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Modelling of phase change in spheres for applications in solar thermal heat storage systems

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Abstract

Thermally stratified solar energy accumulation tanks are an effective technique widely used in solar collector systems. Thermal energy storage (TES) systems using phase change materials (PCM) is another technology that can be applied to accumulation tanks to improve thermal energy density. To analyze the impact of placing PCM inside the tanks, it is crucial to understand the parameters that describe the processes that take place in each of the PCM sphere. In this study COMSOL Multiphysic is used to analyze the energy accumulation in PCM through thermal conductivity, which is one of the first steps to full simulate PCM in stratified water environment. The assumption stated by other studies that for low Rayleigh numbers the thermal conductivity is the dominant heat transfer principle is tested by comparing the model to experimental data. The simulation results showed that the thermal conductivity method can be successfully used to model the process until the material has melted, suggesting that additional effects has to be considered to increase the accuracy of the model.

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Keywords: phase; change; materials; accumulation; obstacle; thermal; energy

1. Introduction

Solar thermal energy systems require storage of heat to provide on-demand hot water at any time during the day. One of the ways to decrease the cost of solar energy is to develop more efficient TES systems. Most of the TES systems use water as only energy accumulator and thus are called sensible heat storage (SHS) systems.

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Nomenclature

Cp	specific heat, kJ/(kg*K)
CT	computational time
CFD	computational fluid dynamics
g	gravity acceleration, m/s^2
LHS	latent heat storage
k	thermal conductivity, W/(m*K)
dL	latent heat, kJ/kg
PCM	phase change material
R	radius, m
Ra	Rayleigh number
SHS	sensible heat storage
TES	thermal energy storage
T	temperature, °C (K)
t	time, s(min, h)
∇	differential vector operator
Greek	
α	thermal diffusivity, m^2/s
β	thermal expansion, 1/K
ν	kinematic viscosity, m^2/s
ρ	density, kg/m^3
Subscripts	
e	effective
i	initial
l	liquid
s	solid
w	water

The use latent heat systems (LHS) have been researched in the latest years as potential technology to increase efficiency [1].

By combining sensible and latent thermal storage systems, it is possible to store a larger quantity of energy in smaller volume. Also the phenomena of phase change that occurs as isothermal process is favorable, since specific materials can be used with melting and solidification temperatures selected for each individual case and also reduces the maximum temperature requirements compared to SHS. Few of LHS systems have been commercialized, partly due to the poor heat transfer rate during the charging and discharging processes and high initial cost. In latest years an increasing number of studies are looking into the use of phase change materials [2, 3].

There are a number of great reviews concerning latent TES [2, 4–6]. Additionally review by Salunkhe & Shembekar [7] describes importance in correct encapsulation of PCM.

Multiple studies have used experimental systems to analyze the application of PCM for TES. An experimental system that could replicate the conditions of a real system, and have an ability to repeat same experiment for multiple times could greatly reduce the time needed to commercialize the LHS [8]. Akgün [9] carried out a study in order to investigate the melting and solidification processes of paraffin as PCM in a tube shell heat exchanger. Paraffin is often used because of the low cost, high energy density, large scale availability and availability of physical properties data, since it has been analyzed by many researchers and companies. López-Navarro [3] carried out experiments with LHS tank with paraffin as a PCM. Reddy [1] investigated TES with paraffin and Stearic acid in solar thermal system. The PCM were capsulated in spherical shells and placed in storage tank. Spheres are studied since they provide the largest surface area per volume, thus increasing the heat transfer rate. To create LHS with PCM spheres, numerical modelling can be applied to describe the processes that take place during the energy accumulation in PCM.