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Numerical Investigation of Melting Nano-Enhanced Phase Change Materials in Triangular Enclosure

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ABSTRACT: This paper presents a numerical study of the melting of nano-enhanced phase change materials inside a triangular container using N-eicosane and copper particles as base material and nanoparticle, respectively. Nanoparticles are used in the process of heat transfer and improve lubrication performance. To investigate the effect of nanoparticles on the heat transfer rate, various particles of copper nanoparticles have been added to the base phase change materials. The increase in the performance of the heat transfer of nanoparticles in the solid state was more than the liquid state in the laminar flow and the natural convection heat transfer. Also, the effect of entropy has been investigated. The simulation results show that the nanoparticles cause an increase in the thermal conductivity of nano-enhanced phase change materials compared to conventional phase change material. Increasing thermal conductivity by reducing the latent heat, increases the rate of melting of nanoparticles. The time of the melting of the phase change material has significantly decreased with increasing nanoparticles. Increasing the thermal conductivity effective in reducing the entropy production of the system is much more than the reduction of the specific heat and the heat of fusion of nano-enhanced phase change materials.

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1- Introduction

As global populations increase, the use of fossil fuels increases rapidly. Some energy storage devices are needed for efficient use of energy resources. In this regard, solar energy, which is an alternate energy source, should also be stored for reuse. Among the various thermal energy storage techniques, the latent thermal energy system has been studied using the appropriate phase change material over the past three decades. Phase Change Materials (PCM) are very much considered due to a large amount of energy absorbed as a discontinuous heat at constant phase transition temperatures. These materials can be used for passive heat storage. The main weakness of the phase change material is their low thermal conductivity. Which prevents the high speed of charge and discharge of thermal flux. This feature allows phase change materials to be used in many industrial applications such as solar thermal storage [1-2] thermal management of electronic devices [3], thermal storage in buildings [4]. Subsequently, the first study of phase change materials was presented by Barakman and Westin [5] for use in buildings.

2- Numerical Procedure and Boundary Conditions

Fig. 1 shows the physical configuration of the double-tube heat exchanger, which has an inner tube with diameter (di) of 1.7 mm, and an externally balanced triangular tube with a height of 19.5 mm and a 6 mm base. an annulus space is filled with Nanoparticle-Enhanced Phase Change Material (NEPCM) and PCM in solid phase. Also, water is used as the Heat Transfer Fluid (HTF) that flows through the inner tube and exchanges heat with NEPCM. The initial temperature below the solidus of the phase change material is considered to be 298.15. the temperature of container wall is maintained at 313.15, 318.15 and 328.15 K for temperature difference of 5°C, 10°C and 20°C, respectively. Adiabatic boundary conditions are considered in the outer tube walls. The condition of non-slip and non-permeability in the solid interface and internal and external pipe walls can be expressed. Adiabatic boundary conditions are considered in the outer tube walls.

3- Numerical Model and Mathematical Formulation

In order to simplify physical and mathematical equations, the following assumptions are considered. The porous enthalpy

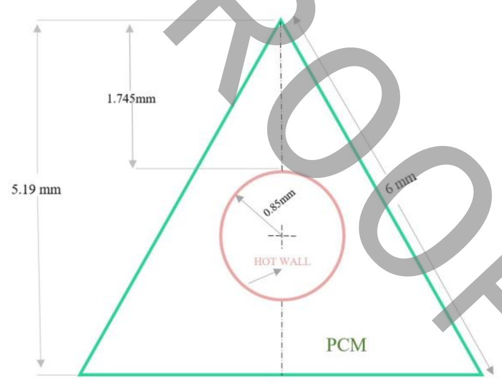

Fig. 1. The physical shape represents the simulation domain filled with phase change material

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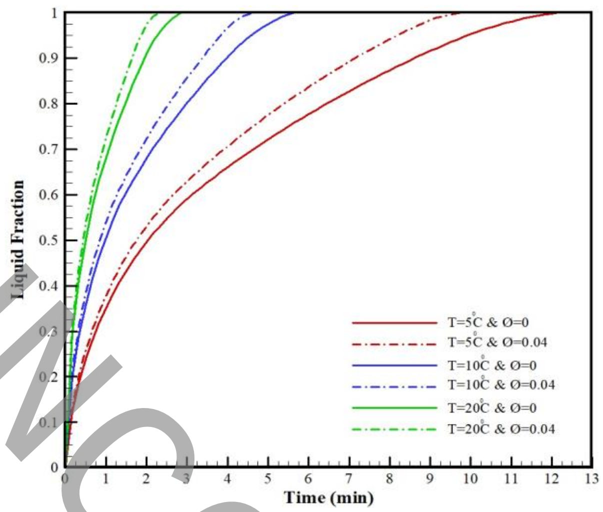

Fig. 2. Variation of liquid fraction versus time for various volume fractions and different wall temperatures

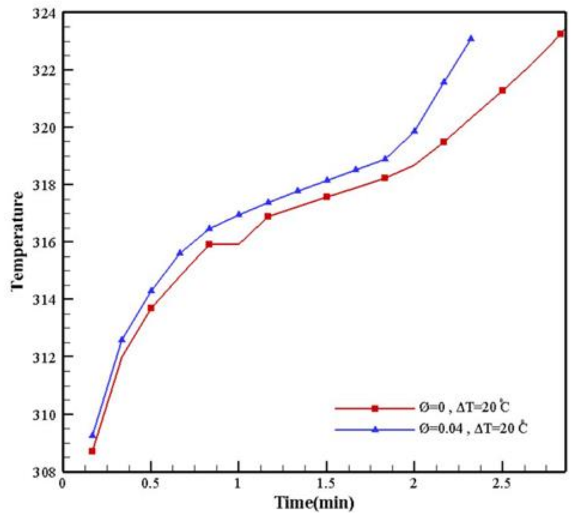

Fig. 3. Variation of temperature versus time for the various volume fraction of nanoparticle and constant wall temperature at ΔT=20°C.

Table 1. Thermal energy generation rate of the storing system

Time (min)	Ø=0.04	Ø=0
1	28.98	28.37
2	18.22	17.26
3	13.06	12.82
4	11.32	10.55

method is used to model the phase change process [6]:

Continuity:

$$\nabla \cdot \vec{V} = 0 \tag{1}$$

Momentum:

$$\frac{\partial V}{\partial t} + \vec{V}.\nabla\vec{V} = \frac{1}{\rho}\left(-\nabla P + \mu\nabla^2\vec{V} + \rho\vec{g}\beta(T - T_{ref})\right) + \vec{S}_i \tag{2}$$

Energy:

$$\frac{\partial h}{\partial t} + \frac{\partial H}{\partial t} + \nabla \cdot \left(\vec{V}h\right) = \nabla.\left(\frac{k}{\rho C_p}\nabla h\right) \tag{3}$$

The density of the nanofluid is given by:

$$\rho_{nf} = (1-\phi)\rho_p + \phi\rho_n \tag{4}$$

Thermal energy generation rate is given by:

$$S_h''' = \frac{k}{T^2}\left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2\right] \tag{5}$$

Frictional energy generation rate is given by:

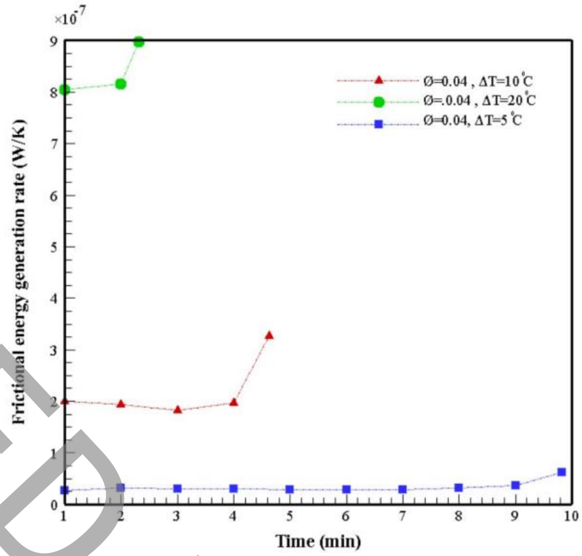

Fig. 4. Variation of frictional energy generation rate versus time for various volume fraction of nanoparticle and different wall temperatures

$$S_f''' = \frac{\mu}{T^2}\left\{2\left[\left(\frac{\partial v_x}{\partial x}\right)^2 + \left(\frac{\partial v_x}{\partial y}\right)^2\right] + \left(\frac{\partial v_x}{\partial y} + \frac{\partial v_y}{\partial x}\right)^2\right\} \tag{6}$$

4- Results and Discussion

The liquid fraction in the melting process at various times for different volume fractions and for three Stefan units are 0.05, 0.1 and 0.2 for different temperature (ΔT) of 5°C, 10°C and 20°C, respectively, is shown in Fig. 2 Stefan (Ste) number describes the operating conditions of the melting converter.

The temperature changes calculation compared to time for temperature at 20°C and 0.04 wt% are shown in Fig. 3 The results show that with a volume fractional change from 0 to 0.04 wt%, the temperature of the phase change material with a 0.04 wt% at a constant time is greater. Also, at full melting time, the temperature of the phase transition material with a volume fraction of 0 is higher than 0.04 wt%.

In Table 1, a comparison is made to determine the rate of thermal entropy generation with time for a Stephen number is 0.05, ΔT of 5°C The rate of entropy production increases first and then decreases with time. The heat entropy generation rate increases by changing the volume fraction from 0 to 0.04 wt% at a constant time.

Fig. 4 Comparison to determine the variation in the time of the melting of phase change material in terms of the frictional energy generation rate for 0.04 wt% volume fraction was investigated. The results show that higher friction entropy rates are higher in Stefan numbers. When the temperature difference is small, the frictional energy generation rate cannot be more than that.

5- Conclusions

Comparing the results for increasing the Stefan number, it is observed that increasing the number of Stefan has a much greater effect on reducing the melting time. Increasing the Stefan number increases the temperature difference between the inlet fluid and the phase change material, which increases the potential of hot fluid to melt. Therefore, increasing the Stefan number from 0.05 to 0.1 and from 0.05 to 0.2 decreases the melting time to 53% and 76% percent. Also, by increasing the volume fraction of nanoparticle up to 0.04 wt% to phase change materials in three Stefan decreases the melting time by up to 20%.

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