CFD Analysis for the Comparison of Melting of Paraffin Wax with Different Concentration of Al2o3 and Fe2o3 Nanoparticles in A Square Enclosure

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Abstract- **Thermal energy storage (TES) is a technology that stocks 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. PCM materials are one of the most efficient ways of storing thermal energy. The latent heat storage provides much higher storage density with a smaller temperature difference between storing and releasing heat. However, practical difficulties often occur in the application of the latent heat method, due to the low conductivity, the changing density and the instability of PCMs properties.**

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. In this work, melting of paraffin wax with Fe2O3 nanoparticles used in a partially heated square cavity. The geometry used is a square box of size 20mm × 20mm .The initial temperature of the Nano particle with PCM is 300 K, the hot wall side is at a constant temperature of 355 K (Tmax) and the cold wall, opposite the hot wall, is at 300 K (Tmin) in order, the other two walls are adiabatic with the help of simulation software Ansys 14.5. The melting rate by using 1% Fe2O3 reduced by 13.92% while in the case of 3% Fe2O3 melting rate is reduced by 6.67%.The highest enhancement is achieved for the enclosure filled with Ø= 1 vol% of Fe2O3 nanoparticle concentration.

Index Terms- **Latent heat storage, PCM, paraffin, Thermal conductivity, Ansys.**

I. INTRODUCTION

As renewables gain a greater foothold in the energy system, the importance of energy storage is going to increase in kind. With the on going gradual shift away from traditional base load energy sources, the development of efficient energy storage systems is imperative.

Thermal energy storage (TES) is a technology that stocks 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.

There are three kinds of TES systems, namely:

1. Sensible heat storage: that is based on storing thermal energy by heating or cooling a liquid or solid storage medium (e.g. water, sand, molten salts, rocks), with water being the cheapest option.
2. Latent heat storage: using phase change materials or PCMs (e.g. from a solid state into a liquid state)
3. Thermo-chemical storage (TCS): using chemical reactions to store and release thermal energy.

2.1 Phase Change Materials for TES

- Phase change materials (PCM) are ‘‘Latent’’ heat storage materials.
- Phase change materials (PCMs) are materials that undergo the solid-liquid phase transformation, more commonly known as the melting-solidification cycle, at a temperature within the operating range of a selected thermal application.
- As a material changes phase from a solid to a liquid, it absorbs energy from its surroundings while remaining at a constant or nearly constant temperature.
- The energy that is absorbed by the material acts to increase the energy of the constituent atoms or molecules, increasing their vibrational state.

- At the melt temperature the atomic bonds loosen and the materials transitions from a solid to a liquid.
- Solidification is the reverse of this process, during which the material transfers energy to its surroundings and the molecules lose energy and order themselves into their solid phase

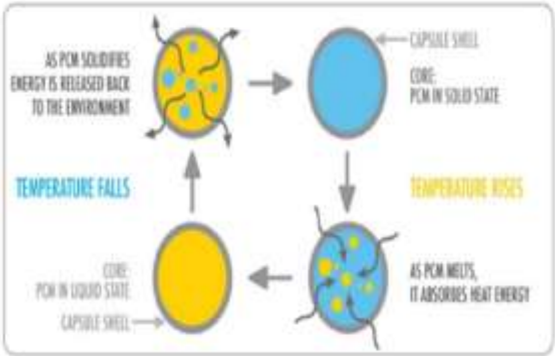

Figure 1 Energy Stored in PCM

2.2 Types of Phase Change Materials

2.2.1 Organic PCMs

- Organics are arguably the most popular type of PCM. Organics can include a wide range of PCMs such as those in the alkane (paraffin) family (C_nH_{2n+2}), and the fatty acids family ($CH_3 (CH_2)_{2n}COOH$). The organic PCMs tend to be abundantly available, relatively inexpensive and easy to work with.

Fig.2 Paraffin wax (left) and stearic (fatty) acid (right)

2.2.2 Inorganic PCMs

- The family of inorganic PCMs includes the salts and salt hydrates. Salt hydrates are combinations of members of the inorganic salt family (oxides, carbonates, sulfates, nitrates and halides) with water molecules in a specific ratio.
- Salt hydrates are named using the name of the salt compound *n H_2O.

2.2.3 Metal and Metal Alloy PCMs

- The family of metal and metal alloys is perhaps the most underused of all the common PCM families, perhaps due to the low latent heat that most of these materials exhibit.
- However, despite this the metals do show promise in certain applications. The metal and metal alloys PCMs include a number of materials with melting points in the range of desired PCM applications. Many of these metals are easy to work with and have been used for years in other applications requiring molten metals, for example, the hobby of casting tin soldiers.

II. LITERATURE REVIEW

Hasan Karabay et al. (2017) [3] in this study, melting of paraffin wax with Al_2O_3 nanoparticles in a partially heated and cooled square cavity are 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 (Ø = 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. Thermo physical 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 Ø= 1 vol% of nanoparticle concentration and heated from bottom, and nanoparticle concentration beyond Ø = 1 vol% defeats the purpose thus enhancement decreases.

Khodadadi and Hosseinizadeh (2016) [4] studied numerically the solidification of water with Cu nanoparticles in a differentially heated square cavity and reported that heat release rate of NEPCM is increased compared to the conventional PCM.

G. Sonnenrein (2014) [5] Evaluated the influence of latent heat storage elements on the condenser temperature of a commercial household refrigerator. In order to determine the power consumption and the temperature distribution, a standard wire-and-tube condenser is equipped with different heat storage elements (containing water, paraffin or copolymer compound). The results indicate that particularly the application of phase change materials (PCM) lowers the condenser temperature, which leads to a significantly reduced power consumption.

MD. Mansoor Ahamed (2013) [6] Proposed the use of a passive system integrated into the walls of the cold storage facility i.e., PCM (Ethylene Glycol) is located behind the five sides of the evaporator cabinet in which the evaporator coils are immersed. Experimental application of PCM into a cold storage has shown that the temperature rise during loss of power is limited. With PCM, the air temperature is kept constant at -8°C for 8 hours, compared to without PCM where the air temperature rises continuously and rises above -8°C in just 1 hour. Experimental result also compares the Coefficient of performance (COP) with and without PCM for the cold storage plant. Hence proposed system could be a new option for performance improvement of a cold storage by enhancing heat transfer of the evaporator and useful for commercial establishments as presently there are frequent power cuts.

III. METHODOLOGY

As it is stated earlier that the model which is pre-defined in previous study would be followed in this study, Hereby there lies an opportunity of validating the new model developed in simulation software ,as the variation of melting rate for previous model is already known.

Similar Plot of melting rate will be plotted for present model, which would be compared with previous study, since all the boundary conditions as well as dimension remain same in both models the outcome is expected to remain same hence the existing model would be validated.

The geometry used is a square box of size 20mm × 20mm. It contains paraffin wax or paraffin wax dispersed with 1% and 3% by volume of two different nanoparticles Al_2O_3, & Fe_2O_3. The initial temperature of the Nano particle with PCM is 300 K, the hot wall side is at a constant temperature of 355 K (Tmax) and the cold wall, opposite the hot wall, is at 300 K (Tmin) in order, the other two walls are adiabatic with the help of simulation software Ansys 14.5.

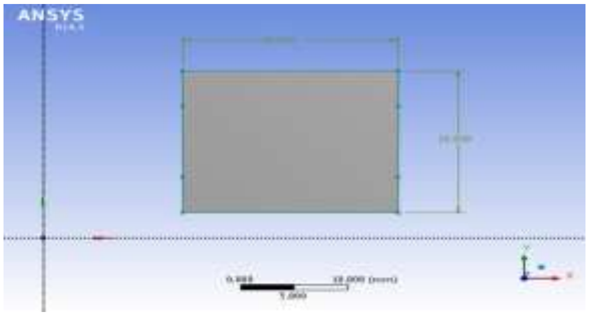

Figure 3 Geometry of the enclosure with partially active walls

Meshing

- Curvature - On
- Smoothing- medium
- Number of nodes- 1681
- Number of elements -1600
- Mesh type – Quardcore.

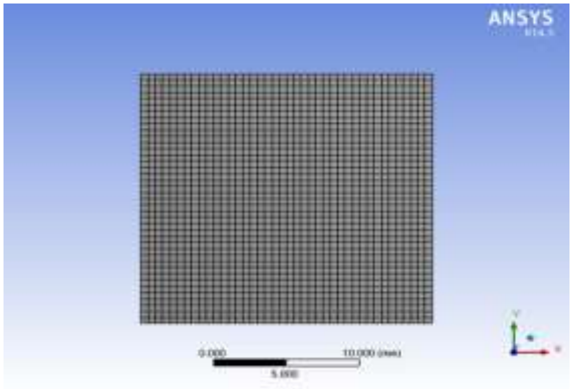

Figure 4 Meshing of the enclosure with partially active walls

- The cold wall is maintained at $T_{c.}$
- The hot wall is maintained at $T_{h.}$
- The inactive parts of the enclosure are thermally insulated.
- The length of active portions is equal to half of the length of the enclosure and the positions of the hot and cold portions are symmetric with respect to centerlines.

Model Selection

- It is assumed that the melted liquid is Newtonian and incompressible.
- Fluid motion in the melt is laminar and two-dimensional.
- Energy- On
- Transient State
- Solidification and Melting – On
- Method – Simple and Presto.

- It is also assumed that the base fluid and the nanoparticles are in thermodynamic equilibrium and flow at the same velocity.

Governing Equations

The governing equations for conservation of mass, momentum and energy can be written as:

$$\frac{\partial \rho_{\text{nepcm}}}{\partial t}+\frac{\partial(\rho_{\text{nepcm}}\ u)}{\partial x}+\frac{\partial(\rho_{\text{nepcm}}\ v)}{\partial y}=0$$

$$\frac{\partial(\rho_{\text{nepcm}}u)}{\partial t}+\frac{\partial(\rho_{\text{nepcm}}\ uu)}{\partial x}+\frac{\partial(\rho_{\text{nepcm}}\ vu)}{\partial y}=-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left(\mu_{\text{nepcm}}\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_{\text{nepcm}}\frac{\partial u}{\partial y}\right)+S_x$$

$$\frac{\partial(\rho_{\text{nepcm}}v)}{\partial t}+\frac{\partial(\rho_{\text{nepcm}}\ uv)}{\partial x}+\frac{\partial(\rho_{\text{nepcm}}\ vv)}{\partial y}=-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left(\mu_{\text{nepcm}}\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_{\text{nepcm}}\frac{\partial v}{\partial y}\right)+S_y+(\rho\beta)_{nepcm}\,g(T-T_m)$$

$$\frac{\partial(\rho_{\text{nepcm}}H)}{\partial t}+\frac{\partial(\rho_{\text{nepcm}}\ uH)}{\partial x}+\frac{\partial(\rho_{\text{nepcm}}\ vH)}{\partial y}=\frac{\partial}{\partial x}\left(K_{\text{nepcm}}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{\text{nepcm}}\frac{\partial T}{\partial y}\right)$$

Table 1 : Properties of paraffin wax + Fe2O3 at 1% and 3%.

	Density(Kg/ m^3)	Specific Heat(J/ Kg-K)	Thermal Conductivity (W/m-K)	Dynamic Viscosity(N-s/m^2)
Paraffin+ 1% Fe_2O_3	943.4	2765.61	0.21924	0.004
Paraffin+ 3% Fe_2O_3	1030.2	2548.26	0.25356	0.12

IV. RESULTS

Study is conducted to study melting of paraffin wax in a square cavity with partially heated and cooled walls considering orientations of active walls different volume fractions of Fe2O3 nanoparticles (Ø = 1vol% and 3 vol%). Afterward, the effect of hot wall temperature on melting is analyzed. The obtained results are presented below. As a representative case, the evolution of streamlines and isotherms at times of 120 s, 300 s, 600 s, 1200 s and 1800 s are displayed.

4.1 Results for 97 % Paraffin wax + 3% Fe2O3

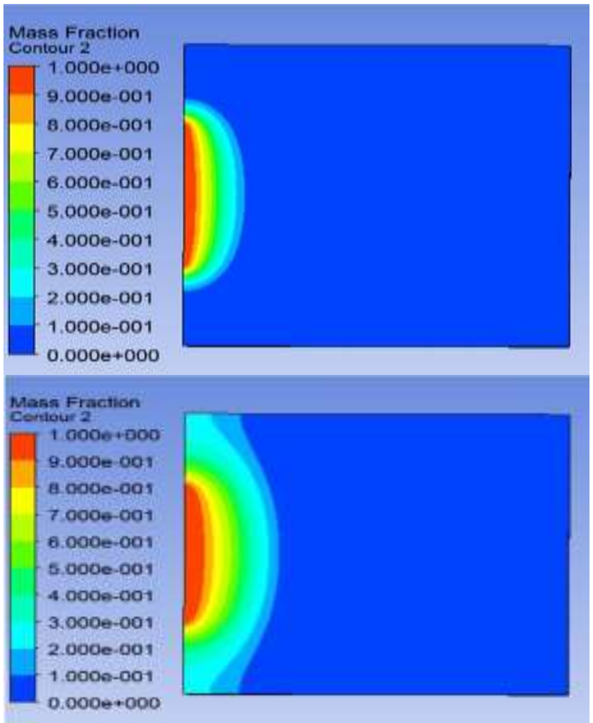

Figure 5 Mass fraction PCM + Fe2O3 (3%) 120 Sec, 600sec

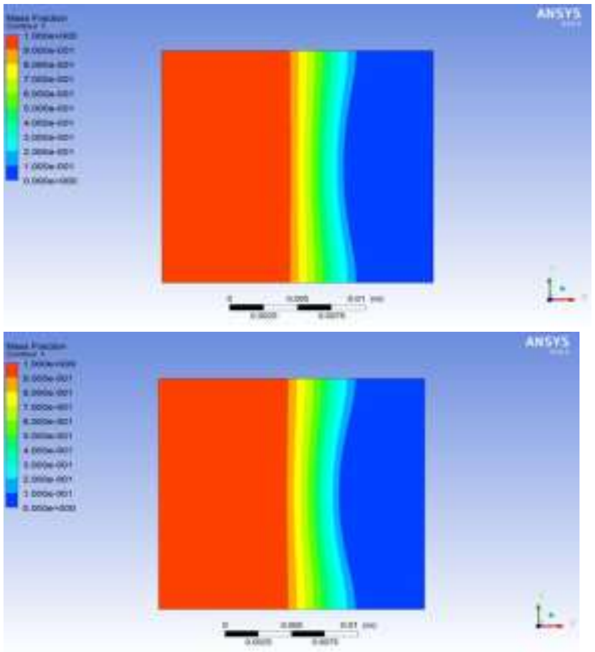

Figure 6 Mass fraction PCM + Fe2O3 (3%) 1200 Sec, 1800sec

4.2 Results for 99 % Paraffin wax + 1% Fe2O3

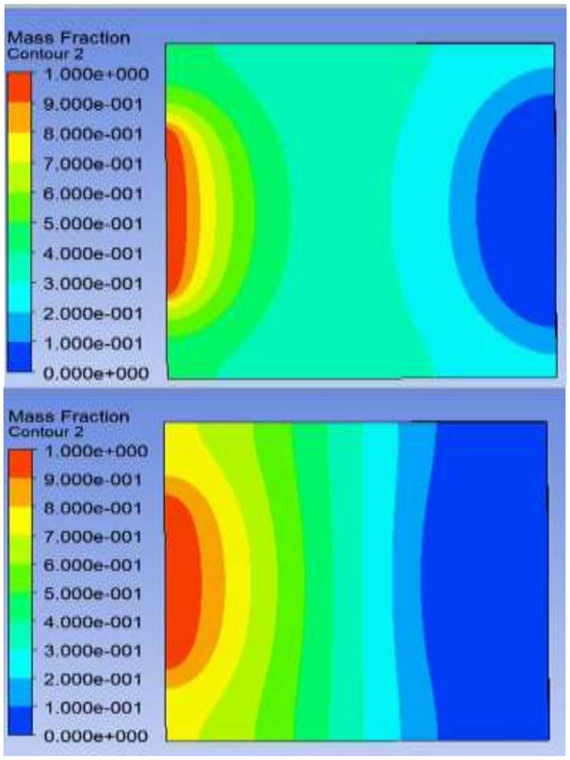

Figure 7 Mass fraction PCM + Fe2O3 (1%) 120 Sec, 300 sec

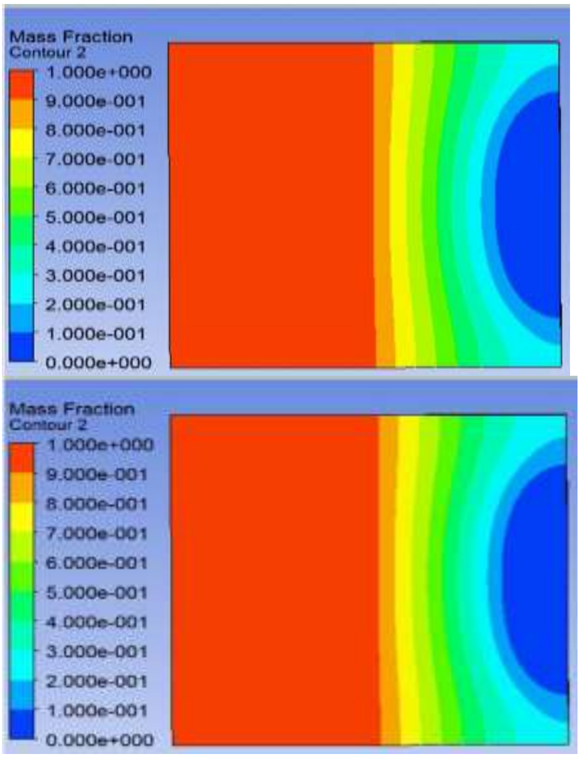

Figure 8 Mass fraction PCM + Fe2O3 (1%) 1200 Sec , 1800 sec

Table 2 Comparison of liquid fraction with respect to time.

Time (in second)	Liquid Fraction			
	99% PCM+ 1% Al_2O_3	97% PCM+ 3% Al_2O_3	99% PCM+1% Fe_2O_3	97% PCM+ 3% Fe_2O_3
120	0.079	0.075	0.068	0.07
300	0.09	0.1	0.085	0.087
600	0.192	0.212	0.185	0.192
1200	0.514	0.523	0.404	0.432
1800	0.623	0.635	0.543	0.552

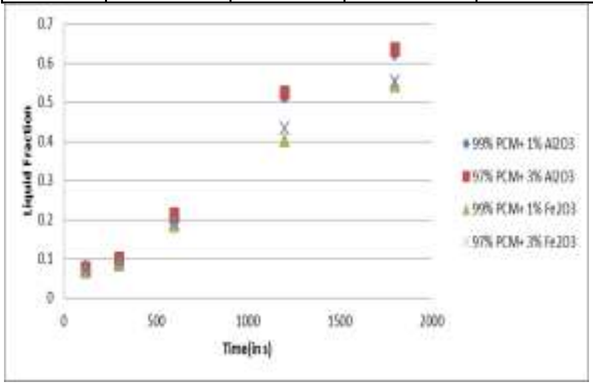

Figure 9 Comparison of liquid fraction with respect to time form PCM with different concentration.

V. CONCLUSIONS

- In this numerical work, melting of paraffin wax dispersed with Fe_2O_3 nanoparticles in a square enclosure with thermally partially active walls was investigated for different concentration.
- Increasing hot wall temperature initiates convection earlier resulting in increase in liquid fraction given time and decreases the effect of nanoparticle as melt fraction approaches to unity.
- The melting rate by using 1% Fe_2O_3 reduced by 13.92% while in the case of 3% Fe_2O_3melting rate is reduced by 6.67%.
- The highest enhancement is achieved for the enclosure filled with Ø= 1 vol% of Fe_2O_3 nanoparticle concentration.

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