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Numerical investigation of the effect of the shape of the cooling chamber containing paraffin phase change material on the performance of solar panels

Payam Jalili[1*], Amir Khosravi Soufi[2]

[1] Assist. Prof., Department of Mechanical Engineering, North Tehran Branch, Islamic Azad University, Tehran, Iran
[2] M.Sc graduate, Department of Mechanical Engineering, North Tehran Branch, Islamic Azad University, Tehran, Iran

*Corresponding author: p.jalili@iau-tnb.ac.ir

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Abstract

Due to the high importance of energy and the limitations of fossil fuels, the use of renewable energy has become increasingly significant. One major challenge in solar energy systems is the decrease in solar panel efficiency with increasing temperature, making it necessary to cool the panels effectively.Based on this, previous research on using phase change materials as a cooling method for solar panels investigated the cooling performance of PureTemp29 material as a phase change material in different geometries. It was simulated using the finite element method in AnsysAPDL software. The chambers were specified with simple and finned geometries in two-dimensional and three-dimensional modes. The results showed that the finned chamber's efficiency with the fin's depth equal to the tank's depth is better than other chambers due to the proper temperature distribution in different parts of the phase change material. In order to validate the temperature outputs at different times in finned geometry, it was compared with previous experimental research, and it was found that the simulation had good accuracy.

Keywords: Phase change material; Solar Panel; Cooling chamber; PureTemp29.

1. Introduction

Solar energy, as a free and renewable resource, has attracted significant attention globally due to its potential to address energy demands [10]. Despite its widespread use, photovoltaic (PV) panels exhibit low efficiency (10-16%), as they can only convert a small fraction of solar radiation into electricity [7-9]. Most solar energy is absorbed as heat, causing a rise in panel surface temperature, which reduces the electrical output by approximately 0.4-0.65% per degree Celsius above 25°C [7].

To address this challenge, phase change materials (PCMs) have been investigated as an effective solution for thermal management in PV systems. PCMs can absorb and release substantial amounts of thermal energy during phase transitions, thus stabilizing the surface temperature of PV panels [6]. Early PCMs designs faced challenges such as poor thermal contact and material corrosion [5]. Subsequent studies improved heat transfer by introducing fins or utilizing aluminum-based absorbers [4].

Recent advancements, including experimental and numerical analyses, demonstrated that PCM-integrated PV systems with fins enhance heat transfer and maintain optimal temperatures [1, 2, 3]. These studies underscore the importance of optimizing PCM configurations to improve both thermal management and electrical efficiency.

This study builds upon previous research by numerically analyzing the performance of different PCM geometries using finite element methods. It aims to identify optimal configurations for improving the thermal regulation of PV panels, reducing temperature-induced power losses, and ensuring system durability.

2. Geometry Considered in the Study

Based on the previous sections and the research background, it is evident that phase change materials (PCMs) can be effectively utilized as thermal regulators for solar panel surfaces. This study's numerical simulations complement previous experimental studies by investigating two different PCM arrangements. The PCM is stored in a container in direct contact with the rear side of the solar panel. The effectiveness of each PCM geometry can be compared by analyzing the temperature variations of the solar panel over time.

This research examines the thermal management of a solar panel with a power output of 15 watts and a surface area of 929 cm². It is assumed that an aluminum plate is attached to the rear side of the panel, with one surface in contact with the panel and the other with the PCM. The primary role of the aluminum plate is to transfer heat between the panel and the PCM. The plate's thickness is set at 3.175 mm (1/8 inch), chosen for its high thermal conductivity, affordability, and lightweight properties.

The PCM is contained within a chamber measuring 25.4 × 25.4 cm (10 × 10 inches), fabricated from aluminum. The chamber's design ensures maximum thermal conductivity, minimizing thermal resistance. Two distinct PCM geometries are considered for the solar panel thermal regulation system, described and analyzed below.

3. Results and Discussion

The bulk PCM chamber's temperature distribution was analyzed in 2D and 3D models. Significant temperature differences were observed between the two models, particularly near the chamber's boundaries, as shown in Figure 1.

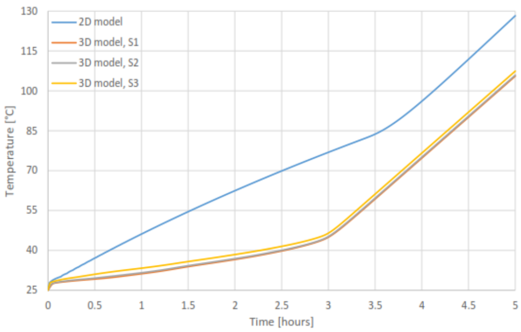

Figure 1. Comparison of temperature variations in 2D and 3D models for the bulk PCM geometry at three critical points.

In the 2D model, the temperature rises more steeply due to heat accumulation within the PCM. The 3D model, however, accounts for heat dissipation through the aluminum sidewalls, resulting in a more uniform temperature distribution.

3.1. Finned PCM Chamber

The finned PCM chamber was evaluated under identical conditions, with straight aluminum fins placed inside the chamber. The fins significantly enhanced heat transfer, as they provided additional pathways for heat conduction. Figure 2 shows the comparison of surface temperature variations for the 2D and 3D models at six critical points.

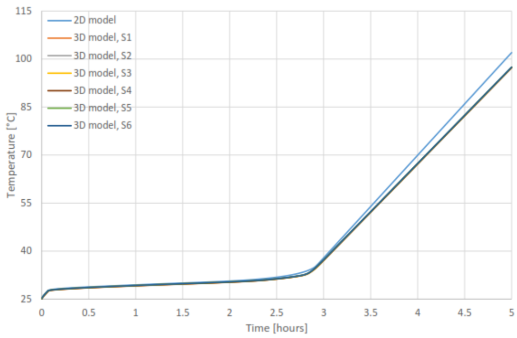

Figure 2. Temperature variations at six critical points in the finned PCM chamber for 2D and 3D models.

The 3D model predicted lower temperatures due to better heat dissipation through the sidewalls, emphasizing the importance of considering full 3D geometries in such simulations.

According to the simulations conducted and the comparison of the results of the two simulations shown in Figure 3, it was observed that by adding fins to the chamber, the saturation time slightly decreases, but the temperature significantly decreases at all stages. This indicates that in the finned chamber, due to much better conduction occurring and different points of the phase change material being simultaneously involved in the heat treatment operations, the effect of using the phase change material is enhanced in the second configuration, and this chamber provides better performance.

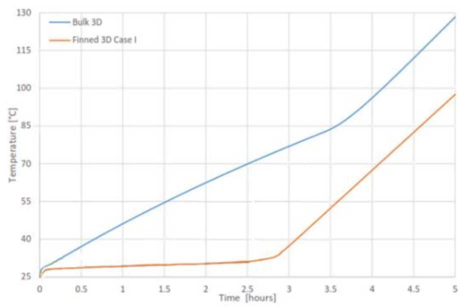

Figure 3. Comparison of temperature profiles for bulk and finned PCM chambers.

4. Conclusions

This study investigated the effect of different PCM chamber geometries on the thermal regulation of solar panels. The following conclusions were drawn:

1. The finned PCM chamber significantly reduced the surface temperature of the solar panel compared to the bulk PCM chamber.

2. While the saturation time of the PCM decreased slightly with the addition of fins, the overall temperature

reduction was more substantial, leading to improved thermal regulation.

3. The 3D models provided more accurate results compared to the 2D models, highlighting the role of sidewalls in enhancing heat transfer.

Although a conclusion may review the main points of the extended abstract, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions. Conclusions should include (1) the principles and generalizations inferred from the results, (2) any exceptions to, or problems with these principles and generalizations, (3) theoretical and/or practical implications of the work, and (4) conclusions drawn and recommendations.

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