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Effects of void spaces in a phase change material based thermal energy storage system

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Abstract

A study is conducted to examine the effects of void spaces of air in phase change material based thermal energy storage (PCM-TES) system. A thermal simulation and analysis on a 2d axis symmetrical model is performed to simulate the effect of phase change, buoyancy driven convection and heat transfer. Two models are compared, one with a 20% air space and the other without. Both models are consistent in PCM volume. Results obtained from the simulation are validated by experimental results and showed good agreement. The model with the void space demonstrated characteristics which resembles a sensible heat storage system rather than the constant temperature characteristics of a latent heat storage system. The significant volume taken up by the void space could be reduced and replaced with more phase change material (PCM); which will increase the heat storage capacity of the system. Hence, understanding the effects of void spaces will be paramount in the development of future PCM-TES system designs.

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Keywords: phase change material; latent energy storage; thermal energy storage system; macro-encapsulation; thermal simulation; void space

1. Introduction

In the recent decades, the need to source for and develop renewable energy sources have been an increasing concern. Replacing traditional and environmentally unfriendly methods with solar energy is not novel but there are many ways to further improve its systems. There are two main methods of conversion of solar energy into electrical energy, namely the use of photovoltaic (PV) cells or concentrating solar power (CSP) plant [1, 2]. PV cells utilize semiconductors and directly convert solar energy into an electrical output [3]. Meanwhile, CSP plants use mirrors to concentrate the solar rays to thermal energy, and using the stored thermal energy to drive power generation cycles such as steam engines. The benefit of a CSP method over the PV method is the ability to produce electricity in the absence of sun irradiance [4]. This conversion of solar energy into thermal energy is made possible by the use of thermal energy storage (TES) systems [1, 2].

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Phase change material based thermal energy storage (PCM-TES) system embodies sensible and latent heat storage method as its primary working principle. It has many practical applications in the urban clean and green cities such as in concentrated solar power plants, waste heat thermal storage systems and even in building materials.

PCM based TES systems usually consist of a PCM macro-encapsulated within a thermally conductive enclosure, with or without a thermal enhancing component such a metal lattice structure to improve the overall thermal conductivity of the system. The containing vessel is often considered as a pressure vessel and takes on multiple stresses [5], depending on the method in which it was filled. The PCM will typically fill up about 80% of the enclosure's volume [6, 7] while a void space remains to accommodate for the thermal expansion of the PCM during its phase transition from solid state to liquid state [6, 7]. A method used to work around this problem is to encapsulate the PCM while in its expanded liquid form [8]. This method causes a vacuum to form during solidification which forms a negative pressure.

However, the void space is absolutely necessary within the current design of the PCM-TES system [9-13], but the space of air creates a layer of insulation which adversely affects the overall thermal conductivity of the system [6]. In theory, the rate of heat transfer will be hindered by the reduction in contact surface area and the blanket of air.

This study explores numerically and experimentally the effect of the air void space on the heat transfer within a cylindrical enclosure. The comparison study comprises of two models, one with a standard 20% air void space and the other without; both models with equal volumes of PCM. In this paper, the numerical simulation and CAD drawing will all be conducted via finite element analysis, solver and simulation software, COMSOL Multiphysics and SOLIDWORKS respectively. An experiment with the physical PCM-TES model will be carried out under similar circumstances to obtain the actual surface temperature data. Verification of the simulated results is performed by comparing the simulated results with the experimental results.

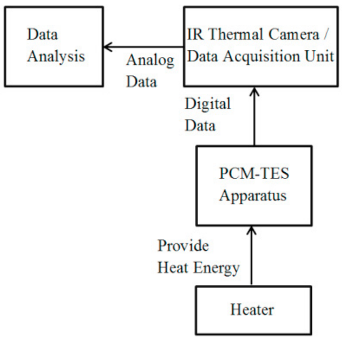

Figure 1: Proposed Experiment Workflow

The figure above shows the proposed workflow for the experiment that consists of the equipment required and the flow of data. The apparatus will be heated up via an electronic heating bed and temperature captured by an IR thermal camera [14].

The simulation and experimental results demonstrated a good agreement that the void space has an adverse and undesirable effect on the overall heat transfer in a phase change material based system. Therefore, the obtained results could be beneficial and valuable to the future design of PCM based TES systems as well as other encapsulated PCM based system.

Nomenclature

C_P	Specific Heat Capacity (J/kgK)
$\boldsymbol{F}$	Volume Force Field (N/m^3)
H_f	Heat Storage Capacity (J/kg)
k	Thermal conductivity (W/mK)
p	Pressure (Pa)
q	Heat Power (W)
s	Seconds
t	Time (s)
T	Temperature (℃ or K)
$\boldsymbol{u}$	Velocity Field (m/s)
Q	Heat Source (W/m^3)

Greek symbols

α	Phase Volume Fraction
Δ	Difference
θ	Phase Mass Fraction
μ	Dynamic Viscosity (kg/m s)
ρ	Density (kg/m^3)

1.1. PCM-TES System Information

The PCM-TES system is made out of a two circular aluminum bodies which encapsulates the phase change material (PCM) and the air void space. The system houses a commercially available PCM, RT35HC by RUBITHERM® Technologies GmbH, which has a melting point of 35℃ over a temperature range of 3℃. The system also has a vent valve to prevent over-pressuring during the encapsulation process, after all, the system is largely considered as a pressure vessel whose dimension is Ø100 x H 20.5 mm.