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Project Report

“ Optimization of cooling solution for Hybrid Photovoltaic system”

Submitted by

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Sumedha Shekhar

Abstract

The higher operating temperature of Photovoltaic panels (above standard operating temperature, usually 25^{o} C) adversely affects the panel's efficiency. PV panels coupled with phase-changing material could be a feasible solution due to the higher energy storage density of such materials. Till now, no comprehensive study has been carried out that has effectively combined solar PV with PCM of various thicknesses and melting points. Most of the literature uses one or a few materials for all the seasons therefore as a result, we can see that the PV-PCM system is not effectively lowering the temperature of PV panels besides a few months or seasons. Optimization is required in the PVT-PCM system. Parameters affecting the better functioning of PVT-PCM need to be considered to provide optimal results. In this research, we have used Computational Fluid Software like Ansys Fluent and COMSOL Multiphysics to build various models like the PV-PCM 2D model, PVT-PCM 3D model, and PCM model to analyze the effect of changing PCM materials, their thicknesses and use of different fluid channels to extract the heat from PCM material and converting it into energy hence increasing the overall efficiency of the PVT-PCM model. This research uses PCM material like RT 25 to obtain graphs for surface temperature vs. time and distance graph, surface velocity magnitude vs. time and distance graph, density vs. temperature graph, thermal conductivity vs. temperature graph, heat capacity at constant pressure vs. temperature, beta vs. temperature and graphs of surface velocity and surface temperature for 2 hours.

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Introduction

Photovoltaics **(PV)** is the technology of converting sunlight into electricity via certain semiconductor materials that exhibit the photoelectric effect. It is a reliable technology that can move the globe towards a clean and sustainable energy future. The efficiency of a photovoltaic (PV) panel depends on certain parameters, such as solar radiation intensity falling on the PV surface, PV panel operating temperature, heat loss from the panel surface, and its material technology. For a typical PV panel, 15 to 25% of radiated solar energy on the PV panel's front surface is transformed into electricity, and the remaining is transformed into heat that leads to enhancing the module temperature. Several studies have proven that the higher operating temperature of the PV module significantly decreases the power output. Therefore appropriate cooling technologies must be used to enhance panels' electrical efficiency. The cooling methodologies could be of two types i.e., active (methodologies which directly reduce the temperature of PV panel) and passive (which act as a heat sink and absorb extra heat from PV panel). Due to the higher operating and maintaining charge of active cooling technologies, the passive method of cooling a photovoltaic panel is preferred to maintain the PV module temperature at a level consistent with higher efficiency. The PCM technique is a passive temperature regulation technique for PV modules that requires less operational cost and has a higher energy density. The ability of the PCMs to absorb large amounts of heat energy as latent heat at almost constant temperature makes them innovative materials for passive cooling of c-Si PV modules. PCM latent heat storage allows them to keep the absorbing interface at a temperature close to their melting point.

Researchers are carrying out studies involving PV-PCM. They reported the technology achieves a significant reduction in temperature of c-Si PV modules. In a further investigation into the yearly energy performance of a PV-PCM system deployed in hot climate conditions of United Arab Emirates (UAE) it is shown that PV-PCM module records consistent lower temperature throughout the year. A maximum temperature reduction of 13°C in April and minimum reduction of 8°C in June compared to the reference PV system is observed. Their PV-PCM records higher power compared to the PV module. The researchers studied the energy and cost saving of a PV-PCM and reported that the system is financially viable in higher temperature and higher solar radiation environment. A similar research recorded PV-PCM improvements achieving increased electrical and thermal yield by 7.2% and 9.5%, respectively.

These studies conducted on PV-PCM module indicate its usefulness in achieving better outputs in terms of both maximum output power and power conversion efficiency. Earlier studies mainly were focused on comparing the PV module without PCM to that with

PCM and see how different factors like maximum output power, power conversion efficiency, open circuit voltage (V_{oc}) and short circuit current (I_{sc}) etc. vary.

The novelty of this research lies in using Computational Fluid Dynamics software such as Ansys Fluent and COMSOL Multiphysics to build PV-PCM 2D and 3D models to analyze which PCM materials and for what thicknesses are suitable for obtaining lower temperatures throughout the year. Using PCM as a passive cooling material helps maintain a consistent temperature, thus maintaining the PV panels' efficiency. However, if not utilized, the heat absorbed by PCM material goes in vain. This study utilized this heat by using a cooling solution to absorb and generate electricity, increasing the overall efficiency to 60-70%.

Methodology

Geometry and problem statement

The schematic of the PV-PCM 2D model under consideration is illustrated in figure 1. It consists of a PV panel with PCM material. The panel and the PCM material are thermally interconnected so that the heat generated in the panel during operation is removed when PCMs undergo melting. Thus, the PV temperature reduces to the extent that it is operatively effective. The side walls of the PCM material are made of aluminum as a heat conductive material to accelerate heat dissipation from PV into PCM during daylight and later from PCM to the surrounding during the night. The PV panel comprises glass, silicon, two ethylene vinyl acetate (EVAs), and Tedlar, as shown in figure 2. The model build using COMSOL Multiphysics for computational fluid dynamics (CFD) simulation and analysis using Heat transfer to fluids and laminar flow as physics. The model was meshed in a COMSOL meshing environment using appropriate mess size with correct relevance, sizing, and quality. The schematic of the PVT-PCM 3D model was built with a slight variation in the PV-PCM model by adding pipes to it along with a cooling solution flowing into it to extract the unused heat stored in the PCM material to increase the overall efficiency of the PVT-PCM. The schematic of the PCM 2D model under consideration is illustrated in figure 4. It consists of PCM material. The side walls of the PCM material are made of aluminum as a heat conductive material to accelerate heat dissipation from PV into PCM during the daytime and later from PCM to the surrounding during the night. PCM model is used to study variation in systems velocity magnitude and temperature with respect to time. RT 25 is used as PCM material in the PCM model to conduct numerical simulations. While building the PCM model, we defined specific properties like density, thermal conductivity, heat capacity at constant pressure, etc. The values of these properties can be obtained from table 1.

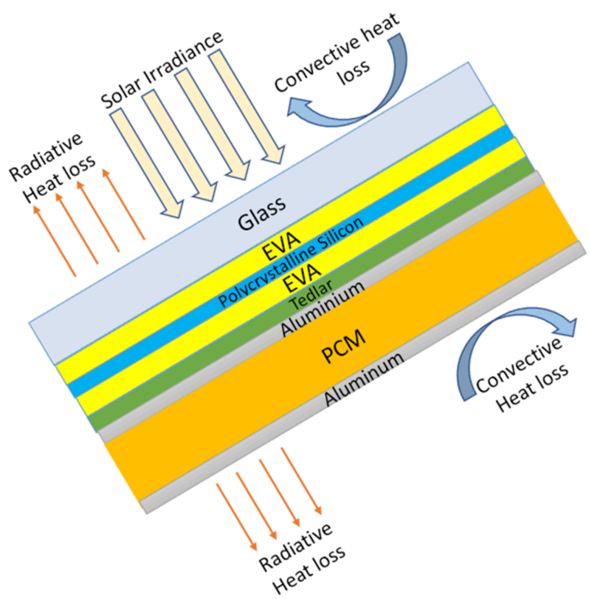


Figure 1. PV-PCM system

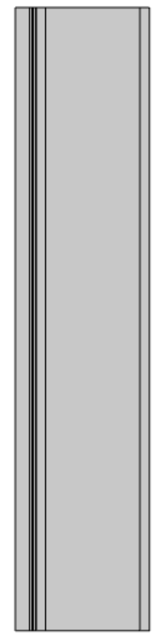


Figure 2. PV- PCM model

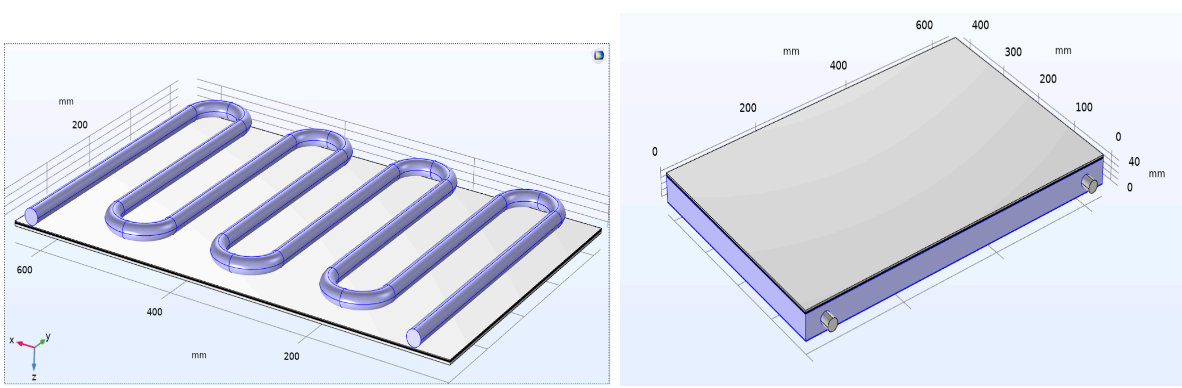


Figure 3. Pipes

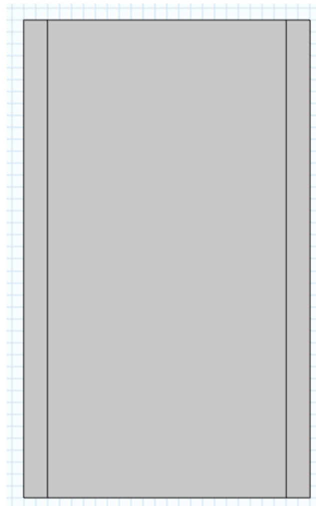


Figure 4. PCM system

Table 1
Thermophysical properties of "RT25" [37], paraffin wax [38] and aluminium [39]

Property	Phase change material "RT25" (for experiment and validation simulations)	Paraffin wax (for simulation)	Aluminium (for experiment and validation simulations)
Density			
Solid, $kg\,m^{-3}$	785	830	2675
Liquid, $kg\,m^{-3}$	749	830	Not applicable
Specific heat capacity			
Solid, $J\,m^{-3}\,K^{-1}$	1,413,000	1,593,600	2,415,525
Liquid, $J\,m^{-3}\,K^{-1}$	1,797,600	2,705,800	Not applicable
Thermal conductivity			
Solid, $W\,m^{-1}\,K^{-1}$	0.19	0.514	211
Liquid, $W\,m^{-1}\,K^{-1}$	0.18	0.224	Not applicable
Melting temperature, °C	26.6	32	Not applicable
Latent heat of fusion, $J\,kg^{-1}$	232,000	251,000	Not applicable

Table 1.

In the study of the PCM model, specific properties are modeled. The density of the PCM can be modeled using Eq. (1):

$$\rho_{PCM}(T) = \rho_{solid} + (\rho_{liquid} - \rho_{solid})B(T) \quad (1)$$

where ρ_{PCM} is temperature dependent density of PCM. The densities of PCM in the solid and liquid phases are ρ_{solid} and $\rho_{liquid,}$ respectively. The density of PCM varies linearly in the transition zone according to the function B(T), which can be given as:

$$B(T) = \begin{cases} 0 & T < (T_m - \Delta T) \\ (T - T_m + \Delta T)/ (2\Delta T) & (T_m - \Delta T) \leq T \leq (T_m + \Delta T) \\ 1 & T > (T_m + \Delta T) \end{cases} \quad (2)$$

Eq. (2) represents that B is zero when PCM is in a solid state and 1 when it is melted, and it linearly grows from 0 to 1 between the two states. Where T_m is the melting temperature, and ΔT is the transition temperature of PCM. The specific heat and the latent heat of fusion for the PCM can be modeled using Eq. (3):

$$C_{\rho PCM}(T) = C_{\rho solid} + (C_{\rho liquid} - C_{\rho solid})B(T) + L_f D(T) \quad (3)$$

$C_{\rho PCM}$ is the temperature-dependent specific heat of PCM, and specific heat in the solid and liquid phases are $C_{\rho solid}$ and $C_{\rho liquid,}$ respectively. The L_f is the latent heat of fusion, and D(T) depends on the temperature T. ΔT and T_m of the PCM.

Function D is the Delta function which is zero everywhere except in interval $[T_m - \Delta T, T_m + \Delta T]$. It pinpoints on $T_{m,}$ and the value of its integral is one. The main role of function D is to distribute the latent heat of fusion similarly nearby the melting point of PCM. The thermal conductivity of the PCM, depending on its phase, can be modeled by Eq. (4):

$$k_{PCM}(T) = k_{solid} + (k_{liquid} - k_{solid})B(T) \quad (4)$$

The study of the PVT-PCM model is conducted to use the heat absorbed by the PCM in the form of latent heat of fusion; otherwise, it will get wasted. The PVT-PCM model uses fluid channels and PCM material to enhance the maximum output power. When solar irradiance falls on the PV panel, approximately 83% of the incident solar irradiance is converted to heat within the cells, increasing the cell temperature beyond its standard operating temperature and decreasing its power conversion efficiency. To maintain power conversion efficiency, PV panel is incorporated with PCM material, which helps them keep the absorbing interface at a temperature close to their melting point. The energy absorbed by the PCM, if not utilized, will go in vain, so to utilize the absorbed energy, fluid channels are incorporated, which will absorb this energy and store it by doing so, we can increase our maximum power output to 60-70%.

Result

The graph obtained by carrying out numerical simulations on PCM model is illustrated in Figure 5. which shows the plot of Surface temperature(K) with respect to time and distance.

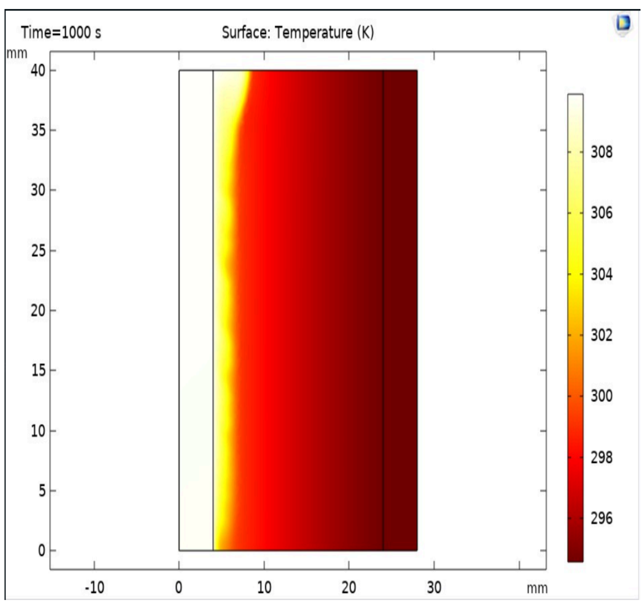


Figure 5. Surface Temperature(K)

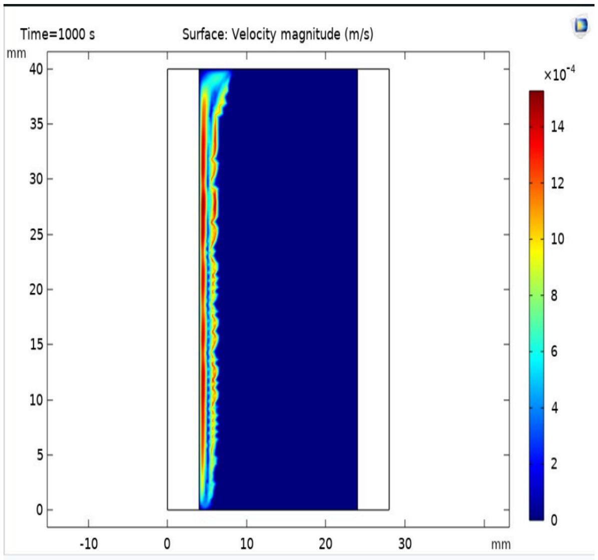


Figure 6. Surface Velocity magnitude (m/s)

Figure 6. Shows the plot of Surface velocity magnitude with respect to time and distance of PCM model using RT 25 as a PCM material.

Several other graphs are obtained for the PCM model for different properties with respect to temperatures, such as density, thermal conductivity, heat capacity at constant pressure, and beta function. This is illustrated in Figure 7, Figure 8, Figure 9, and Figure 10, respectively.

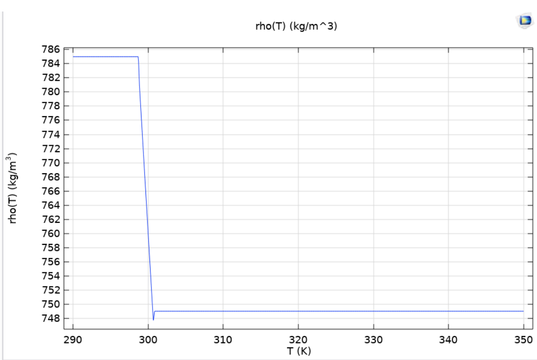


Figure 7. rho(T) vs. T(K)

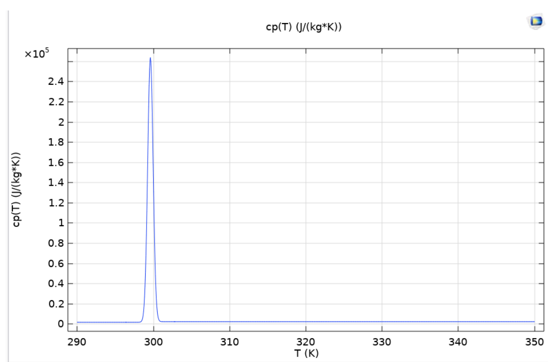


Figure 8. cp(T) vs. T(K)

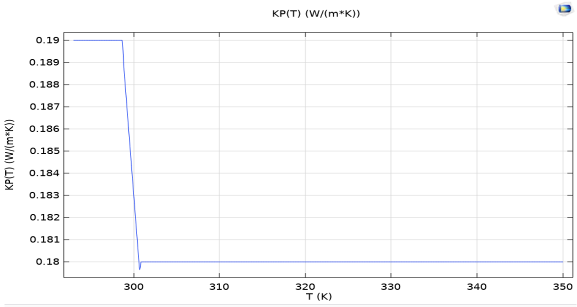


Figure 9. KP(T) vs. T(K)

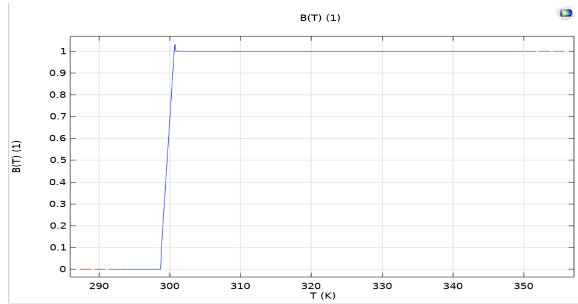
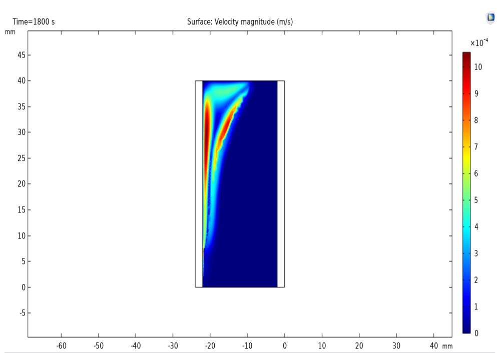
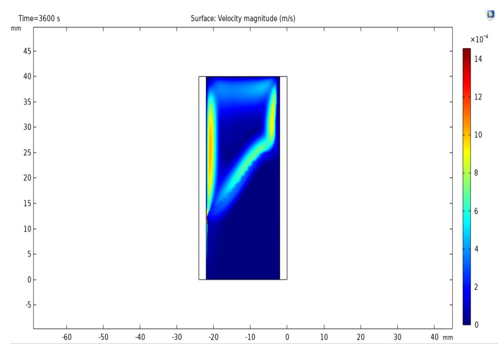


Figure 10. B(T) vs. T(K)

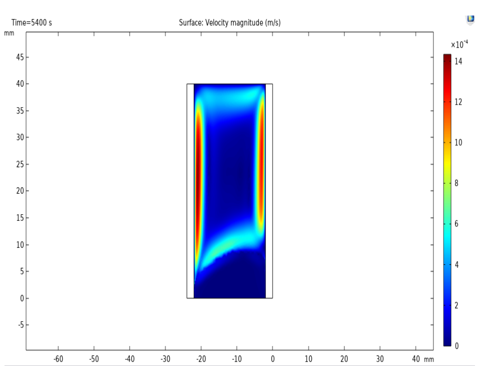
The plot of surface velocity magnitude vs. time and distance for 2 hours is plotted every 30 minutes, as illustrated in figure 11.



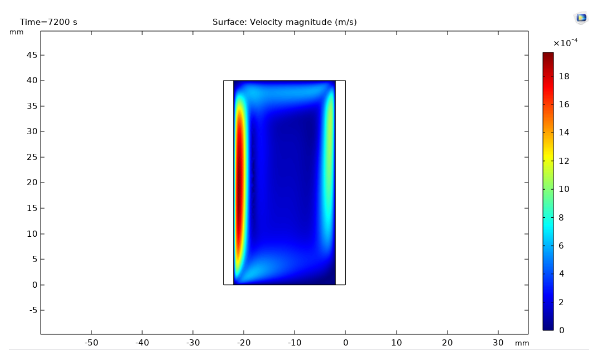
Velocity after 30 minutes



Velocity after 60 minutes



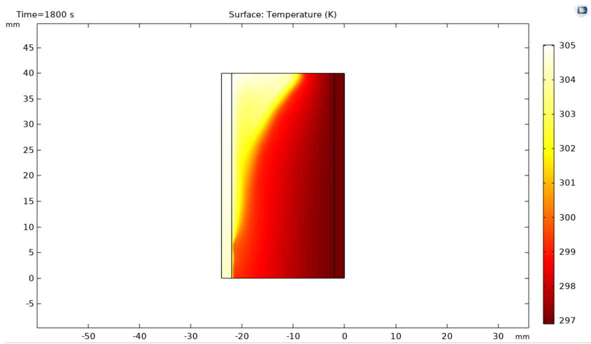
Velocity after 90 minutes



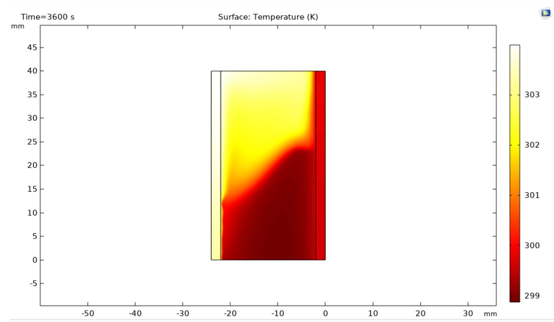
Velocity after 120 minutes

Figure 11. Plot of Surface velocity magnitude vs. time and distance for 2 hours.

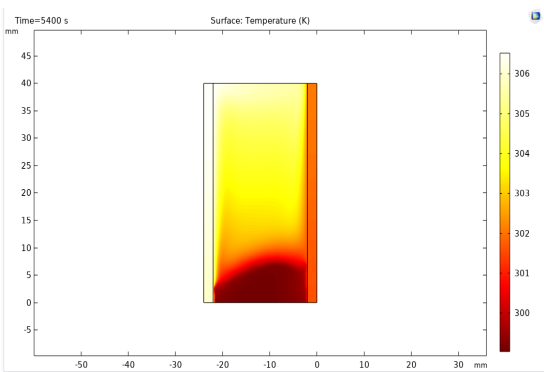
The plot of surface temperature vs. time and distance for 2 hours is plotted every 30 minutes, as illustrated in Figure 12.



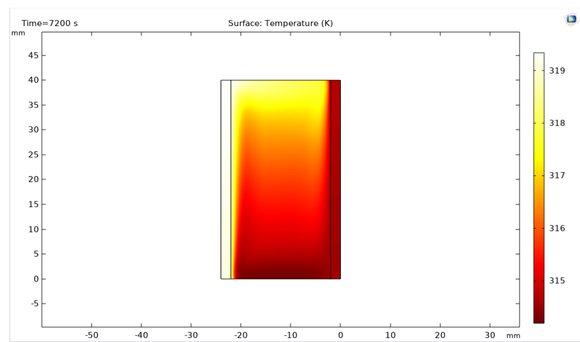
Temperature after 30 minutes



Temperature after 60 minutes



Temperature after 90 minutes



Temperature after 120 minutes

Figure 12. Plot of Surface Temperature vs. time and distance for 2 hours.

Conclusion

The use of COMSOL Multiphysics software to perform numerical simulations on the PCM model produced several graphs like surface temperature vs. time and distance graph, surface velocity magnitude vs. time and distance graph, density vs. temperature graph, thermal conductivity vs. temperature graph, heat capacity at constant pressure vs. temperature, beta vs. temperature and graphs of surface velocity and surface temperature for 2 hours. This graph depicts the changes happening in values of specific parameters when other parameters like temperature, time, and distance change. We have built the PV-PCM 2D model and PVT-PCM 3D model using COMSOL Multiphysics software, but the numerical simulations and experimental verification is still going on.

Reference

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