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Simulation of heat transfer characteristics of phase change material dispersed with Titanium oxide nanoparticles in horizontal channel

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Abstract. Phase Changing Materials (PCM) is proving to be one of the major breakthroughs in industries as it has various applications in sustainable and renewable energy. The present study investigates the melting and solidification of phase change material (ice) in the presence of titanium oxide nanoparticles in a horizontal channel with internal heat source. The parametric study is carried out by varying the inlet velocity, heat source strength and nanoparticle volume fractions. The problem is modeled as three-dimensional laminar steady flow considering the effects of melting and solidification using Ansys Fluent. The heat sources mounted at the lower wall of the channel are specified with constant wall temperature boundary condition and the remaining walls are considered as adiabatic. The forced velocity inlet boundary condition is specified for the longitudinal velocity at the inlet and pressure outlet boundary condition is considered at the outlet of the channel. The results are analyzed by plotting the pathlines, longitudinal velocity contours, pressure and temperature contours. The results indicate that the longitudinal inlet velocity significantly affects the flow and heat transfer characteristics inside the horizontal channel. The increase in inlet velocity strengthens the melting rate and increases the heat transfer rate inside the channel. It is also found that the melting rate increases linearly with increase in the heat source intensity and nanoparticle volume fraction.

1. Introduction

The use of conventional energy sources is posing a lot of threat such as global warming greenhouse gas emissions, and dwindling supplies [1] which has forced scientists and technologists to shift their focus towards renewable resources. Harnessing the large amount of heat that is getting wasted during combustion processes is the prime focus for all industries. Sensible heat and latent heat are the different forms in which energy(thermal) is stored[2]. Energy storage of latent heat is considered to be the best option among the three because of its high density of thermal storage and operations at constant temperature conditions. PCMs are devices which store and release significant amount latent heat during phase changing over a specific temperature range. Latent heat refers to the undetected heat transfer which is associated with phase transition. This latent heat is significantly larger than the sensible heat and harnessing it would save a lot of energy. The PCMs are the most efficient devices in storing this heat energy within the temperature and finds a lot of applications in industries such as thermal, solar, electronic, battery thermal management[3-5], intelligent building[6-10], food packaging, heat pipes and textiles [11,12].On the basis of properties of materials, PCMs can be broadly classified into organic and inorganic PCM. Organic PCMs were extensively used for its energy storage because of its thermal stability. But due to its low thermal conductivity, the increased use of encapsulated phase change materials(EPCM) was visible. So the PCM acts as the core and polymer such as polystyrene and melamine formaldehyde resin acts as the encapsulation material. The encapsulation material can be made into shapes like oval and round and also incorporation of multiple cores can be done. Encapsulation is done because it provides good protection against external environment during applications, increases heat transfer area and controls the volume changes during phase change. Based on size, the EPCMs are classified into 3 categories: micro, macro and nano particles. But micro and macro PCMs exhibited low thermal conductivity and low diffusivity which reduces the efficiency of the device. Also, in high thermal applications micro PCMs started to rupture after a few thousand operations. This would lead to leakage of the micro particles into the system thereby increasing the viscosity and reducing the thermal conductivity. This led to the extensive amount of research in nano encapsulated phase change materials (NEPCM) in various engineering and scientific domains. Khodadadi and Hosseinizadeh [13] were the first to report on the improved properties by dispersing nano particles in phase change materials Incorporating nanomaterials increased the thermal conductivity of the PCMs with high surface area to volume ratio [14]. Optimum amounts of nanoparticles can be really effective in heat transfer. Aluminum oxide, copper, copper oxide, gold, silver, silicon carbide, titanium carbide, titanium oxide, and carbon [15] are some of the commonly used nanoparticles for thermal applications. Nanoparticles also exhibit distinctive properties like quantum tunneling(macroscopic), surface effect and similar properties which is very important in making the nanoparticles steadily dispersed in the fluid and for better stability. These nanoparticles are synthesized by different polymerization methods. Miniemulsion[16], in situ and interfacial polymerization techniques are the one's which are extensively used for various engineering fields. A number of studies are being conducted on the preparation methods emphasizing affordability and large-scale production. For instance, Fang [17] Produced NEPCM by using the in-situ methodology and Luo [18] had adopted miniemulsion polymerization technique.

A lot of research is primarily done on simulating heat sinks surrounded by nano particles emulsions and capturing the behavior of the NEPCM particles in cavities[19][20]. N.S Dhaidan [21] simulated the melting behavior of NEPCM under various shapes of enclosures and calculated enhanced properties like thermal conductivity which is an important aspect in a number of industries. In the current study, forced convection heat transfer of a suspension of Nano–Encapsulated Phase Change Materials (NEPCMs) is simulated and analyzed in a horizontal channel with internal heat source. Titanium oxide is used as the nanoparticle an ice is used as the base fluid in which the nano particles are embedded. Ice is taken as the PCM due of its high latent heat of fusion(333J/g) Forced convection is used in order to increase the heat transfer rate which is coming from the heat source. A horizontal channel is used in applications where large amount of heat is produced which is present inside a fluid domain. Usually these types of horizontal channels are used in electronic applications. It involves melting and solidification of phase change material (ice) which contains suspended titanium oxide nanoparticles in the horizontal channel as seen in figure1. The thermal properties of the Phase change material and nanoparticles are tabulated in Table1. The walls of the channel are thermally insulated and the heat source is specified with constant temperature boundary conditions. Laminar flow is used. The synthesized NEPCM-water suspension is employed as the working-fluid for heat removal from the channel. The working fluid enters the horizontal channel and absorbs the heat emitted from the heat source in the form of sensible and latent heat. The behavior of the NEPCM under different conditions is tested by varying the inlet velocity, heat source strength and nanoparticle volume fractions the temperature, pressure and velocity distribution at different locations can be obtained by including a horizontal and a vertical plane and varying their heights within the domain. The software used to model the channel is ANSYS Fluent 19.1. The test results are analyzed by plotting the path lines, velocity contour, pressure and temperature contours. Finally, the conclusions of tests make it very evident that

NEPCM is a very efficient and a reliable heat storage system. Therefore, this study offers a new dimension for cooling heat sinks and other thermally activated devices.

Table1: Thermo-physical properties of ice and Titanium oxide

	ρ [kg/m^3]	C_p [J/kg K]	k [W/m-K]	μ [kg/m-s]
ice	916	2050	2.22	0.78
Titanium oxide	4230	697	11.8	1.72e-05

Subscripts

H_c	Horizontal channel
H_s	Heat source
vf	volume fraction
np	nano particle

2. Methodology

The three-dimensional channel shown in figure 1 is filled with phase change material and titanium oxide np. The fluid domain which surrounds the H_c is of the dimensions 150mm*130mm*40mm. Multiphase and energy equations are turned on while maintaining a laminar flow while Double precision is used for setting up the analysis. The velocity formulation is set to absolute and the solver type is set to pressure based. Ice is taken as the PCM because of its high latent heat of fusion (333J/g) into which titanium oxide nanoparticles are dispersed. The thermal conditions for the bottom wall are set to system via coupling and the temperature at the inlet is set to 290k. The green gauss cell based model is used for special discretization An Eulerian model is used for the multiphase model with the number of eulerian phases being 2. The under relaxation factors of pressure, density, body forces, momentum, liquid fraction and energy are set to 0.3,1,1,0.7,0.9 and 1 respectively. The gravitational acceleration at the Y-axis is -9.81m/s^2 while the rotation axis is set to 1 along the Z -axis. The graph is plotted by taking reference lines at heights 15 mm, 20 mm, 25 mm and 30 mm respectively. The energy source is set to 40000w/m^3 for the H_s domain. The temperature at the H_s domain is around 438k.

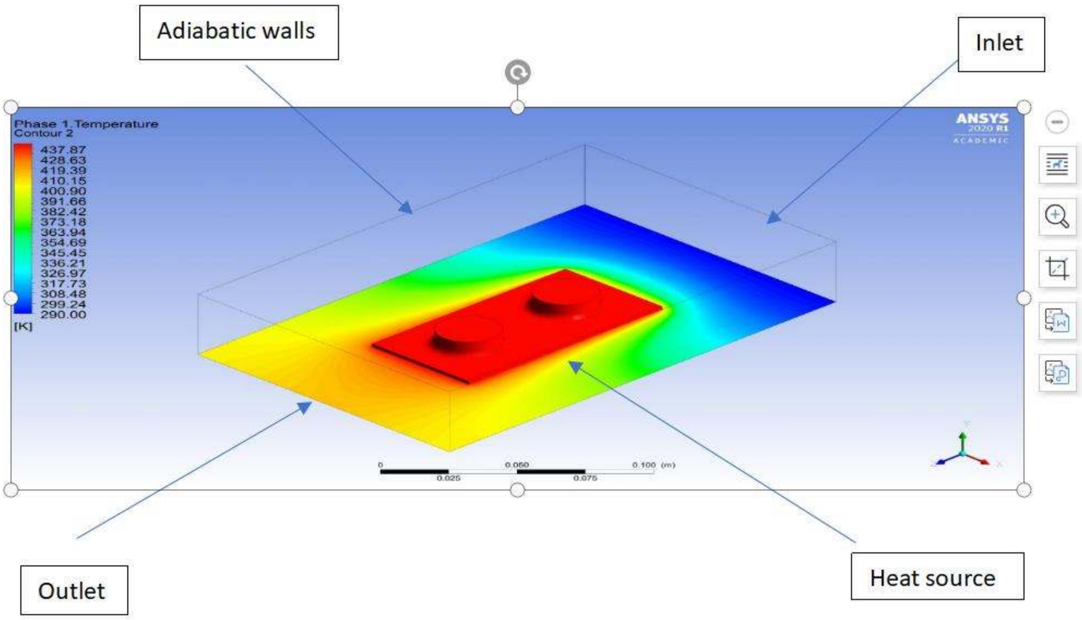

Figure1: schematic diagram of nano encapsulated phase change material (ice+titanium oxide)

3. RESULTS AND DISCUSSIONS:

The temperature, velocity and pressure contours of the H_c are taken in this section.
A temperature vs distance graph for distances 15mm, 20mm, 25mm and 30mm are taken respectively. The contours at these distances are taken by taking a plane along the horizontal direction and by varying the distance from the H_s.

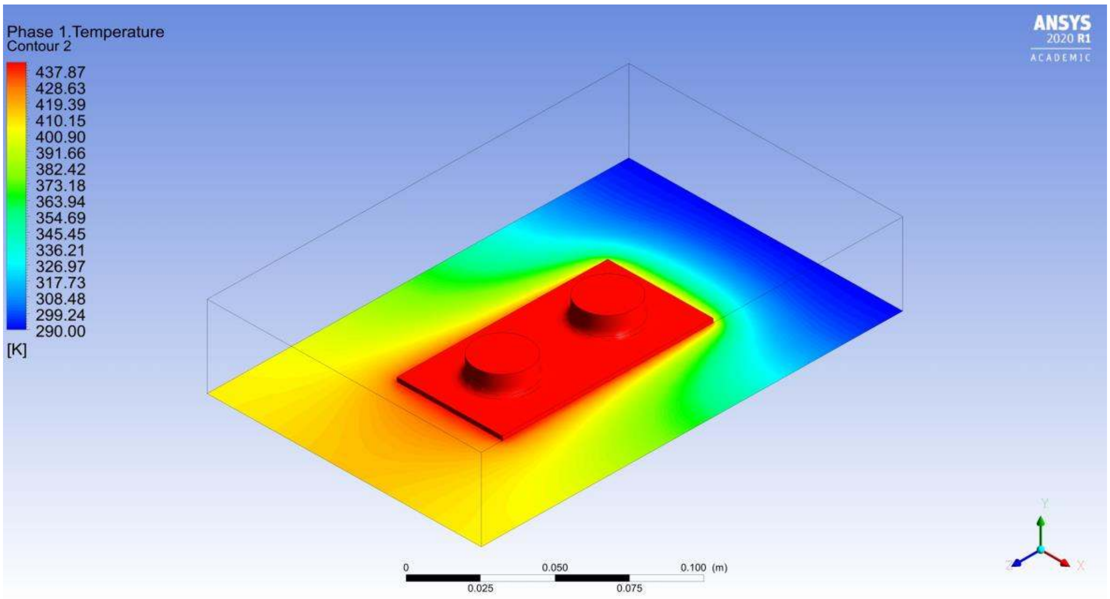

Figure 2: Temperature distribution of the horizontal channel(isometric view)

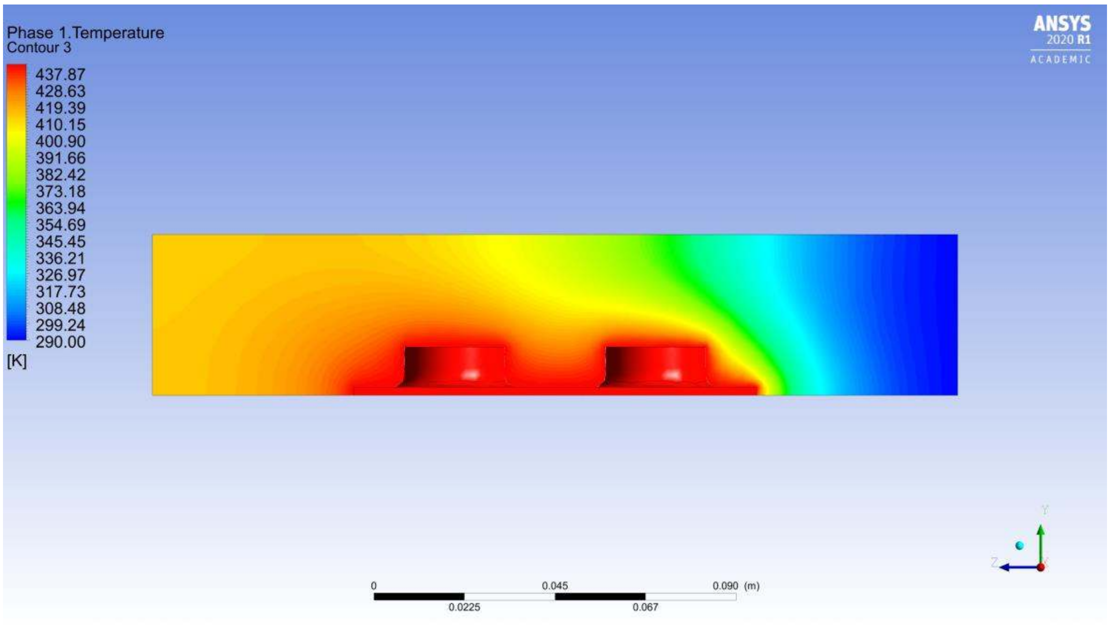

Figure 3: Temperature distribution of the horizontal channel(isometric view)

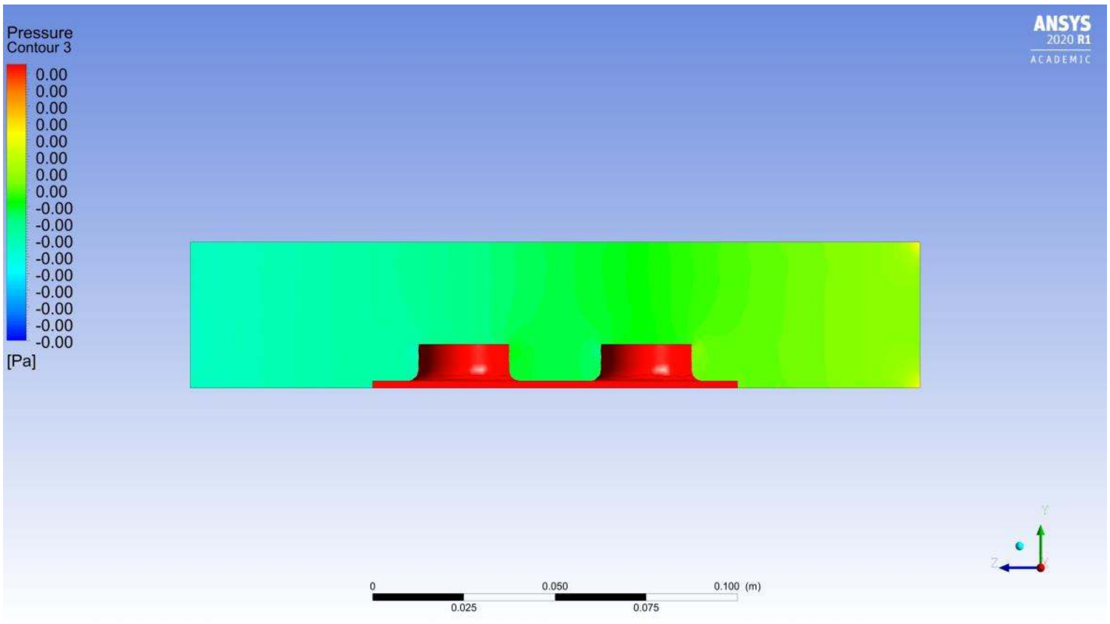

Figure 4: Pressure distribution of the horizontal channel(side view)

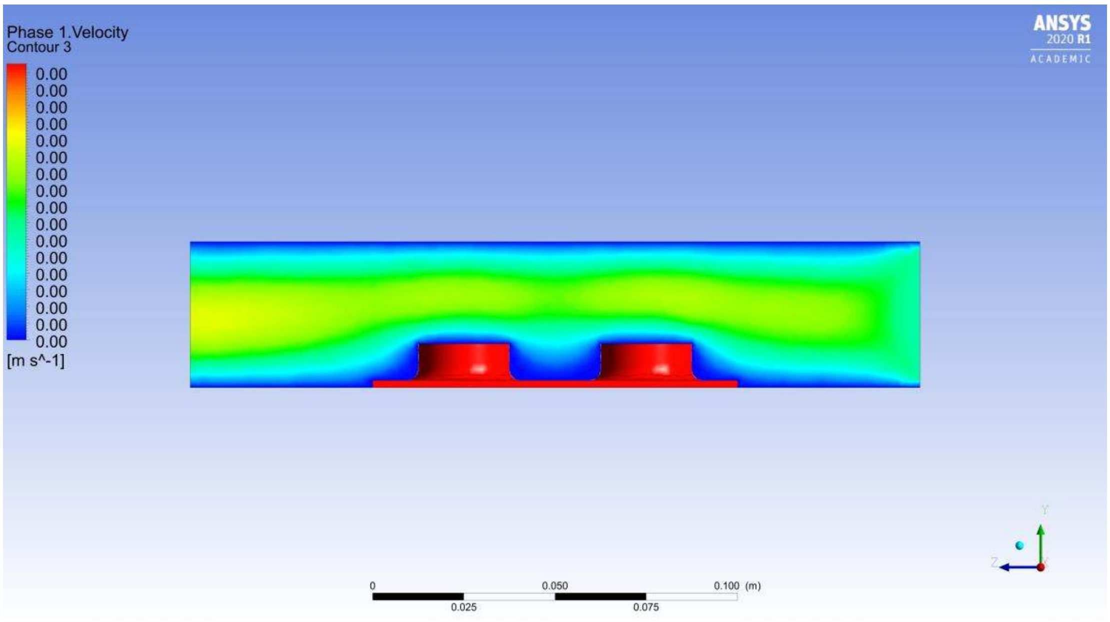

Figure 5: Longitudinal flow velocity of the horizontal channel(side view)

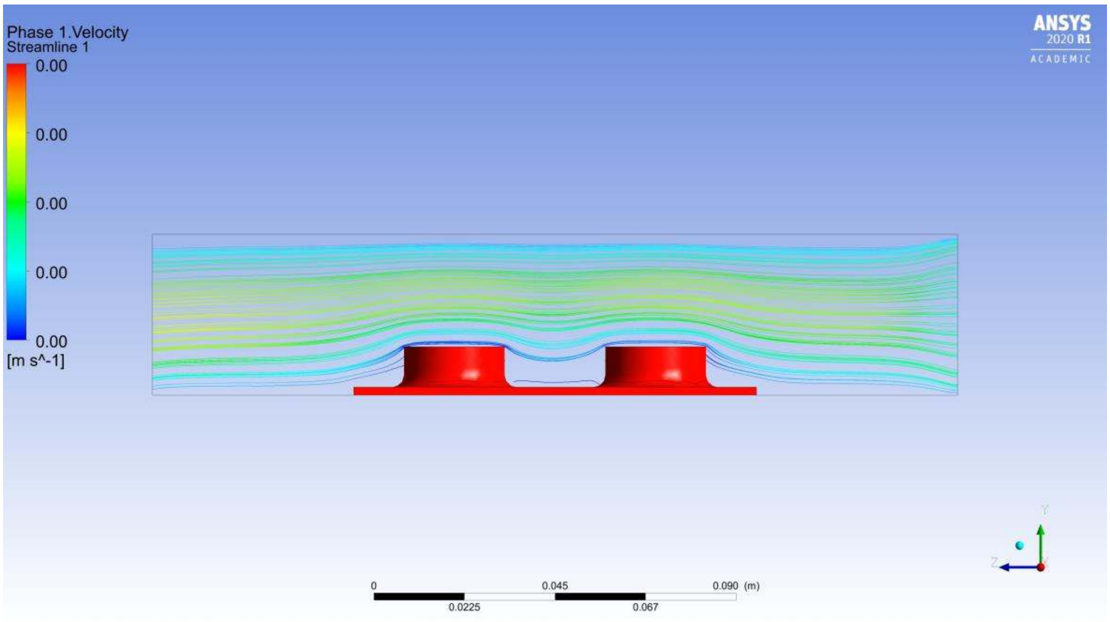

Figure 6: Longitudinal flow velocity of the horizontal channel(side view)

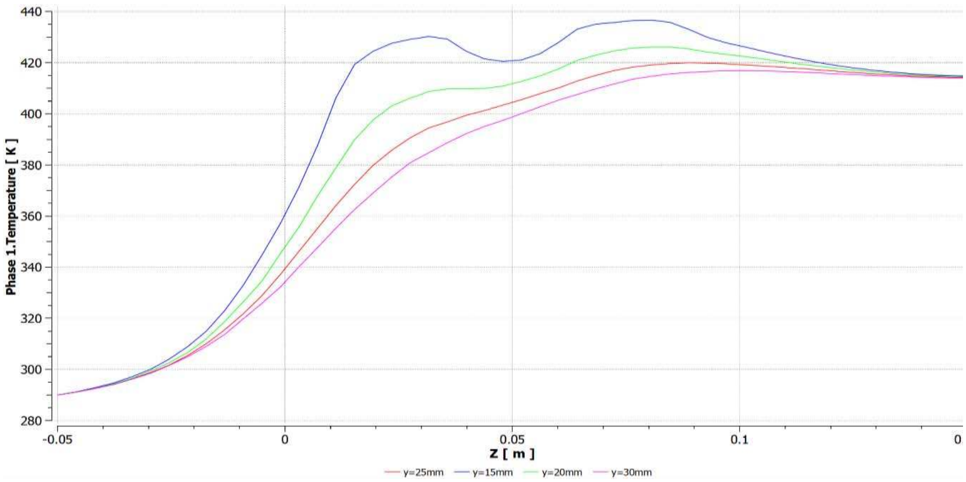

Figure 7: Temperature distribution with height variation graph

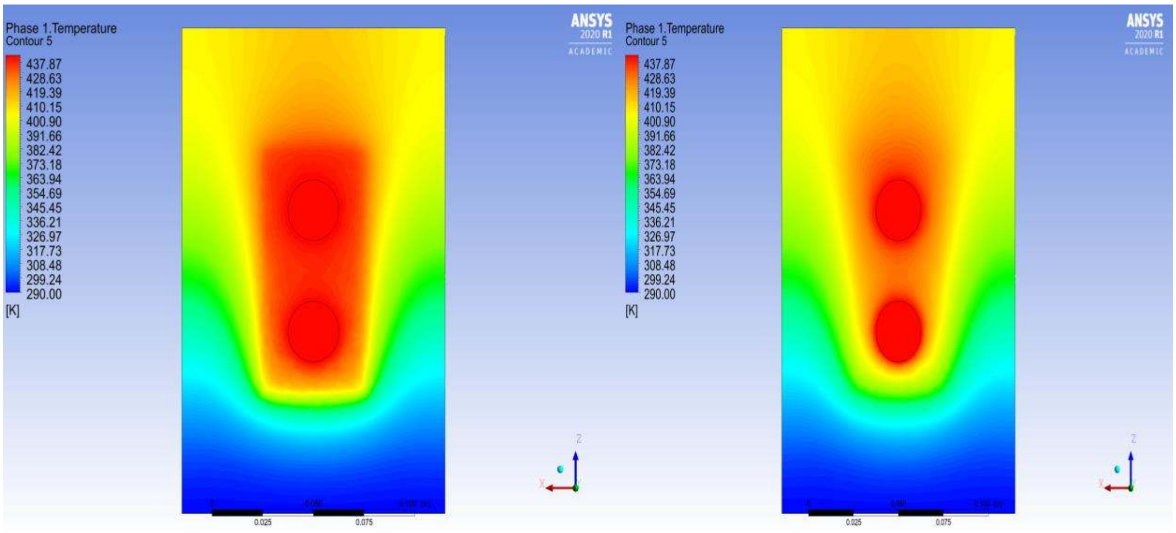

Figure 8: The above two images are the temperature contours of a plane located horizontally at distances 15mm And 20mm from the heat source respectively.

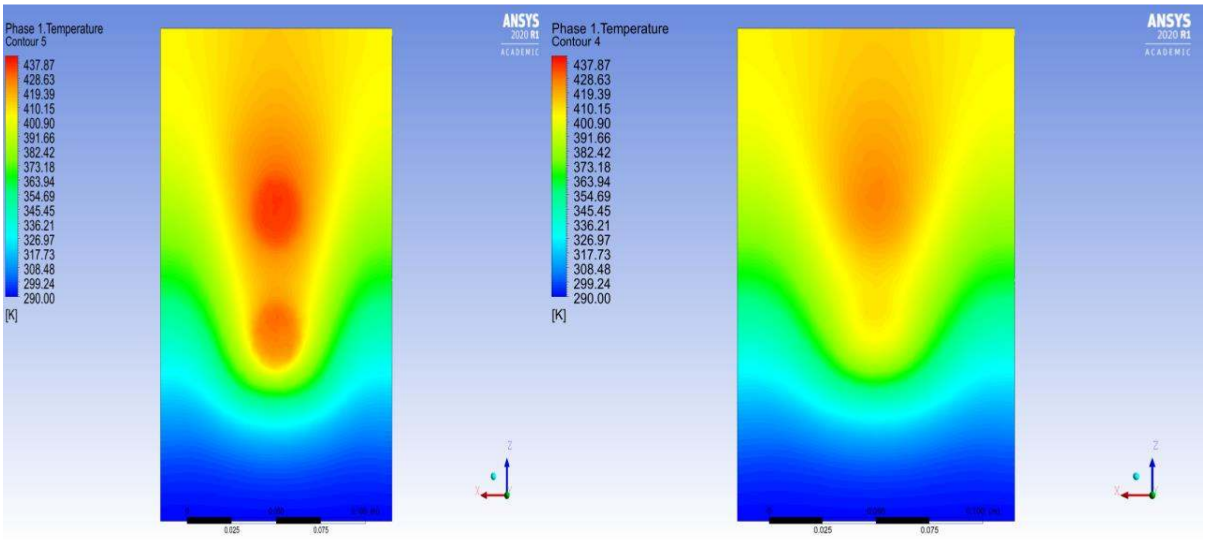

Figure 9: The above two images are the temperature contours of a plane located horizontally at distances 25mm And 30mm from the heat source respectively.

Figure 2 and 3 indicates the temperature distribution of NEPCM inside the H_c considering ice as the phase change material and titanium oxide as the np for vf of 2%. It is observed that the twin H_s which are at higher temperature melts the phase change material close to the surface of the heat source. It is evident that the melt zone temperature distributions are higher in locations closer to the H_s. The thermal convection generated near the H_s further accelerates the melting process and the heat transfer takes place inside the channel due to influence of thermal conduction effects. The temperature contours in the isometric view also indicates that the heat transfer rate is predominant in the longitudinal and transverse directions of the channel. Figure 3 indicates the longitudinal velocity and stream line patterns for NEPCM inside the channel. It is evident that the forced velocity at the inlet assists the motion of the melt zone towards the downstream side of the H_s. The blue regions in the velocity contours indicate the influence of no-slip velocities specified on the channel walls and H_s surfaces. The streamline patterns indicates the flow separation regions located near the H_s and it is also observed that the flow intensity and velocity distributions are higher at the mid-section of the channel where the influence of the no-slip boundary conditions are insignificant. Figure 4 represents the temperature distribution in the longitudinal directions at different vertical locations inside the channel. It is observed that the temperature distribution decreases with increase in the vertical location inside the channel. This is due to the fact that the effects of thermal convection and conduction are significant in the melt regions closer to the surface of the H_s. It is also observed that the temperature distribution is decreased by 16% to 18% by varying the normal locations from 15 mm to 30 mm.

4. Conclusions

Numerical investigation is carried in a horizontal channel filled with phase change material and titanium oxide nanoparticles. The enhanced properties and flow of the fluid (ice) suspended with titanium oxide nanoparticles are investigated using a two-phase approach using eulerian model. . The results indicates that the inlet velocity significantly affects the flow and heat transfer inside the channel, i.e.the melting rate and the heat transfer rate increases with increase in inlet velocity. It is also observed that the melting rate increases linearly with increase in the heat source intensity and nanoparticles volume fraction. It is observed that the twin heat sources which are at higher temperature melts the phase change material closer to the surface of the heat source. It is also evident that the melt zone temperature distributions are higher in locations closer to the heat source. The thermal convection generated near the heat source further accelerates the melting process and the heat transfer takes place inside the channel due to influence of thermal conduction effects. The temperature contours in the isometric view also indicates that the heat transfer rate is predominant in the longitudinal and transverse directions of the channel. It is observed that the temperature distribution decreases with increase in the vertical location inside the channel. This is due to the fact that the effects of thermal convection and conduction are significant in the melt regions closer to the surface of the heat source. It is also observed that the temperature distribution is decreased by 16% to 18% by varying the normal locations from 15 mm to 30 mm. Using NEPCMs in the horizontal channel improved the heat dissipation rate of the channel. Finally, the conclusions of tests make it very evident that NEPCM is a very efficient and a reliable heat storage system.

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