Study of Thermo Physical Properties of PCM with Dispersion of BeO Nano Particles

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Abstract- **Thermal energy storage (TES) systems provide several alternatives for efficient energy use and conservation. Phase change materials (PCMs) for TES are materials supplying thermal regulation at particular phase change temperatures by absorbing and emitting the heat of the medium. Thermal storage has been characterized as a kind of thermal battery. A phase change material (PCM) can absorb heat during melting and release it during solidification. Most PCM have very low thermal conductivity values, which leads to slow melting rates. Therefore, a thermally conductive enhancer (TCE) is needed to melt the PCM at a faster rate. Beryllium oxide can be used as a TCE due to their relatively low weight, and their ability to be manufactured with high thermal conductivity. This work examines the melt behavior of the PCM due to dispersion of Beryllium oxide nanoparticles. The integrated simulation system ANSYS Workbench 14.5 for the study was used. In FLUENT, the melting model with Volume of Fluid that includes the physical model to disperse nanoparticles in the PCM and their interactions is applied.**

Index Terms- **Thermal energy storage, Phase change material, Latent heat, Nano-Particle, Thermal Conductivity, CFD, ANSYS.**

INTRODUCTION

In this scenario, the availability of energy storage would be essential allowing a large number of solutions and combination of different technologies from already existing power generation systems. Energy storage not only reduces the mismatch between supply and demand but also improves the performance and reliability of energy systems and plays an important role in conserving the energy. The energy storage could also be used to offset the temporary decreases of production from conventional energy sources, ensuring the expected level of demand, allowing a reduction of the peak and an improvement of the efficiency of the plant, with the result of fuel savings. The different forms of energy that can be stored include mechanical, electrical and thermal energy.

THERMAL ENERGY STORAGE

The thermal energy storage is the transitory saving of high-temperature or low-temperature energy to use later. It connects the gap amid the demands and actual energy use. A thermal energy storage (TES) unit should have the ability to absorb the heat quickly and dissipate it within a desired time interval. This is achieved by using a phase change material. Phase change materials (PCM) are used because of their ability to store and release high amounts of heat energy with a relatively low volume and small temperature variation. Since a phase change involves a large amount of latent energy at small temperature changes, PCMs are used for temperature stabilization and for storing heat with large energy densities in combination with rather small temperature changes. The successful usage of PCMs is on one hand a question of a high energy storage density, but on the other hand it is very important to be able to charge and discharge the energy storage with a thermal power, that is suitable for the desired application. One major drawback of latent thermal energy storage is the low thermal conductivity of the materials used as PCMs, which limits the power that can be extracted from the thermal energy storage.

PHASE CHANGE MATERIALS

Thermal energy storage systems based on phase change materials are considered to be an efficient alternative to sensible thermal storage systems. Furthermore, these systems have high energy density compared to sensible heat storage systems. As said before PCM include the solid-solid, the solid-liquid, the solid-gas and the liquid-gas type.

Phase change materials (PCM) are ‘‘Latent’’ heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, or ‘‘Phase.’’ Initially, these solid–liquid PCMs perform like conventional storage materials; their temperature rises as they absorb heat.

LITERATURE REVIEW

Agarwal A. et al. [2001]: He used aluminum and carbon fiber in different form to increase thermal conductivity of PCMs. This research works focuses on variety of PCMs, heat exchange between HTF and PCMs during charging and discharging, arrangement of heat storage system. After studying this paper it is concluded that due to insertion of high conductivity nonmoving structure, there is effective enhancement in thermal conductivity of the PCM.

B. Zalba et al.[2003]Studied the performance of a latent heat storage system with solid, liquid phase change. This paper also provides a review of studies dealing with thermal energy storage (TES) using phase change materials. This paper contains a complete review of the types of material which have been used as latent heat storage materials, their classification. Characteristics, advantages and disadvantages and the various experimental techniques used to determine the behavior of these materials in melting and solidification. The paper contains listed over 150 materials used in research as PCMs, and about 45 commercially available PCMs.

Chieruzzi M. et al. [2004]: In this study, binary salt $NaNO_3$- KNO_3 (60:40 ratio) is used to prepare the different nano fluid. Measurements on thermo physical properties were performed by differential scanning calorimetry analysis and the dispersion of the nanoparticles was analyzed by scanning electron microscopy (SEM). The nanoparticles used were silica (SiO_2), alumina (Al_2O_3), titania (TiO_2), and a mix of silica-alumina (SiO_2-Al_2O_3). Three weight fractions 0.5, 1.0, and 1.5% by weight are selected for the experimentation work. Each nano fluid was firstly prepared in water solution then it is sonicated and evaporated. The results from the experiments show that the addition of 1.0 wt. % of silica and aluminium oxide nanoparticles to the base salt increases the specific heat 15% to 57% in the solid phase and of 1% to 22% in the liquid phase. There is also decrease in melting point by 8oC for addition of 1.0% of SiO_2 and Al_2O_3 nanoparticles. These nanofluids can be used in concentrating solar plants with a reduction of storage material due to improvement in the specific heat is achieved.

M.Cheralathan et al.[2006] Investigated the transient behavior of a phase change material based cool thermal energy storage (CTES) system comprised of a cylindrical storage tank filled with encapsulated phase change materials (PCMs) in spherical container integrated with an ethylene glycol chiller plant. A simulation program was developed to evaluate the temperature histories of the heat transfer fluid (HTF) and the phase change material at any axial location during the charging period. The results of the model were validated by comparison with experimental results of temperature profiles of HTF and PCM. The results showed that increase in porosity contributes to a higher rate of energy storage.

Nayak A.O. et al. [2008] He has considered various PCM like paraffin wax, sodium acetate tri-hydrate and phenolphthalein which are used to absorb heat from the coolant water from the engine. Due to conduction and convection of heat transfer heat is stored inside the PCM. in the form of latent heat. Convection and heat flux effect due to temperature change has been simulated and studied in detail using GAMBIT and FLUENT. From the temperature profiles obtained from the analysis he concluded that sodium acetate tri-hydrate gives us the most promising results as compared to paraffin wax and naphthalene. Coolant water loses maximum heat to sodium acetate trihydrate which is obtained as drop in temperature from 343 K to 324 K (in the coolant water). He observed that the heat absorption in the PCM material decreases gradually as it travels from the inlet of coolant water towards the outlet of coolant water.

Hajare V. S. et al. [2010]In this work paraffin wax is taken as PCM for experimentation work. In paraffin wax Al_2O_3 nanoparticles were added in 0.5%, 1% and 2% to enhance its thermal performance. For the experimentation solar water heating system is considered as latent heat thermal storage. Experiments were carried out with both base and nano mixed PCM to ensure the enhancement in heat transfer. From experimental investigation carried out it is found that there is enhancement in heat transfer rate of PCM due to the incorporation of nanoparticles. Heat transfer rate in the PCM is totally depends upon the amount of melt fraction. As melt fraction increases, there is increase in movement of nanoparticles which increases the heat transfer rate. From the experiment carried out it is clear that enhancement is depending on the percentage of nanoparticles inside the PCM and position of the spherical ball into the tank. Also maximum enhancement in melting point of 10.65% is observed for dispersion of 0.5% Al2O3 nanoparticles.

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.

Dudha B. et al [2013]. In this study, eutectic of sodium nitrate and potassium nitrate at 60:40 by weight were chosen as the base molten salt and silica nanoparticles were used to enhance the specific heat capacity of the salts. A modulated differential scanning calorimeter was employed to measure the specific heat capacity. He used sizes 5, 10, 30 and 60 nm of nanoparticles for the investigation of effect of size of the nanoparticle on the specific heat capacity. It was seen that the doping of nanoparticles enhanced the specific heat capacity by approximately 27% for 60nm. Material characterization is carried out with the help of the Scanning Electron Microscope (SEM) to explore the cause of the enhanced specific heat capacity. It was observed that as the amount of nanostructures increases the enhancement of specific heat capacity also increases.

MüslümArıcı, EnsarTütüncü, MiraçKan, HasanKarabay [2016] 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. 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 / = 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. 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.

PROBLEMS FORMULATION

Almost all phase change materials (PCMs), whether organic or inorganic, have a drawback of having low heat transfer rates during melting and freezing processes due to their inherent low thermal conductivity. Low thermal conductivity in PCM hinders the heat transfer process within its domain by prolonging the charging (heat addition) or discharging (heat rejection) period. This problem not only drastically affects the melting and solidification performance of the LHTES system, but also limits their widespread use as latent heat storage material. The thermal conductivities of organic and inorganic materials usually swing around approximately 0.2 W/m-K and 0.5 W/m-K, respectively.

RESEARCH OBJECTIVES

A CFD analysis 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. We will focus on numerical investigation of the melting of paraffin wax dispersed with Beryllium Oxide (BeO) Iterate for different concentration (i.e. 1% & 3% for both) that is heated from one side of square enclosure of dimensions of 25mm × 75 mm.

METHODOLOGY

The geometry used, shown in figure below is a rectangular enclosure of size 25mm × 75mm. It contains paraffin wax or paraffin wax dispersed with 1% and 3% by volume of nanoparticles BeO. The initial temperature of the Nano particle with PCM is 300 K, the hot wall side is at a constant temperature of 330 K (Tmax) and the cold wall, opposite the hot wall, is at 300 K (Tmin) in order, the other two walls are adiabatic. The geometry of Paraffin wax performing the simulation study is taken form one of the research scholar's M.Auriemmaand A. Iazzetta (2016) paper with exact dimension. The part of model was designed in ANSYS (Fluent) workbench14.5 software. The geometric dimension of the Paraffin wax is shown as:

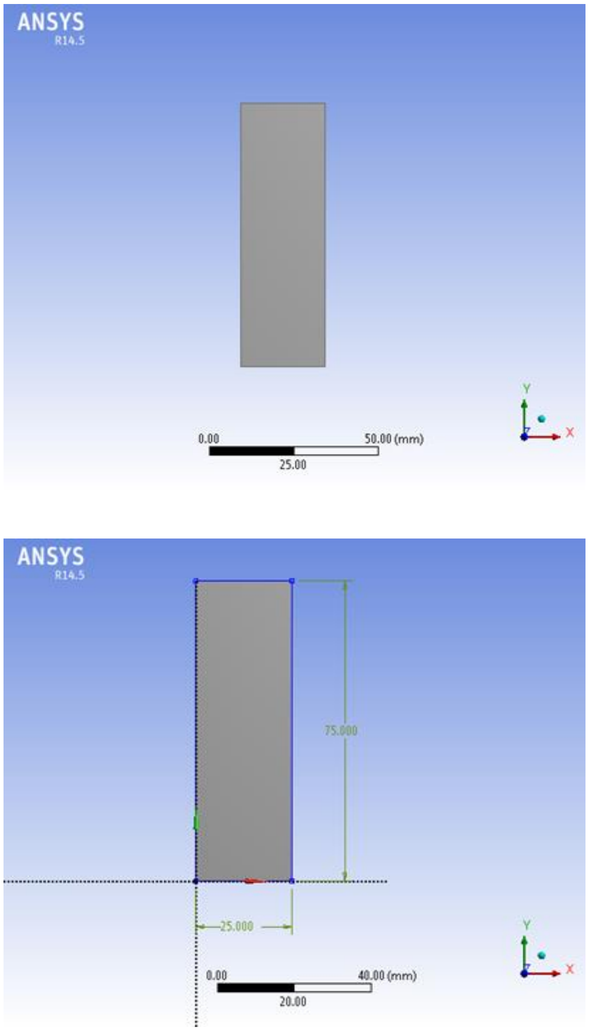

Figure 1 Wall of the paraffin wax of rectangular enclosure 25mm*75mm

MESHING By using ANSYS software in meshing edge sizing has been done. Inflation also makes for proper contact mesh. Mesh contains mixed cells per unit area (ICEM Tetrahedral cells) having meshing type tetrahedral and quadrilateral at the boundaries. However, for current problem the mesh having 1924 nodes and 1825 elements in generated. These nodes and element are sufficient to perform this research as we found that the variation in melting rate compared to the one in base paper is less than 1%. Increasing the no. of nodes and element will unnecessarily complicate the study and will require a heavy simulation software to support it. Boundary is taken as no slip boundary and the fine meshing is preferred for modes. The meshing of the given geometry of heat exchanger is shown in Figure 2.

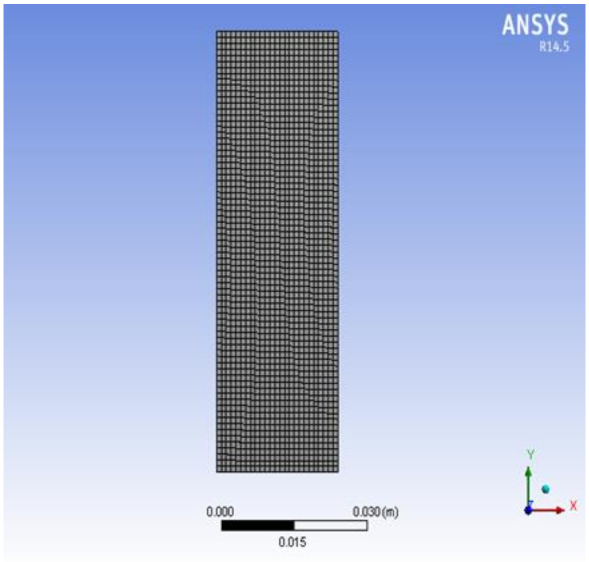

Figure 2: Meshing of PCM wall

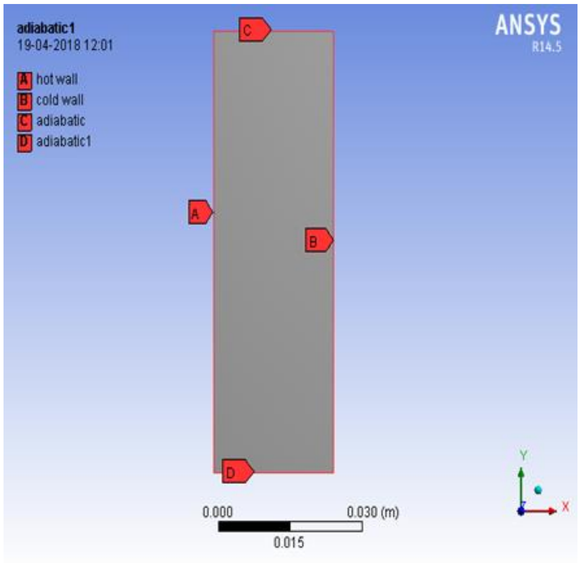

Fig 3: Name selection of PCM wall

NAME SELECTION A different part of the PCM Material is selected and the names are given to them so that boundary conditions can be applied on different boundary. 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 3.

FLUENT SETUP The mesh is properly checked and fine mesh is obtained. The analysis type is changed to heat transfer analysis type. The problem type is 2D and type of solver pressure-based solver.

MODEL SELECTION In model selection only three parameters are selected. Remaining parameter is remained as default. The three parameters are Multiphase – Eulerian, Energy – on and Viscous – Standard k-e standard wall Fn, mixture

BOUNDARY CONDITIONS Here in the analysis the boundary condition is same as considered by scholar's M.Auriemmaand A. Iazzetta (2016) during the work.

- Hot wall T = 330 K
- Cold wall T = 300K
- Adiabatic walls (Knpcm ΔT) =0
- Initial condition Ti = Tmin

PCM	Density(Kg/m^3)	Specific Heat(J/Kg-K)	Thermal Conductivity(W/m-K)	Dynamic Viscosity(N-s/m^2)
Paraffin+1% BeO	787.26	2819.12	.13845	.0046136
Paraffin+ 3% BeO	831.96	2688.79	.1451	.005978

Table 1 Properties of Paraffin wax+ Beryllium oxide for 1% and 3%

CFD study is conducted to study melting of paraffin wax in a rectangular enclosure with partially heated and cooled walls considering orientations of active walls (being vertical) and different volume fractions of Al2O3 and Be O nanoparticles 1 vol%, and 3 vol%). Afterward, the effect of hot wall temperature on melting and stored energy is analyzed. The obtained results are presented below.

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

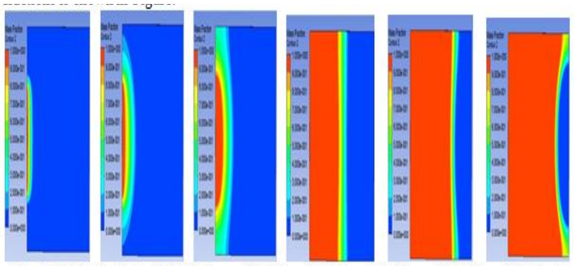

Fig 4 PCM+Al_2O_3 for 1 % (100 sec, 1600 Sec, 4800 Sec, 9600 Sec, 16000 Sec, 2400 Sec)

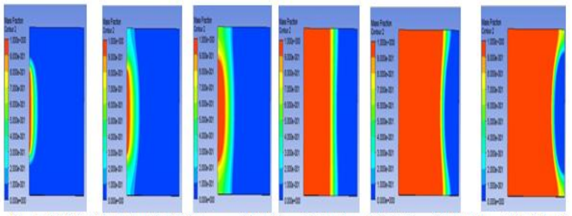

Fig 5 PCM + BeO for 1 % (100 sec, 1600 Sec, 4800 Sec, 9600 Sec, 16000 Sec, 2400 Sec)

Metal Oxide Concentration is 3 % With Paraffin Wax Liquid Fraction:

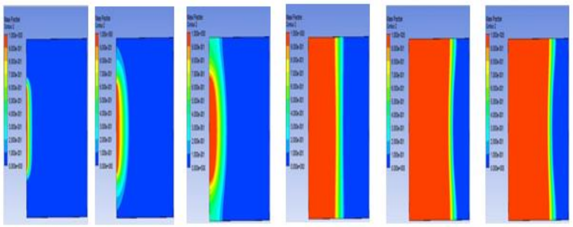

Fig 6 PCM+Al_2O_3 for 3 % (100 sec, 1600 Sec, 4800 Sec, 9600 Sec, 16000 Sec, 2400 Sec)

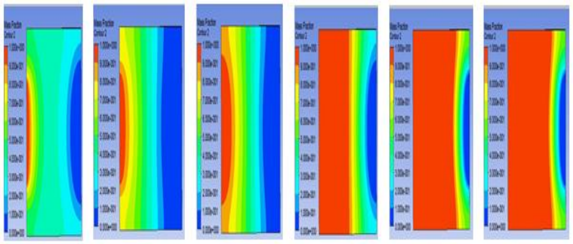

Fig 7 PCM + BeO for 3 % (100 sec, 1600 Sec, 4800 Sec, 9600 Sec, 16000 Sec, 2400 Sec)

The melting rate of Al2O3 and BeO nanoparticles enhanced paraffin for two volumetric concentrations 1%, and 3% wax is examined.

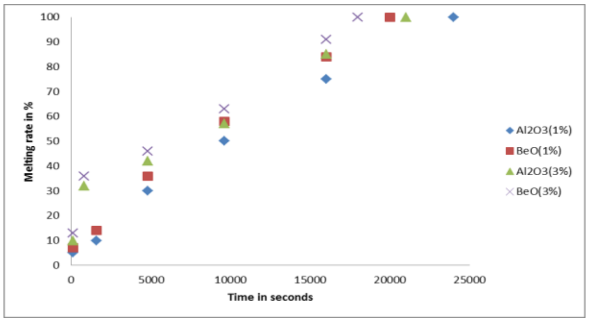

Fig 7 Melting Percentage V/S Time of Al2O3 and BeO at different volumetric concentration

Table 2Dynamic Viscosity at 300Kelvin for Al2O3 and BeO at different volumetric concentration

Thermal Conductivity(W/m-K) Temperature(in Kelvin)	Dynamic Viscosity in N-s/m2			
	Paraffin wax + 1% Al2O3	Paraffin wax + 3% Al2O3	Paraffin wax + 1% BeO	Paraffin wax + 3% BeO
300	0.0046	0.0059	0.00461	0.005978

Table 3 Thermal conductivity at 300Kelvin for Al2O3 and BeO at different volumetric concentration

Thermal Conductivity(W/m-K) Temperature (in Kelvin)	Thermal Conductivity in W/m-K				
	Paraffin wax	Paraffin wax + 1% Al2O3	Paraffin wax + 3% Al2O3	Paraffin wax + 1% BeO	Paraffin wax + 3% BeO
300	0.12	0.1235	0.13	0.12360	0.1311

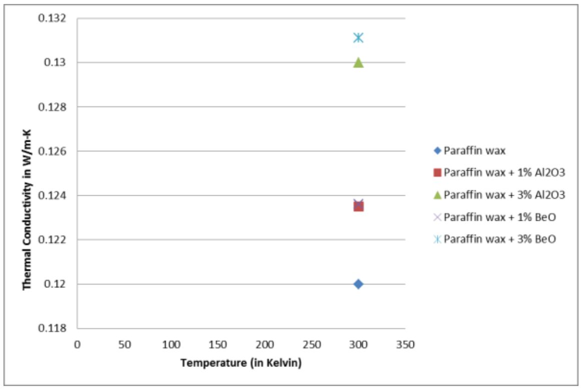

Fig 8 Thermal conductivity at 300Kelvin for Al2O3 and BeO at different volumetric concentration

CONCLUSIONS

In this analysis, the cumulative effect on melting rate and thermo-physical properties in phase change material has been investigated using CFD analysis. Based on the results obtained by the CFD and mathematical calculations it is found that:

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

The melting percentage of PCMS having 3% Al2O3concentration is more compared to nanoparticle concentration of 1% Al2O3. It requires 24000 Sec for paraffin wax + Al2O3 (1%) to fully melt while in case of paraffin wax + BeO (1%) 20000 Sec are needed for the fully melting of the PCM wall. It requires 21000 Sec for paraffin wax + Al2O3 (3%) to fully melt while in case of paraffin wax + BeO (3%) 18000 Sec are needed for the fully melting of the PCM wall.

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