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The design and numerical study of a 2MWh molten salt thermocline tank

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Abstract

The two tank molten salt thermal storage system is widely used in the commercialized solar thermal power plant. However, the thermocline storage system with a low-cost filler material is a more economically feasible option. In this study, a transient two-dimensional and two-temperature model is developed to investigate the heat transfer and fluid dynamics in a molten salt thermocline thermal storage system. After model validation, the effects of inlet flow boundary condition and storage medium properties including fluid and solid materials on the thermal performance of thermocline storage system are investigated. The results show that thermoclne thickness increases slowest with solar salt as heat transfer fluid (HTF) and Cofalit® as solid material in the thermocline tank. Any non-uniformity in the inlet velocity flow would only enhance mixing and widen the thermocline appreciably, which contributes to the loss of thermodynamic availability of stored energy. The thermocline thickness increases with the non-uniformity of the inlet velocity boundary condition. So smaller non-uniformity of inlet flow is better in non-uniform flow though it may causes larger fluctuations in average outlet temperature. Smaller inlet mass flow rate is better for the thermocline storage tank, while it also causes smaller discharging power. With the chosen basic design parameters such as fluid and solid materials, the size of a 2MWh thermocline tank is determined by a simple one-dimensional design method. Tank with larger H/D ratio has higher discharge efficiency. It helps to figure out the thermal stratification mechanism of a storage tank and thereby to determine optimum design and operating conditions.

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1. Introduction

Power generation using concentrated solar power plants (CSP) is one of the several promising, emerging renewable energy technologies. The advantage of CSP systems relative to other utility scale renewable energy technologies is the ability to store energy as high temperature heat and continue producing power when solar energy is not available. A lot of research efforts have been recently focused on the integration of solar thermal energy storage (TES) as a viable means to enhance dispatchability, increase the value of concentrated solar energy and make the plant more reliable.

Nomenclature

C_p	specific heat capacity, J/kg·K	V	velocity, m/s
D	diameter of the tank, m	**Greek symbols**	
d_p	diameter of the solid filler, m	ε	porosity of packed-bed region
$\vec{e}_r$, $\vec{e}_x$	unit vector in the r and x direction, respectively	η	efficiency
F	inertial coefficient	μ	viscosity, kg/m·s
g	acceleration due to gravity, m/s^2	ρ	density, kg/m^3
H	tank height, m	**subcripts**	
h_i	interstitial heat transfer coefficient, W/m^3·K	air	air
K	permeability of porous material, m^2	crit	critical value
k	thermal conductivity, W/m·K	c	cold fluid
l	length, m	dc	discharging
$\dot{m}$	mass flow rate, kg/s	eff	effective value
Nu	Nusselt number	h	hot fluid
P	thermal power, W	i	insulation layers or tank steel
p	pressure, Pa	in	inlet
Pr	Prandtl number	l	length
Q	heat, J	out	outlet
Re	Reynolds number	s	solid material
T	temperature, K	st	steel wall
t	time, s	store	energy stored

There are a number of viable candidates for TES systems that might be developed and applied on a commercial scale for CSP plants. Presently, sensible molten salt TES systems including two-tank system and one-tank thermocline system are widely applied or under development worldwide [1], as molten salt used as the storage medium and direct heat transfer fluid can offer the best balance of capacity, cost, efficiency and usability at high temperatures [7]. The two-tank system has a high-temperature tank and a low-temperature tank for storing molten salt. It is the most mature utility-scale TES system for CSP plants, and has been applied or projected in many CSP plants. However, the two-tank molten salt TES system has very limited space for cost reduction. The one-tank thermocline system has only one storage tank and would use molten salt as the direct heat transfer fluid, storing energy gathered in the solar field, and transferring that energy when needed. With the hot and cold fluid in a single tank, the thermocline storage system relies on thermal buoyancy to maintain thermal stratification and discrete high- and low-temperature regions of the TES system. A low-cost filler material used to pack the single storage tank acts