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Parametric study and standby behavior of a packed-bed molten salt thermocline thermal storage system

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A comprehensive transient, two-dimensional, two-phase model for heat transfer and fluid dynamics within a packed-bed molten salt thermocline thermal storage system has been developed in our prior paper. In the present paper, based on the developed model, the effects of various parameters, such as flow rate and temperature of inlet molten salt, porosity and height of the system, and the thermal losses on the thermal performance of the system, are investigated. The standby behavior focusing on the effects of wall structure, ambient air velocity on the thermocline expanding behavior is also studied. The results show that both the fluid inlet velocity and the inlet temperature have negligible influence on the thermocline development and hence the effective discharging efficiency, while increasing the tank height can effectively shrink the normalized thermocline region and lead to a higher efficiency. With good insulation, the heat losses from the standby system with a uniform initial temperature can be significantly lowered, and uniformly distributed molten salt temperature in the radial direction can be achieved. However, for the standby system with a thermocline region, the interior molten salt temperature can be influenced by the insulation layers and steel wall, causing temperature gradient in the radial direction.

1. Introduction

A thermal energy storage (TES) system which stores solar thermal energy for later use is vital for concentrating solar power (CSP) technologies including parabolic trough, power tower and dish/engine, as it can significantly increase the hours of electricity generation, improve the dispatchability of CSP plants and help to reduce the levelized cost of electricity (LCOE) [1]. Presently, TES systems using molten salt are widely implemented or under development worldwide [2–8], as molten salt offers the best balance of capacity, cost, efficiency and usability at high temperatures. The most mature molten salt TES system is the two-tank system which has two tanks for storing the molten salt: one at high temperature and the other at low temperature. It has been used or projected in many utility-scale CSP plants including the 10 MW Solar Two power plant in America, the Andasol (1–3) parabolic trough power plant (50 MW per plant) in Spain and the 280 MW Solana parabolic trough power plant in America [3,4,9].

The one-tank thermocline system is the other molten salt TES system. It has only one storage tank within which a portion of the medium is at high temperature and a portion is at low temperature. The high- and low-temperature regions are separated by a temperature gradient or thermocline. Compared to the two-tank system, the one-tank thermocline system requires only one storage tank, and low-cost solid storage medium can be used in the tank to replace part of the molten salt (referred to packed-bed thermocline), which can effectively reduce the cost of TES system by 20–37% [2].

Due to the benefit of low cost, the packed-bed thermocline system has attracted more and more worldwide attention. However, large-scale utilization of the packed-bed thermocline system is still hindered by several technical problems. For instance, the thermocline region is prone to expanding with time or degrading after several charging–discharging cycles. To overcome these problems, it is essential to gain a comprehensive understanding about the operation process of the system and the related inherent-coupled heat and mass transport mechanisms. To this end, numerical investigations have been employed in the development process of this system to minimize the expensive and time-consuming experimental investigations.

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