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CFD Analysis of Melting of Paraffin Wax with Al_2O_3 & MGO Nanoparticles in Square Enclosure

P Bala Subrahmanyam[1], Prof. Rohit Soni[2]

[1]Trinity Institute of Technology and Research, Research Scholar, RGPV Bhopal, Madhya Pradesh, India

[2]Trinity Institute of Technology and Research, Professor, RGPV Bhopal, Madhya Pradesh, India

ABSTRACT

Thermal energy storage is considered advanced energy technology, and there has been an increasing interest in using this essential technique for the thermal applications such as heating, hot water, air conditioning, and so on. The selection of the TES systems mainly depends on the storage period required i.e. ., diurnal or seasonal. Economic viability, operating conditions, and the like. Paraffin waxes are cheap and have moderate thermal energy storage density but low thermal conductivity and, hence, require a large surface area. Thermal storage has been characterized as a kind of thermal battery. This study is based on variations of thermo-physical properties of Phase Change Material (PCM) due to dispersion of nanoparticles. This work focuses on CFD investigation of the melting of paraffin wax dispersed with two different metal oxide Alumina (Al_2O_3) & Magnesium oxide (MgO) that is heated from one side of square enclosure of dimensions of 20 mm × 20 mm. The integrated simulation system ANSYS Workbench 14.5 for the numerical study was used including mesh generation tool ICEM and FLUENT software. Dispersed nanoparticles in larger volumetric fractions show a rise in the heat transfer rate. The melting percentage is slightly greater using MgO as compared to Al_2O_3 nanoparticles.

Keywords : Thermal Energy Storage, Phase Change Material, Latent Heat.

I. INTRODUCTION

TES system deal with the storage of energy by cooling, heating, melting, solidifying or vaporizing of a material and the thermal energy becomes available when the process is reversed. Thermal energy storage (TES) systems correct the mismatch between the supply and demand of energy.

Thermal energy storage (TES) is a technology to stock thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. TES systems are particularly used in buildings and industrial processes.

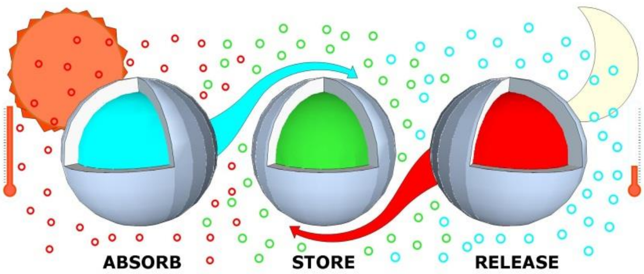


Figure 1. Process of Absorption & Releasing of Energy

1.1 Phase Change Materials

LHS materials are known as PCMs due to their property of releasing or absorbing energy with a change in physical state. The energy storage density increases and hence the volume is reduced, in the case of LHS. The heat is mainly stored in the phase-change process (at a quite constant temperature) and it is directly connected to the latent heat of the substance. The use of an LHS system using PCMs is an effective way of storing thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process. The main advantage of using LHS over SHS is their capacity of storing heat at almost similar temperature range. Initially, these materials act like SHS materials in that the temperature rises linearly with the system enthalpy; however, later, heat is absorbed or release at almost constant temperature with a change in physical state.

1.1.1 Characteristics Proprieties of PCMs

PCMs have been used in thermal applications for a few decades. PCMs have:

- Thermo-physical properties (latent heat of transition and thermal conductivity should be high, and density and volume variations during phase-transition should be, respectively, high and low in order to minimize storage volume),
- Kinetic and chemical properties (super-cooling should be limited to a few degrees, and materials should have long-term chemical stability, compatibility with materials of construction, no toxicity, and no fire hazard)
- Economic advantages (low cost and large-scale availability of the PCMs are also very important).

1.1.2 Classification of Phase change Material

LHS materials are broadly classified based on their physical transformation for heat absorbing and desorbing capabilities.

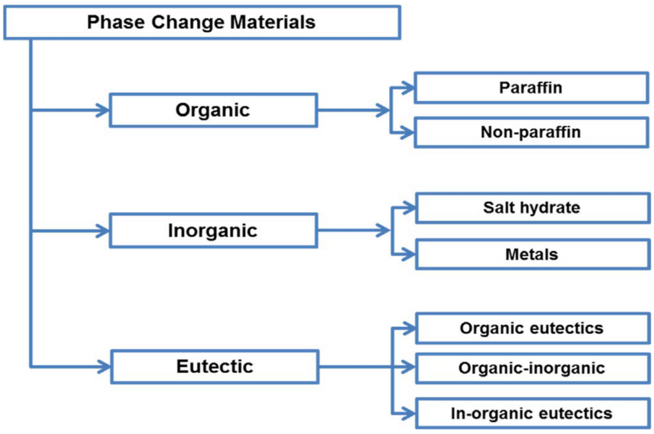


Figure 2: Classification of phase change materials.

II. LITERATURE REVIEW

Thermal energy storage, in general and LHS in particular, has gained more popularity in the past two decades, due to its advantages discussed in the previous chapter. In the present work, a detailed survey has been made of the various aspects in this field of research, which includes thermal storage materials, storage system configuration, applications, experimental investigations and modeling of phase change problems.

Progress in LHS systems mainly depends on heat storage material investigations and on the development of heat exchangers that assure a high effective heat transfer rate to allow rapid charging and discharging. Latent heat TES systems are broadly classified into the capsule-type and the shell and-tube type, according to the method of containing the thermal energy storage material and to the mode of exchanging heat energy within the container. The various studies carried out by the researchers on different configurations are classified under i) Tubular exchanger ii) packed bed units iii) system with different heat transfer enhancement techniques.

Bauer T. et al. [2012] This paper focuses on latent heat storage using a phase change material (PCM). The paper lists of literature and gives the current status of medium working range temperature of 200 to 350oC. In this paper the system with KNO3-NaNO3 is discussed in detail with their thermo-physical properties in the liquid and solid phase. A comparison of literature data and own measurements for the density, heat capacity, thermal diffusivity and thermal conductivity is presented in detail. The melting temperature and enthalpy of the KNO3-NaNO3 is 222oC and 108j/g was identified respectively. Different properties such as thermal conductivity, density are also collected from the different literatures.

Thogiti Arunkumar[2016] Analyzed the thermal characteristics of evaporator in refrigerator and compared for with pcm chamber and without pcm chamber at different refrigerants HFC – 134A, Ethylene glycol and propylene glycol and water. CFD analysis is done on the evaporator to determine the heat transfer coefficients without pcm and with pcm. Thermal analysis is also done by varying two materials for the evaporator Copper and Aluminum.
Müslüm Arıcı , Ensar Tütüncü, Miraç Kan, Hasan Karabay [2017] In this study, melting of paraffin wax with Al_2O_3 nanoparticles in a partially heated and cooled square cavity is investigated numerically. The thermally active parts of the enclosure which are facing each other are kept at different constant temperatures while the other parts of the enclosure are insulated. The effect of nanoparticle concentrations (/ = 0 vol%, 1 vol%, 2 vol% and 3 vol%) and orientation of the activated walls together with the temperature of the hot wall on the melting process and stored energy is investigated. Thermophysical properties of NEPCM are considered to be temperature and phase dependent. The computed results showed that considered parameters have a significant effect on the melting rate and stored energy. The results reveal that the highest enhancement is attained for the enclosure filled with / = 1 vol% of nanoparticle concentration and heated from bottom, and nanoparticle concentration beyond / = 1 vol% defeats the purpose thus enhancement decreases.

M.Auriemma and A. Iazzetta [2016] A numerical study on variations of thermo-physical properties of Phase Change Material (PCM) due to dispersion of nanoparticles is presented in this article. Dispersed metal oxide nanoparticles in paraffin wax might be a solution to improve latent heat thermal storage performance. Thermo-physical properties such as thermal conductivity and latent heat could be changed for different concentration of dispersed nanoparticle. The paper will focus on numerical investigation of the melting of paraffin wax dispersed with three different metal oxide Alumina (Al_2O_3), Copper Oxide (CuO) and Zinc Oxide (ZnO) that is heated from one side of rectangular enclosure of dimensions of 25 mm × 75 mm. The integrated simulation system ANSYS Workbench 15.0 for the numerical study was used including mesh generation tool ICEM and FLUENT software. In FLUENT, the melting model with Volume Of Fluid (VOF) that includes the physical model to disperse nanoparticles in the PCM and their interactions is applied. During melting process, the enhancement of heat transfer is considered. For each nanoparticle analyzed, three different volume fractions are considered and compared. Dispersed nanoparticles in smaller volumetric fractions show a rise the heat transfer rate. The thermal performances are slightly greater using Al_2O_3 respect both ZnO that CuO nanoparticles.

The literature review reveals that no researcher was used the Beryllium oxide as nanofluid for optimizing the thermal energy storage system parameters in which PCM is stored.

III. METHODOLOGY

The ANSYS Design Modeler provides the following approaches for model generation: Creating a surface model within ANSYS Design Modeler. The Phase change material (PCMs) setup, in which the rectangle of length & width are 20mm & 20mm respectively, a schematic wall model of phase change material in a two-dimensional square enclosure in size of 20 mm ×

20 mm is prepared using design modular in Ansys environment as shown in Fig.3

Figure 3: 2D wall of Phase Change Material

The mesh created in this work is shown in figure 4. The total Node is generated 5234 & Total No. of Elements is 5864 for PCM wall.

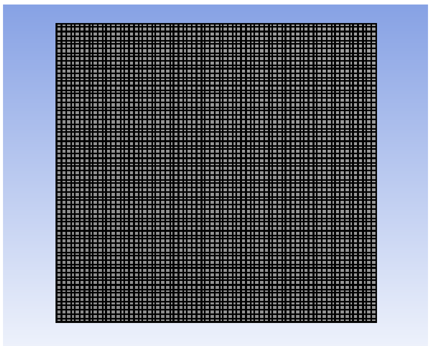


Fig 4: Meshing of PCM wall

The PCM wall prepared for the analysis is considered with partially thermally active sides and remained side thermal isolated or adiabatic. The name selection of hot and cold side of the PCM wall is shown in fig 5(a) and wall with two thermally insulated sides is shown in fig 5(b).

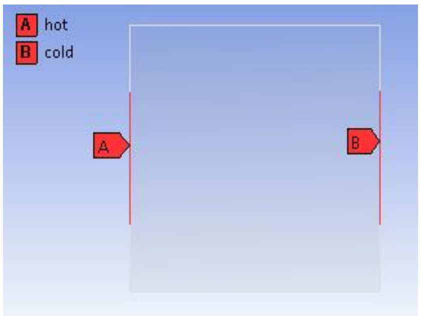


Fig 5(a) PCM wall with hot & cold sides

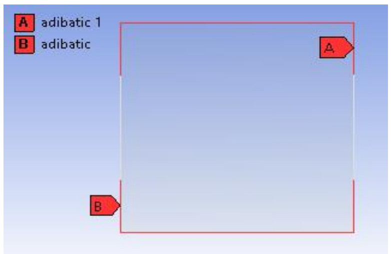


Fig 5.(b) PCM wall with two adiabatic sides

	<u>Paraffin Wax</u>	<u>Al_2O_3</u>	<u>MgO</u>
Density(kg/m^3)	764.91	3600	3560
Specific heat(J/kgK)	2890	765	955
Conductivity(W/mK)	0.21 if T<Tsolid 0.12 if T>Tliquidous	36	45
Viscosity (N-s/m^2)	0.001 $exp^{[-4.25+(1700/T)]}$		
Latent Heat (J/kg)	173400		
Solid Temperature (K)	319		
Liquid Temperature (K)	321		
T ref (K)	298.15		
dnp(nm)		59	59

Table 1 Thermo-physical properties of Paraffin wax and metal oxides.

IV. RESULTS

Liquid fraction

The contour of liquid fraction in melting process at various times for different volume fractions is shown in Figures:

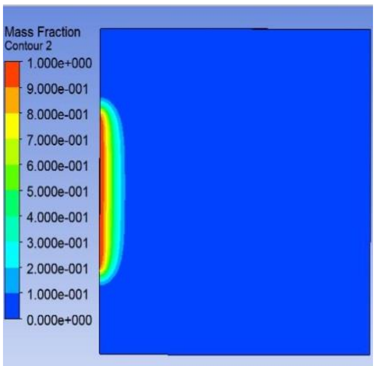


Fig 6. Mass fraction PCM+Al_2O_3 (1%) 100 Sec

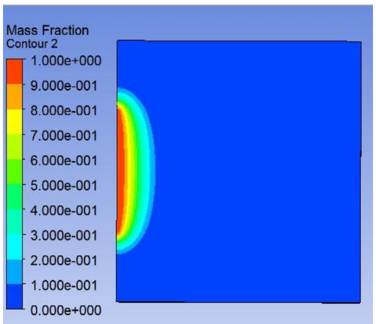


Fig 7 Mass fraction PCM + MgO(1%) 100 Sec

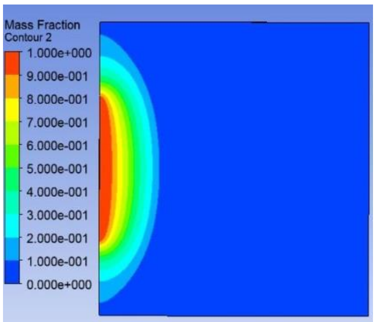


Fig 8 Mass fraction PCM+Al_2O_3 (1%) 1600 Sec

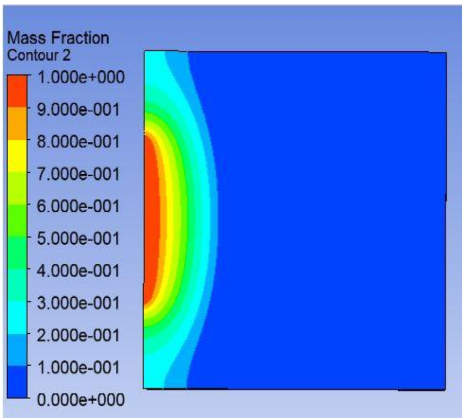


Fig 9 Mass fraction PCM + MgO(1%) 1600 Sec

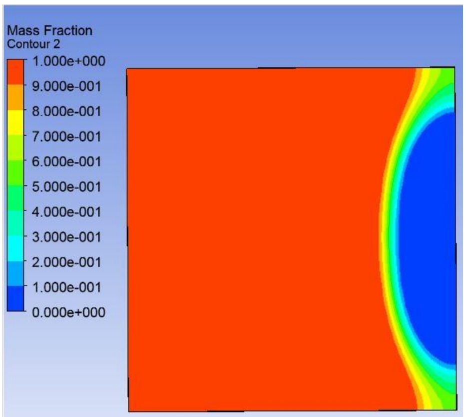


Fig 10 Mass fraction PCM+Al_2O_3 (3%) 24000 Sec

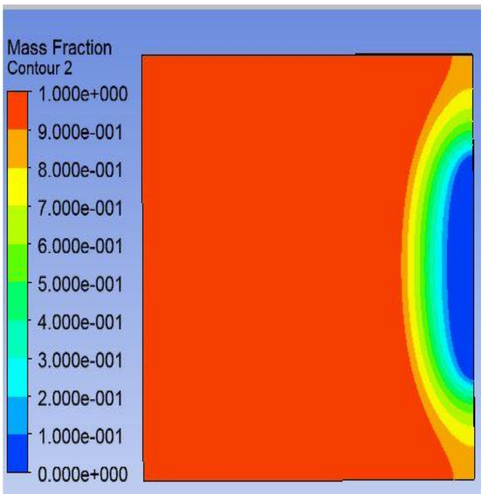
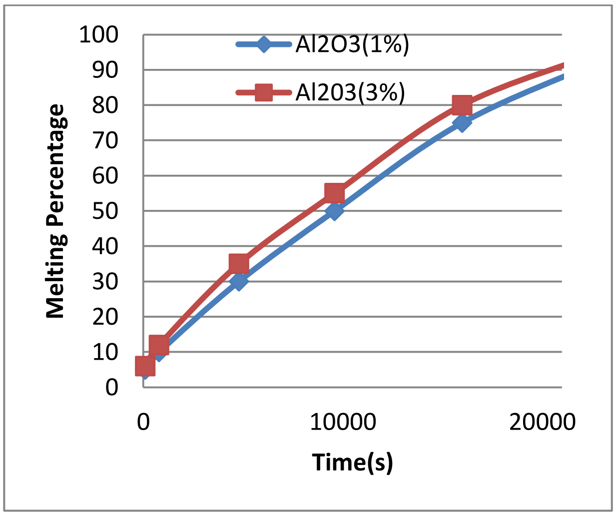
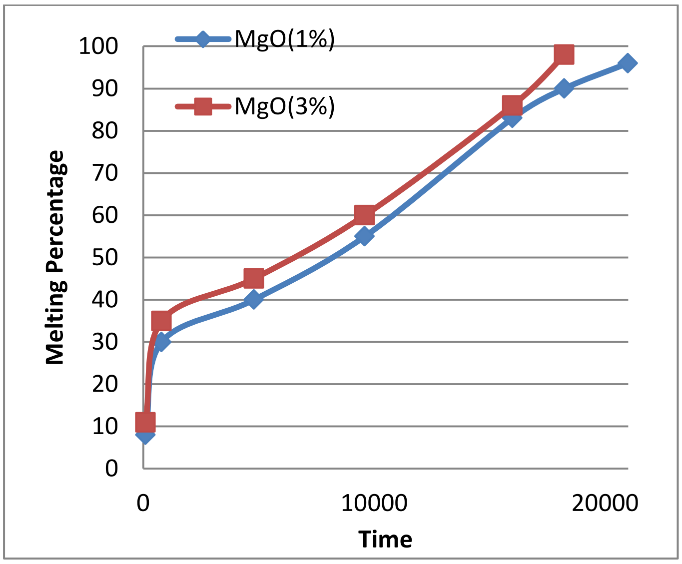


Fig 11 Mass fraction PCM + MgO(3%) 24000 Sec

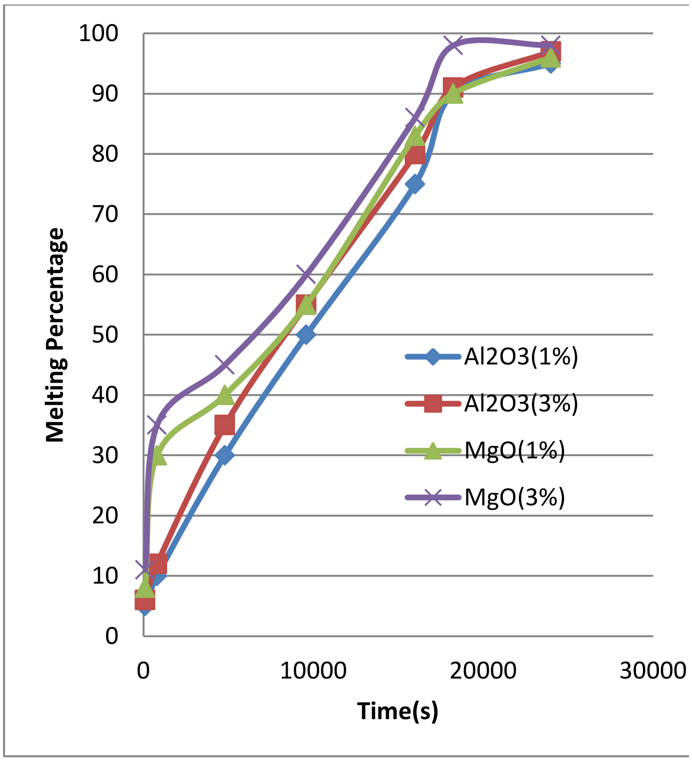
The melting rate of Al_2O_3 and MgO nanoparticles enhanced paraffin for two volumetric concentrations 1%, and 3% wax is examined.



Graph 1. Melting Percentage V/S Time for 1% and 3% of Al_2O_3



Graph 2 Melting Percentage V/S Time for 1% and 3% of MgO



Graph 3. Melting Percentage V/S Time of Al_2O_3 and Fe_2O_3 at different volumetric concentration

V. CONCLUSIONS

For all Nano PCM considered at 1% and 3% volumetric concentration, results confirm that:

- The thermal performance of paraffin wax is enhanced only marginally with the dispersion of Al_2O_3 & MgO nanoparticles.
- The melting percentage of PCMS having 3% Al_2O_3 concentration is more compared to nanoparticle concentration of 1% Al_2O_3 .
- In the early stages of the melting process the heat transfer take place mainly by conduction process and after further heating it changes to natural convection.
- It requires 24000 Sec for paraffin wax + Al_2O_3 (1%) to fully melt while in case of paraffin wax + MgO (1%) 21000 Sec are needed for the fully melting of the PCM wall.
- It requires 21000 Sec for paraffin wax + Al_2O_3 (3%) to fully melt while in case of paraffin wax + MgO (3%) 18240 Sec are needed for the fully melting of the PCM wall.

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