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ScienceDirect

Energy Procedia 69 (2015) 925 – 936

Energy Procedia

International Conference on Concentrating Solar Power and Chemical Energy Systems, SolarPACES 2014

Solar thermal energy storage in power generation using phase change material with heat pipes and fins to enhance heat transfer.

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Abstract

Phase change materials absorb or otherwise release heat at close to a constant temperature during its melting and solidification phases. This is a very sought after property in power generation, where a high temperature heat source is required within a narrow temperature range as heat input for the turbine. Solar tower technology provides a high temperature heat source, but unfortunately it is time dependent. A sufficient amount of this heat may be stored in a phase change storage system which can deliver dispatchable heat. In such a storage system the phase change material needs to be exposed to a sufficient heat transfer area to melt or solidify at sufficient rates. In this study this is achieved with heat pipes with metallic fins. The analysis of this design included testing an experimental module during heat absorption and heat removal cycles, as well as a numerical analysis to model the storage module. To determine the parameters for a specific phase change storage system in a high temperature solar tower application the validated numerical thermal response simulation is incorporated. Certain solar input conditions and load cases are applied to the phase change storage system model and the size and geometry of the solar thermal storage system are determined from this analysis.

Peer review by the scientific conference committee of SolarPACES 2014 under responsibility of PSE AG

Keywords: Phase change material; solar thermal energy; heat transfer enhancers; heat pipes; metallic fins

1. Introduction

Advances in solar thermal systems have made it possible to achieve a high temperature heat source from solar irradiation. This high temperature heat needs to be stored to achieve dispatchable power. There are some sensible

Peer review by the scientific conference committee of SolarPACES 2014 under responsibility of PSE AG
doi:10.1016/j.egypro.2015.03.176

two tank molten salt systems under construction and in operation around the world [1]. This kind of system stores heat in a sensible form, for example, the solar power plant Crescent Dunes in Tonopah, Nevada, USA will heat a large amount (32 000 tons) of molten salt from 288°C to 565°C during its heat absorption phase. It will deliver 110 MW of electricity for 10 hours during a full heat removal cycle [2]. The larger the temperature difference the larger is the heat storage, and a very large quantity of molten salt is required. Alternatively heat may be stored in latent form by melting a PCM salt from solid to liquid form. The latent heat of PCM salts vary between 60 kJ/kg to 1700 kJ/kg depending on the salt. For example, the latent heat absorbed or removed from table salt (NaCl) is 482 kJ/kg at a melting temperature of 801°C. Phase change materials absorb or release heat at a close to constant temperature during its melting and solidification phases. In this study experimental tests were conducted using paraffin wax melting at 59 °C and having a latent heat of fusion of 200 kJ/kg, and for the CSP power plant test facility a numerical simulation model that uses the properties of a salt containing 45% KCl and 55% KF on a molar basis and melting at 605 °C and having a latent heat of fusion of 407 kJ/kg [3].

The immediate advantages of using such a PCS system is that only one storage tank is required, which reduces containment costs and a smaller size tank will be required because of the high energy density of the phase change material. Also the container need not withstand high pressures, because the volume change is such that the container can be kept at atmospheric pressures. A further advantage is that by using a phase change material as storage medium a large amount of latent heat is available at a close to constant temperature during solidification when heat is extracted from the storage material. This high temperature heat storage system may be able to deliver reliable heat to the heat transfer fluid which in turn can supply heat to another heat exchanger, which boils high pressure water that power the turbine until the PCS system has delivered all its useful heat. However many PCMs have a low thermal conductivity. To remove all the absorbed heat from the PCM it needs to be exposed to a sufficient heat transfer area of the heat exchanger surfaces because of its low thermal conductivity. In this study this is achieved with heat pipes and metallic fins.

In this article the objectives are determined and the relevant literature reviewed. Following these sections a modular PCS concept is described. Following that the experimental and numerical work based on this test module, which uses paraffin wax as the PCM which melts at low temperatures, is summarised. Furthermore, a numerical model is developed based on the validated PCS system's numerical model for a high temperature PCS system using PCM salts and which incorporates a solar tower as solar input. The generated results will be described in the results section. A discussion and conclusion will follow.

Nomenclature

Symbols

$\dot{Q}$	Power
Q	Energy
T	Temperature
X	Fraction

Subscripts

Al	Aluminium
b	Bottom
c	Condenser
E	Experimental
e	Evaporator
ext	Extracted
hp	Heat pipe
i	Inner
N	Numerical
l	Left
r	Right
t	Top
S	Storage
salt	Phase change salt
V	Volume
w	Wall
wax	Paraffin wax

Abbreviations

CSP	Concentrating Solar Power
HTE	Heat Transfer Enhancers
HTF	Heat Transfer Fluid
PCM	Phase Change Material
PCS	Phase Change Storage