FACULTY OF ENGINEERING

TRANSIENT PERFORMANCE OF THERMAL ENERGY STORAGE TES DEVICES USING PHASE CHANGE MATERIALS PCM

BY
ENG. MOSTAFA BAHAA AL-DIN IBRAHIM GHONAMY
PhD MECHANICAL POWER ENGINEERING

A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIRMENTS FOR THE DOCTOR OF PHILOSOPHY IN MECHANICAL POWER ENGINEERING

UNDER SUPERVISION OF

PROF. DR. ABDUL AZIZ MORGAN   DR. EHAB MORIS

MECHANICAL POWER ENGINEERING DEPARTMENT
FACULTY OF ENGINEERING
AIN SHAMS UNIVERSITY
CAIRO, EGYPT

2018

Examiners committee

The undersigned certify that they have read and recommend to the Faculty of Engineering, Ain Shams University, for acceptance of this thesis entitled "Transient Performance of Thermal Energy Storage TES devices using Phase Change Materials PCM ".

Signature

Prof. Dr. Mahmoud Abdel-Wahab Shahin
Professor of Mechanical Power Engineering
Faculty of Engineering, Helwan University.

Prof. Dr. Mahmoud Abdel-Rashid
Professor of Mechanical Power Engineering
Faculty of Engineering, Ain Shams University.

Prof. Dr. Abd Alaziz Morgan
Professor of Mechanical Power Engineering
Faculty of Engineering, Ain Shams University.

Abdul Aziz

INFORMATION ABOUT THE RESEARCHER

Name: Mostafa Bahaa Aldin Ibrahim Ghonamy

Date of Birth: 12th of June, 1983

Place of Birth: Heliopolis, Cairo

Qualifications: M.Sc. in Mechanical Engineering

University: Ain Shams University

Faculty: Faculty of Engineering

Section: Mechanical Power Engineering

Statement

This dissertation is submitted in partial fulfillment for the degree of Doctor of Philosophy in Mechanical Power Engineering, Ain Shams University. The work included in this thesis is carried out by author at the laboratories of the Mechanical Power Engineering Department, Ain Shams University.

No part of this thesis has been submitted for a degree or qualification at any other University, or place of learning.

Signature:

Mostafa Bahaa Al-Din Ibrahim Ghonamy

Acknowledgements

First of All Thanks To God

I wish to express my sincere gratitude to my supervisors, Prof Dr. Abdul Aziz Morgan, and Dr. Ehab Moris, Mechanical Power Engineering Department, Faculty of Engineering, Ain Shams University, for their guidance, keen supervision and continuous encouragement throughout this work and I am proud of working with them as a team. I also appreciate their support to me in all critical situations faced me during lab testing and technical studies.
I wish to Express my thanks for my great family who supplied me by the best environment and to everyone helped or shared me in any stage of this work.

Mostafa Bahaa Al-din

ABSTRACT

Thermal energy storage (TES) is a technology allows the storage of heat energy. It works as a battery for storing thermal energy. Materials can store thermal energy through sensible energy storage (STES) undergoing temperature variation during energy storage. Latent thermal energy storage systems (LTES) allow maintaining constant temperature while storing thermal energy through Phase change materials (PCMs) due to their large latent heats. Due to the low thermal conductivity of PCMs which leads to long time required for phase change, researchers work on developing the thermal performance of PCMs.

In this work, a detailed experimental study is carried out to analyze the impact of mechanical movement expected to introduce forced convection heat transfer through the PCM resulting in faster melting process. Rectangular slab of paraffin is tested as a PCM. The melting temperature, Tm, of the tested paraffin is 55 ˚C with one heating face kept at 70 ˚C. The transient temperature gradients are tabulated and plotted.

Tests show that, at the beginning of heating, the conduction heat transfer dominates the temperature rise with no observed changes between the moving and stationary tests. As the melted portion increases, the forced convection, created by oscillatory motion, dominates leading to a faster and certain complete melting process.

CONTENTS

Chapter (1)

Introduction

Phase change material (PCM) is used to store thermal through isothermally depending on its high latent heat. The PCM allows the gain of its advantages which is mainly the ability to store large amount of energy with fine temperature change.

The study of PCM has been pioneered since 1940s, due to the need to magnify the usage of solar energy to replace fossil fuels. This requires developed means of storing thermal energy. Thermal energy can be stored through materials through sensible energy storage systems SES raising the material temperature or through latent heat in latent heat energy storage systems LHS which allows the advantage of keeping a constant temperature through the thermal energy storing process.

For the phase change material to be mostly useful and effective, in addition to being good conductor, it should be chemically stable to ensure same physical properties even after thousands of melting solidification cycles. Also it should have high heat of fusion to ensure minimized volume and weight of energy storage material. Paraffin wax is one of the promising PCMs as it allows additional advantage of being organic material while its main drawback is the low thermal conductivity which varies from 0.14 to 0.35 W/(mK).

To understand the drawback of paraffins deeply, the hierarchy of Thermal Energy Storage materials should be presented. In 2003, B. Zalba et al. [1] showed in fig 1.1 most of the mostly used energy storage materials.

The analysis of melting and solidification problems during a heat transfer process is complicated due to the continuous movement of the solid liquid interface separating both the solid and liquid phases.

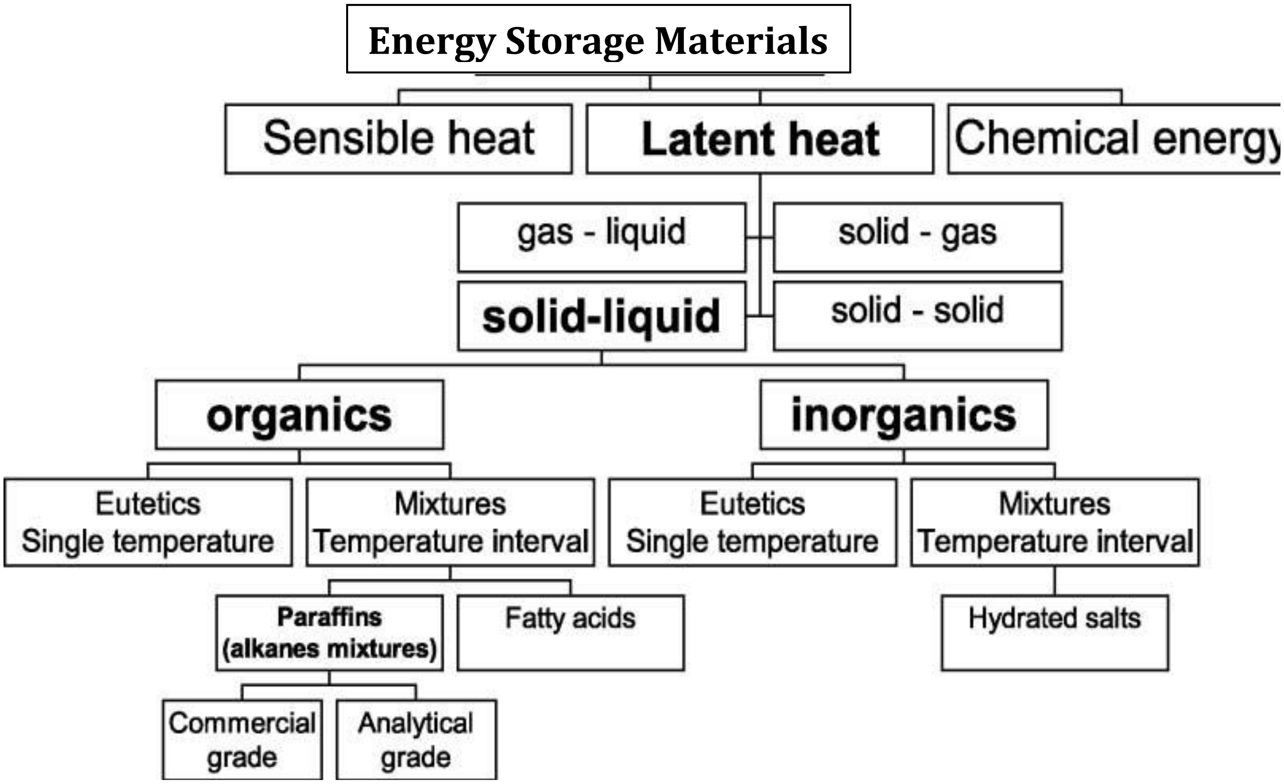

Fig 1.1 Classification of energy storage materials

Chapter (2)

Literature Review

Most recent researches on PCM are focused on how to add enhancing techniques to exaggerate its performance. Most of these enhancing techniques fall in the below areas of interest:

2.2 Study new PCMs with promising thermo-physical properties [2, 36-45]

2.3 Introducing composite mixtures to allow better heat conductivity [4-36, and 75]

2.4 Configuration of Slab that contains the PCM [55-74]

2.5 Encapsulation technology of PCM to allow better heat transfer [3, 46-54]

2.1 Study new PCMs with promising thermo-physical properties

Researchers worked on discovering and experimenting different materials to be introduced as promising PCMs with more efficient Thermo-physical properties.

In 2012, M. Liu et al. [2] examined salts, eutectics and metal alloys to be used as a promising phase change materials with melting point below 300°C.

In 2013, K. Menoufi et al. [38] tested some esters to be used as phase change materials. The results were used to compare the tested materials with other promissing organ materials like paraffins. The chosen esters showed slight advantages.

H. Ge et al. [39] examined Gallium. The liquid metal has been introduced as a phase change material. The experiments showed that the metals have increasing potentials in various thermal and energy management fields, especially for those situations where the cooling space was strictly limited and the heat source works inconsecutively.

A. Gil et al. [44] studied using "D-mannitol" as a phase change material. When used as a PCM, the D-mannitol showed unstable physical properties with slightly variation in its temperature. It is concluded that the usage of D-mannitol as a PCM faces practical challenges.

In 2015, A. Sivakumar et al. [37] studied the nanofluids of both Al_2O_3 and CuO with water. The study concluded that using the CuO with water nanofluid is better than using the water with Al_2O_3.

In 2016, M.M. MacDevette and T.G. Myers studied also the nanofluids to be used as a PCM. Alumina-water nanofluid was tested as a phase change materials but the introduced nanofluid did not show promissing results.
S.N. Gunasekara et al. [41] examined sugar alcohols to be used as phase change materials. Polyethylene glycol and Xylitol have been examine and showed good results. The results were promising even when comparing the tested materials with commonly used organic candidates like paraffins.

2.2 Introducing composite mixtures to allow better heat conductivity

Researchers worked on experimenting different material composites to help overcoming the drawbacks of regular PCMs with more efficient Thermo-physical properties.
In 2011, A. Karaipekli and A. Sarı [23] studied composites of fatty acid ester like erythritol tetrastrearate. The introduced material was tested to allow thermal energy storage to buildings. The introduced PCM was then added to gypsum, cement and other building materials.
In 2012, Y. Qian et al. [26] studied paraffin composites. The research aimed to enhance the thermal stability of paraffins. The added materials improved the thermal stability of the paraffins leading to mixtures of high energy storage capacity as well as very good thermal stability.
S.F. Hosseinizadeh et al. [21] investigated numerically (figure 2.1) improving properties of the phase change materials applying with nano particles. The nano particles helped to overcome the main drawback of most PCMs which is the poor thermal conductivity.
Te simulation considered a spherical shell. where a melting process is applied on the PCM enclosed inside (figure 2.2) .

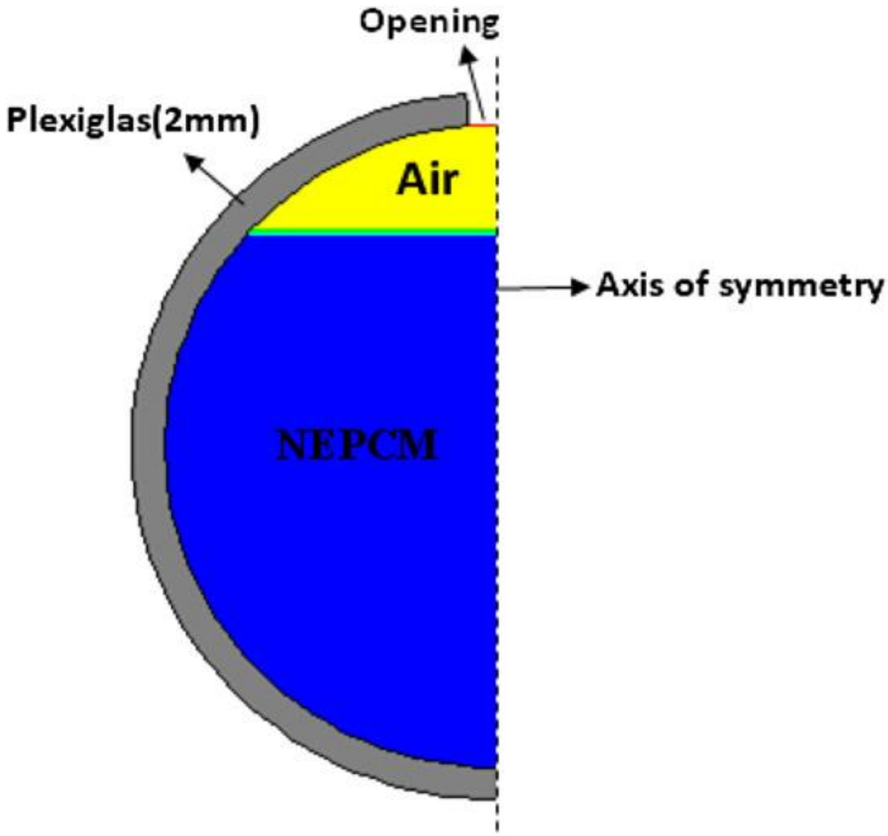

Fig. 2.1 The computational domain.

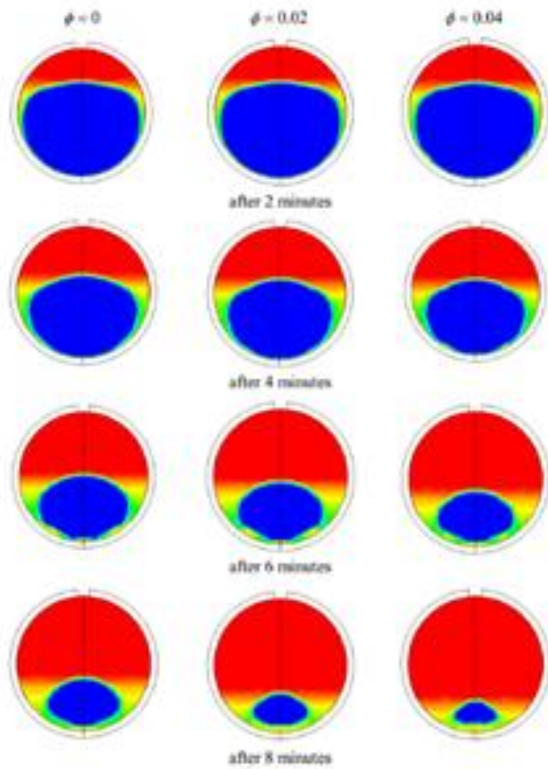

Fig. 2.2 melting phase for various volume fraction of nano-particle when DT =10 C.

In 2013, M. Mehrali et al. [25] introduced newly experimented composite. The teasted palmitic acid when mixed with graphene oxide.

M. Li [4] tested the paraffin after adding nano-graphite (NG). The paraffin was well mixed with the nano graphite particles. The aim of adding the graphite particales was mainly to improve the thermal conductivity of paraffin. The results showd that the added graphite particles improved the thermal conductivityu of paraffin however, the latent heat of the mixture was lower than that of the pure paraffin..

N. Zhang et al. [16] introduced a new tested composite when adding Lauric–palmitic–stearic acid to perlite. The newly introduced composite was expected to show good thermo-physical properties when used as phase change material.

The proposed material showed a very good thermal stability. The thermal conductivity was also enhanced by adding graphite particles to the introduced composit. Generally all results indicated that the prepared form-stable PCM composite can be considered as a potential material for building energy conservation due to satisfactory thermal properties, high thermal conductivity, good thermal reliability and stability.

S. Harikrishnan et al. [15] added nano particles to building materials. The experimental investigation aimed to provide good phase change material that can be used with building heating applications. TiO_2, CuO and ZnO nanoparticle have been added with equal ratio of 1%. The added nano particles enhanced the thermal conductivity of the base material with different ratios. the best results were when adding CuO which increased the thermal conductivity by more than 60%.

In 2015, S. Ramakrishnan et al. [5] introduced a paraffin- perlite composite. The tested PCM was used to prevent the leakage of phase change materials especially in cement composites by impregnating paraffin into hydrophobic coated expanded perlite. The composite showed very good thermal performance with high thermal energy storage capacity.

R. Hossain et al. [13] tested numerically and analytically the phase change material inside porous medium after being enhanced by nano particles. The melting process and heat transfer phenomena were analyzed for nano enhanced phase change material inside a porous medium (figure 2.4). The materials wers selected as follows:

- Porous Medium: Aluminum Foam
- Nano/PCM: Cyclohexane þ CuO nanoparticle

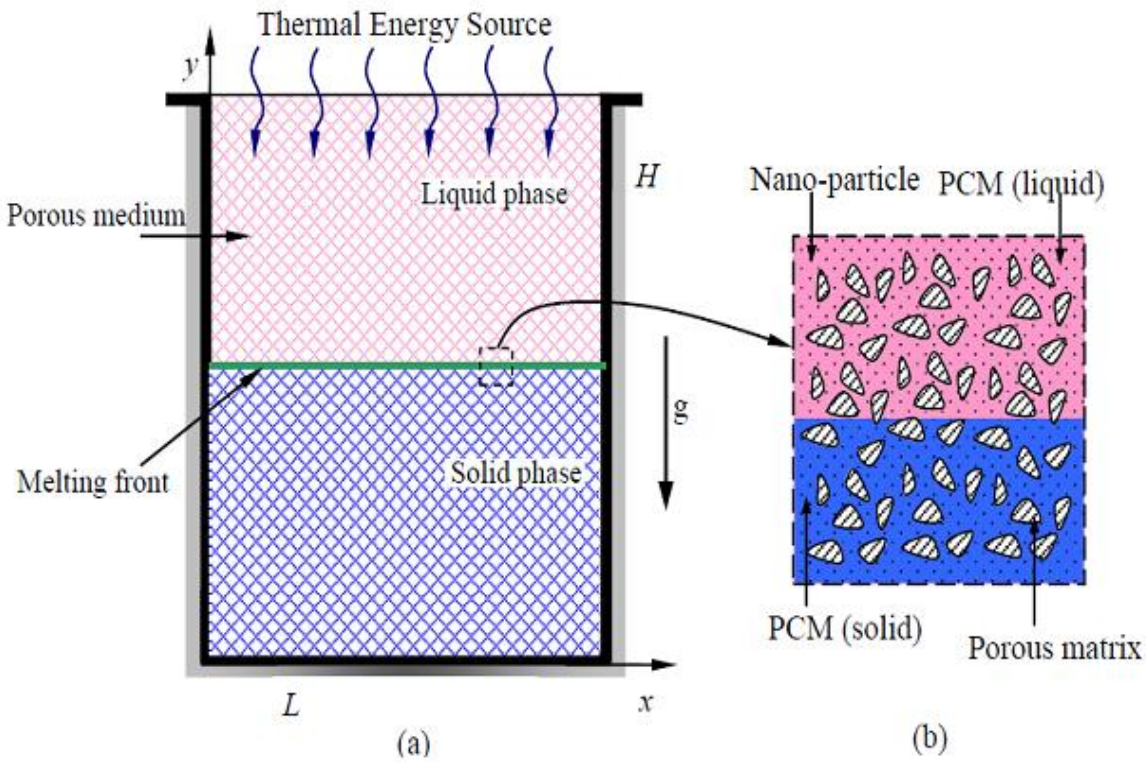

Fig 2.4 (a and b) (a) Schematic diagram of the problem under consideration, (b) a magnified view of a representative control volume

It is observed that the movement of PCM melting front is more significant under the influence of porous medium than that of nanoparticles. Nano-PCM melts at a faster rate inside the porous medium with lower porosity.