062
Received 26 March 2018; Received in revised form 13 May 2018; Accepted 17 May 2018

Nomenclature

a	length of the heat pipe (m)
A	surface of the heat pipe head (m^2)
b	spacing between two heat pipes (m)
C_p	specific heat (J/K kg)
D	tank diameter (m)
g	gravity m/s^2
H	maximum storage tank height (m)
h	heat transfer coefficient (W/K m^2)
h_1	length of the outlet nozzle (m)
h_2	length of the inlt nozzle (m)
j	index
L	horizontal length of the tank (m)
L_c	characteristic length (m)
n	number of used heat pipes
n_i	normal vector
p	pressure (Pa)
Q_{in}	inlet mass flow rate (kg/s)
Q_{out}	outlet mass flow rate (kg/s)
t	time (s)
T	temperature (K)
T^*	dimensionless temperature (K)
T_∞	temperature far from the heated walls of the heat pipes (K)
T_{hpi}	applied temperature at heat pipe (i) (K)
T_i	inlet temperature (K)
T_{ini}	initial temperature (K)
T_j	temperature in node j (K)
T_{max}	maximum temperature (K)
T_{min}	minimum temperature (K)
$T_o(t)$	instantaneous outlet temperature (K)
T_{ref}	reference temperature (K)
ΔT	temperature difference (K)
$\vec{U}$	velocity vector (m/s)
v_c	characteristic velocity (m/s)
Δx	the space steps discretization (m)
V	storage tank volume (l)
y^*	dimensionless height (m)
y	height of vertical storage tank (m)
Δy	the space steps discretization (m)

Greek symbols

α	thermal diffusivity (m^2/s)
β	thermal expansion coefficient (1/K)
λ	laminar thermal conductivity of the fluid
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
Σ_i	tank surface (i)
τ	stress tensor (Pa)

Abbreviations

CFD	Computational Fluid Dynamics
ETC	Evacuated Tube Collector
HTC	Heat transfer coefficient
MENA	Middle East and North Africa
SWH	Solar Water Heaters

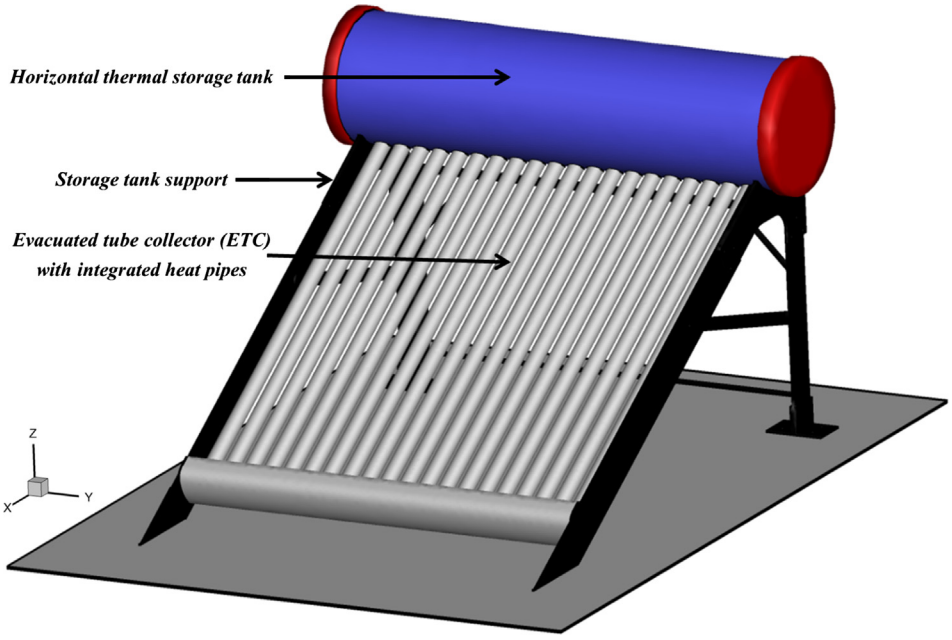

Fig. 1. Solar water heater prototype "*SOL'R SHEMSY*" (iresen). The thermal performances of the storage tank are under assessment and improvement stage (ed Dîn Fertahi et al., 2017).

phenomena that occurs inside a domestic horizontal tank integrating on its lateral shell heating sources and which is subjected to dynamic charging/discharging cycles. An exhaustive required consultancy of the literature's studies showed that the experimental and numerical investigations carried out on the assessment of the energy efficiency of the horizontal storage tank using ETC with heat pipes as heating source are not numerous. Therefore, we were interested to carry out an experimental study to measure the temperature in stagnation of a single heat pipe in the open air by using a thermal camera, and to capitalize on this result considered as thermal boundary condition, which will be useful for conducting unsteady CFD studies to optimize the horizontal storage tank design of the studied SWH.