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Economic evaluation of shell-and-tube latent heat thermal energy storage for concentrating solar power applications

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Abstract

The capital cost and thermal performance of shell and tube type latent heat thermal energy storage (LHTES) is analyzed in this paper. In order to get the lowest cost of the shell and tube LHTES, the ideal one dimensional heat transfer model is used. The discharging process of shell and tube LHTES working in solar thermal power tower system and parabolic trough solar thermal power system were numerically simulated using lumped capacitance method. The capital cost of the LHTES was calculated considering different volume ratio of tubes and tube length. The results of the economic analysis shows that the tube and shell LHTES is a promising method to reduce the thermal energy storage cost.

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1. Introduction

In the past ten years, the concentrating solar power (CSP) technology developed rapidly and more and more CSP plants were put into operation in the world, mainly in Spain and USA. Most CSP plants have the thermal energy storage (TES) system which decouple power generation from solar collection and make the generated electricity

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dispatchable in the grid. In the other hand, TES can reduce costs associated with CSP plants [1]. TES can much reduce the need to dump energy of very high insolation periods and lower turbine start-up losses, which improve the annual solar-to-electricity efficiency. Most of TES systems in operation of commercial CSP plants such as Andasol 1-3 parabolic trough power plants and Gemasolar power tower plant are all based on sensible heat TES (SHTES) using molten salt as the heat storage material[2]. However, latent heat storage has higher energy density compared to the sensible heat storing method and shows potentially reducing the TES size and cost. There are many options for the phase change materials(PCM) and thermal performance enhancement techniques as review by Ming Liu in 2012[3]. For an indirect two tank molten salt TES widely used in the commercial parabolic trough solar power plants, the heat is charged and discharged by thermal oil as HTF. The temperature difference of hot salt and cold tank is 93^{O}C(291^{O}C, 284^{O}C)[4]. The storage heat density is lower than the latent heat of most PCMs. Thus the latent heat TES(LHTES) shows the potential economical competitive in parabolic trough power plant. The direct two tank molten salt TES has been operated successfully in the Gemasolar plant, which the molten salt is used as both HTF and storage material. The temperature difference of hot tank and cold tank is 275^{O}C (290^{O}C, 565^{O}C)[5]. The storage heat density is higher than the latent heat of most PCMs. For the real LHTES system, in order to improve the PCM availability rate, both sensible heat and latent heat should be used at same time. The three basic LHTES techniques to store heat energy are thermocline with PCMs as filter material, shell and tube LHTES and embedded thermosyphons LHTES. In this paper, the shell and tube LHTES is selected to analyze.

Nomenclature

A	section area, m^2
c_p	specific heat, J/kg K
C	cost,$
c	specific cost, $/kWh$_{th}$
h	convective heat transfer coefficient,W/ m^2 K
L	length of tube, m
Q	heat energy, J
r	inner radius of tube
T	temperature, K
V	volume, m^3
Greeks	
δ	thickness of the tube
γ	volume ratio of tubes
ε	volume ratio of HTF
ρ	density ,kg/m^3
Δh	heat of fusion, J/kg
Δt	time interval,s
Subscripts	
C	charging process
container	container of the shell and tube LHTES
Cutoff	cut off point of discharging or charging
D	discharging process
ml	melting point to liquid
ms	melting point from solid
PCM	phase change material
s	solid or PCM
l	liquid
f	fluid
tube	tube
HTF	heat transfer fluid

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