Available online at www.sciencedirect.com
SciVerse ScienceDirect
Solar Energy 86 (2012) 1155–1163
SOLAR ENERGY
www.elsevier.com/locate/solener

Numerical study on performance of molten salt phase change thermal energy storage system with enhanced tubes

Y.B. Tao, Y.L. He *, Z.G. Qu

Key Laboratory of Thermo-Fluid Science and Engineering, Ministry of Education, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China

Received 7 October 2011; received in revised form 30 November 2011; accepted 5 January 2012
Available online 17 February 2012

Communicated by: Associate Editor Halime Paksoy

Abstract

Based on enthalpy method, numerical studies were performed for high temperature molten salt phase change thermal energy storage (PCTES) unit used in a dish solar thermal power generation system. Firstly, the effects of the heat transfer fluid (HTF) inlet temperature and velocity on the PCTES performance were examined. The results show that although increasing the HTF inlet velocity or temperature can enhance the melting rate of the phase change material (PCM) and improve the performance of the PCTES unit, the two parameters will restrict each other for the fixed solar collector heat output. Then three enhanced tubes were adopted to improve the PCTES performance, which are dimpled tube, cone-finned tube and helically-finned tube respectively. The effects of the enhanced tubes on the PCM melting rate, solid–liquid interface, TES capacity, TES efficiency and HTF outlet temperature were discussed. The results show that compared with the smooth tube, all of the three enhanced tubes could improve the PCM melting rate. At the same working conditions, the melting time is 437.92 min for the smooth tube, 350.75 min for dimpled tube which is reduced about 19.9% and 320.25 min for cone-finned tube which is reduced about 26.9% and 302.75 min for helically-finned tube reduced about 30.7%. As a conclusion, the thermal performance of PCTES unit can be effectively enhanced by using enhanced tube instead of smooth tube. Although, the HTF pressure drops for the enhanced tubes are also larger than that of the smooth tube, the largest pressure drop (1476.2 Pa) is still very lower compared with the working pressure (MPa magnitude) of the dish solar generation system. So, the pressure drops caused by the enhanced tubes could almost be neglected.

Keywords: Molten salt; Phase change; Thermal energy storage; Enhanced tube; Enthalpy method

1. Introduction

In recent years, with the deteriorations of energy crisis and environmental pollution, a lot of researches on the utilization of solar energy have been carried out, such as solar buildings (Kuznik and Virgone, 2009), solar water heating systems (Garnier et al., 2009; Sutthivirode et al., 2009) and solar energy generation systems (Tao and He, 2010; Cheng et al., 2010; He et al., 2011). However, solar energy is unstable with different weathers, times and seasons. So, in order to ensure the solar energy system continuous and stable operation with high efficiency, thermal energy storage (TES) unit have become a necessary component in the solar thermal utilization systems. Due to the high energy storage density and constant phase change temperature, phase change thermal energy storage (PCTES) has gradually become one of the preferred TES patterns.

Zalba et al. (2003) performed a review on the history of solid–liquid phase change thermal energy storage applications. Sharma et al. (2009) summarized the investigations on the available thermal energy storage systems. Agyenim et al. (2010) carried out a review of materials, heat transfer and phase change problem formulation for latent heat

* Corresponding author. Tel.: +86 29 82663300; fax: +86 29 82669106.
E-mail address: yalinghe@mail.xjtu.edu.cn (Y.L. He).

0038-092X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.solener.2012.01.004

Nomenclature

c_p	specific heat, J kg^{-1} K^{-1}
d	inner diameter of the tube, m
e	fin height, m
f	liquid fraction
h	heat transfer coefficient, W m^{-2} K^{-1}
k	thermal conductivity, W m^{-1} K^{-1}
L	length of the PCM unit, m
$\dot{m}$	mass flow rate, kg s^{-1}
p_l	longitudinal fin pitch, m
p_t	transverse fin pitch, m
Pr	prandtl number
Q	thermal storage capacity, J
r	radial coordinate, m
R_i	inner radius of the tube, m
R_o	inner radius of the shell side, m
Re	Reynolds number
T	temperature, K
t	time, s
x	axial coordinate, m
Greek symbols	
ε	thermal storage efficiency
μ	dynamic viscosity, Pa s
θ	relative temperature ($T - T_m$), K
ρ	density, kg m^{-3}
υ	kinetic viscosity, m^2 s^{-1}
ΔH	enthalpy, kJ kg^{-1}
Φ	heat flux, W
Superscripts	
*	last time layer value
Subscripts	
f	heat transfer fluid
i	initial state
in	inlet boundary
l	liquid
m	melting point
out	outlet boundary
p	phase change material
s	solid

thermal energy storage system over the last three decades. In the performance analysis, Gong and Mujumadar (1997) numerically analyzed the cyclic heat transfer of molten salt phase change material in a shell-and-tube latent heat energy storage exchanger with finite-element method. Sharma et al. (2005) studied the effects of PCMs physical properties, heat exchanger materials and patterns on the performance of a latent heat storage system with fatty acids as PCMs. Trp (2005) and Trp et al. (2006) performed the experimental and numerical investigations on the performance of paraffin melting and solidification in a shell-and-tube latent thermal energy storage unit. Fang and Chen (2007) investigated the effects of different multiple PCMs on the melted fraction, stored thermal energy and fluid outlet temperature of the shell-and-tube latent thermal energy storage unit. Akgun et al. (2007, 2008) analyzed the latent thermal energy storage system of the shell-and-tube type with three kinds of paraffin as PCMs. A novel tube-in-shell storage geometry was introduced and the effects of the Reynolds number and Stefan number on the melting and solidification behaviors were examined. Guo and Zhang (2008) numerically studied the effects of geometry parameters and boundary conditions on the performance of a new type high temperature latent heat thermal energy storage system. Long (2008) investigated heat transfer performance of a triplex concentric tube thermal energy storage unit. Adine and Qarnia (2009) numerically studied a latent heat storage unit consisting of a shell-and-tube filled with P116 and n-octadecane. Tao and He (2011) performed the numerical study on the PCM TES performance under non-steady-state inlet boundary and the effect of the unsteady inlet temperature and mass flow rate on the performance were examined.

In the performance enhancement studies, Fukai et al. (2000, 2003) adopted the carbon fibers to enhance the thermal characteristics of latent heat thermal energy storage units. Wu and Zhao (2011), Zhao and Wu (2011) performed the experimental investigations on the heat transfer enhancement of high temperature thermal energy storage using metal foams. At the same time, expanded graphite also was used to improve the thermal conductivity of PCM and enhance its performance (Zhang and Fang, 2006; Sari and Karaipekli, 2007; Acem et al., 2010).

The foregoing literature review shows that a lot of studies have been performed on the PCTES performance and its enhancement. But almost all of the studies were focused on the enhancement of the PCM side. For the solar dish thermal generation system with air or gas mixture as the HTF, the heat transfer performance of the HTF side is also poor, so enhancing the HTF side heat transfer performance would be another efficient method to improve the total TES performance. However, the researches on the phase change process with enhanced tubes in solar thermal power plants have little been reported. In present paper, based on enthalpy method, numerical studies were performed for high temperature PCTES unit used in a dish solar thermal power generation system. The molten salt was adopted as the high temperature PCM. And three kinds of enhanced