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2-D Numerical Analysis Of The Photovoltaic-Phase Change Material (PV-PCM) Model With Flat Fins

Muhammed Musab Bayat[1,a,*], Ertan Buyruk[2,b], Mustafa Caner[3,c]

[1]Sivas Cumhuriyet University, Electrical-Electronics Eng. Dept. Sivas, Türkiye
[2]Sivas Cumhuriyet University, Mechanical Eng. Dept. Sivas, Türkiye,
[3]Sivas Cumhuriyet University, Mechanical Eng. Dept. Sivas, Türkiye,
*Corresponding author

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ABSTRACT

In this study, a 2-D numerical analysis was conducted the melting characteristics of phase change material (PCM) placed inside the container formed by using rectangular flat fins and to evaluate its effect on the average surface temperature of the photovoltaic (PV) panel accordingly. Flat fins were used in this study for the purpose of improving heat transfer and thermal enhancement in the latent heat storage system. To produce a two-dimensional analysis of the one-hour experimental study carried out under laboratory conditions, melting fraction, the temperature distribution and flow fields of the PCM were shown using ANSYS Fluent 18.2 software. The experimental results obtained from the previous study and the analysis results carried out in this study were quite similar and the difference between the average surface temperatures of the PV Panel was found to be 4.25%. In addition, the effects on the PV panel average surface temperature were observed by changing the initial ambient temperature and the amount of radiation.

Keywords: CFD analysis; fins; pv-pcm.

[a] *muhammed@cumhuriyet.edu.tr* *0000-0002-4631-6516*
[b] *buyruk@cumhuriyet.edu.tr* 0000-0002-6539-7614
[c] *mustafacaner@cumhuriyet.edu.tr* *0000-0002-3674-7881*

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Main text

Latent heat storage systems, which are methods used for energy saving in environment and engineering, have played an important role in recent years. Heat is stored with latent heat storage systems using PCMs, which are solid-liquid phase change materials. For example, the heat storage capacity of paraffin-based 116 wax is seven times that of rock-based sensible heat storage [1]. Thanks to this high heat storage capacity, it is inevitable to use these materials as thermal management, especially in electronic devices [2]. However, although organic PCMs are stable, low-cost and have a high melting temperature range, the most important problem of these materials is their low thermal conductivity. To improve this disadvantageous situation, various methods have been investigated by researchers to improve the heat transfer performance of PCMs [3-4]. Microencapsulation and fin usage are prominent improvement methods. It has been investigated how to improve PCM thermal conductivity by using a variety of fins [5]. Huang et al. [6] showed in their study that fins placed in PCM container can increase system performance. According to Huang et al. [7], PCM containers with fins reduce PV panel temperatures by 3°C when compared with those without fins. Shatikian et al. [8] reported that less space/thickness of fins causes PCM to melt faster. The use of porous matrix and plate-type fins, Nayak et al. [9] reported that rod type fins outperformed plate type fins. The use of more fins in thermal management leads to better heat dissipation, according to Fok et al. [10]. Biwole et al. [11], in their study investigating the effect of fin length on PCM, showed that the contact of fins to PCM container and increasing the number of fins positively affect the system performance. The temperature of the PV was decreased by 8°C after Huang et al. [12] installed aluminum fins inside the PCM box. Khanna et al. [13], in their study examining the effect of fins with different thickness, length and spacing, showed that the electrical efficiency increased by 8.4% for 1/5 m spacing. Atkin & Farid [14] reported that a PCM with fins reduced the temperature of the PV panel. Sharma et al. [15], by adding fins to the PV panels cooled using PCM, reduced the PV panel surface temperature by 1.1 °C. Tan et al. [16], in their experiments conducted for four different PCM containers containing 3, 6 and 12 fins, without fins, observed a 15 °C decrease in PV temperature with the PCM container with 12 fins. Nehari et al. [17], in their study, determined the optimum fin length by numerical analysis by changing the fin lengths. Indartono et al. [18], in their study using yellow vaseline with fins, found the maximum increase in PV efficiency by 21%.

In this study, the effect of fins with high thermal conductivity on the melting rate and PCM heat transfer will be revealed. A computational fluid dynamics analysis using Fluent software will be conducted for the PV-PCM system. The obtained results will be compared with the results of our previous laboratory experimental study [19]. In addition, the effects on the average PV panel surface temperature will be revealed by changing the initial ambient temperature and the amount of radiation.

Numerical analysis

In this section, the analysis of the PV-PCM container with rectangular horizontal flat fin geometry was carried out in two dimensions and compared with the results of the 60-minute laboratory experiment obtained from the previous study. View of the designed model in cross-section is given in Figure 1. PV module consists of (36cm x 42cm) mono-crystalline silicon cells. ANSYS Fluent 18.2 software was used to solve the momentum, heat conduction and heat diffusion equations. Solid model and equations are shown in detail. The analysis was carried out with wind speed, the initial ambient temperature which are 0 m/s and 20 °C, PV panel tilt angle of 90° and irradiance of 1200 W/m^2 as boundary conditions. The boundary conditions and mesh model are schematically represented in Figure 2 (a) and 2 (b).

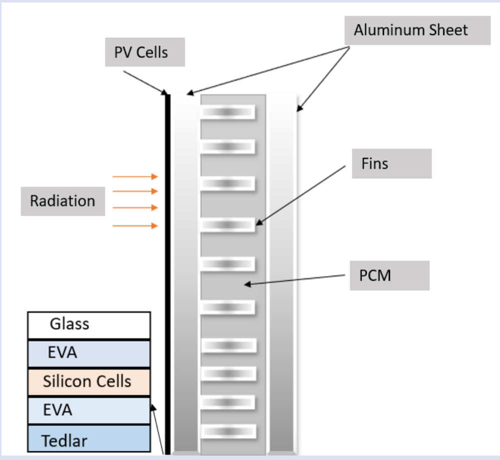

Figure 1. Section view of the 2-dimensional model.

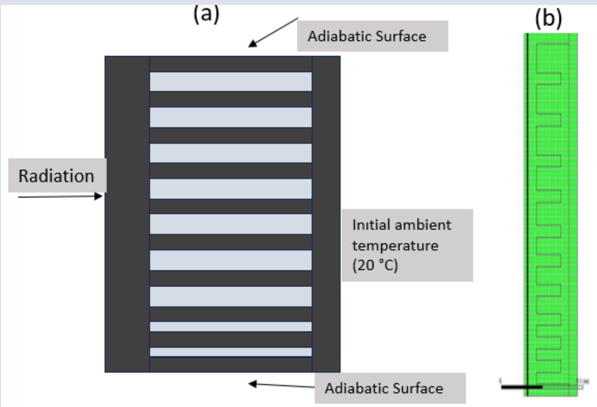

Figure 2. (a) Boundary conditions, (b) ANSYS mesh.

Solid model

The Navier-Stokes equation, which is the two-dimensional momentum equation of the model with fins, was calculated in the CFD software with the following formulas:

$$\rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} = \nabla(\mu \nabla u) - \frac{\partial P}{\partial x} \tag{1}$$

$$\rho \frac{\partial v}{\partial t} + \rho u \frac{\partial v}{\partial x} + \rho v \frac{\partial v}{\partial y} = \nabla(\mu \nabla v) - \frac{\partial P}{\partial x} - \rho g \tag{2}$$

In the Navier-Stokes equation, the variable represented by ρ represents the fluid density (kg/m^3); u represents the x speed and v represents the y speed (m/s); g represents the gravitational acceleration (kg m/s^2) and μ represents the PCM's viscosity (Ns/m^2). As shown in Table 1, the PCM has the following thermophysical characteristics and aluminum has the following characteristics.

Table 1. Thermophysical/physical characteristic of PCM and aluminum

Properties	Aluminum	PCM
Thermal Conductivity (W m^{-1} K^{-1})	202.4	0.2
Density (kg m^{-3})	2719	880(solid)-770(liquid)
Specific heat (kJ kg^{-1}K^{-1})	0.871	2
Latent heat (kJ kg^{-1})	-	250
Melting temperature (˚C)	-	28

Modeling of heat transfer

As a result of a PV-PCM system, the PV panel cannot absorb heat and must transfer it to the PCM as waste heat, and the environment of the two-dimensional PV-PCM model is assumed to be adiabatic [20]. The heat transfer equations of the two-dimensional model are shown below:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{\rho c_p}{k}\frac{\partial T}{\partial t} \tag{3}$$

The specific heat of each solid piece is shown as Cp and its unit is J/(kg K), and the thermal conductivity of each solid piece is shown as k and its unit is W/(m K).

PCM model

When PCM melts or freezes, the equations of solid-liquid phase change can be shown as solid, solid-liquid and liquid states as follows:

$$Phase\ State = \begin{cases} 0 & T < T_s & Solid\ state \\ \dfrac{T - T_s}{T_l - T_s} & T_s < T < T_l & Solid - Liquid\ state \\ 1 & T_l & Liquid\ state \end{cases} \tag{4}$$

Here, PCM's liquid temperature is represented by Tl during melting-freezing; PCM temperature is represented by T while solid temperature is represented by Ts during melting-freezing.

Result and discussion

Before performing the numerical analysis, mesh independence tests were performed and the mesh number was determined as 20000. The mesh visual created in ANSYS for the PV-PCM model is shown in Figure 2 (b). The comparison of the results obtained with the grid test performed with the determined mesh number with the laboratory experiment results is given in Figure 3. The state of the solid-liquid phase transitions of the PCM was recorded a total of 4 times in the one-hour analysis, every 15 minutes, and is shown in Figure 4.

It was observed that the PCM did not undergo almost any phase change at the beginning and towards the end of the experiment, melting occurred especially in the regions where the fins were placed more tightly. The reason for this is that the PCM starts to change phase as soon as it reaches the melting temperature. The change in the average surface temperature of the PV panel obtained in the numerical analysis results with respect to time was compared with the laboratory results and a difference of 1.74 °C was found between the experimental and numerical analysis results. While the average surface temperature of the PV Panel was found to be 40.92 °C in the experimental study, this value was calculated as 39.18 °C in the analysis results. The difference between both studies was found to be 4.25%. The comparison of the laboratory experiment results with the CFD analysis results is shown in Figure 5.

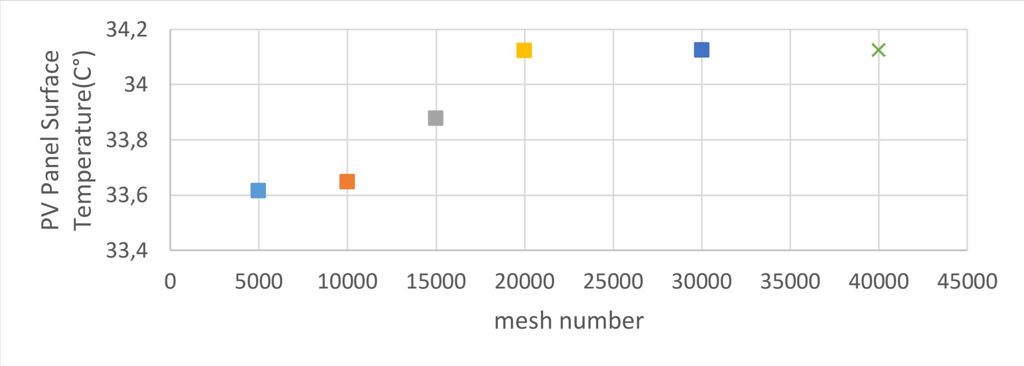

Figure 3. PV-PCM ANSYS grid sensitivity test at different mesh numbers

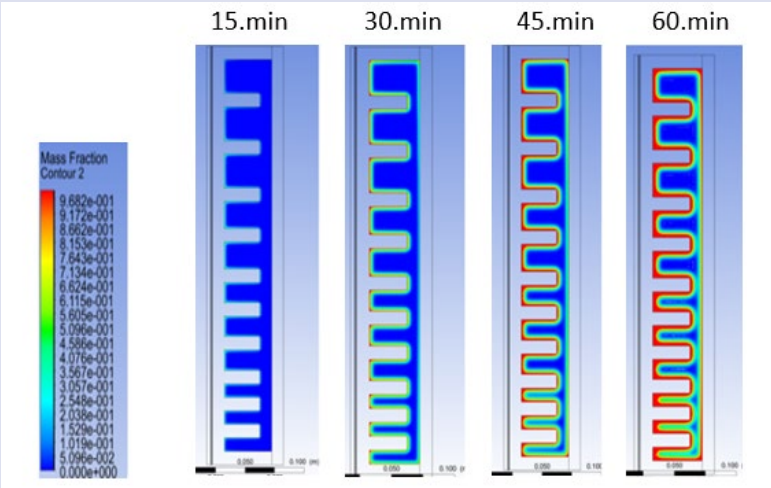

Figure 4. CFD analysis results at 15, 30, 45 and 60 minutes

The numerical analyses were repeated with different values of the initial ambient temperature and radiation amount as boundary conditions. As a result of the analyses performed with the radiation values of 600 W/m^2, 1200 W/m^2 and 1800 W/m^2 and the initial ambient temperature boundary conditions of 15 °C, 20 °C and 25 °C, the boundary conditions with the initial ambient temperature of 20 °C and the radiation value of 1200 W/m^2 were determined as the values that gave the closest results to the experimental study results. According to the analyses performed with different combinations, it was determined that the effect of the change in the radiation amount on the PV Panel surface temperature was greater than the change in the initial ambient temperature.

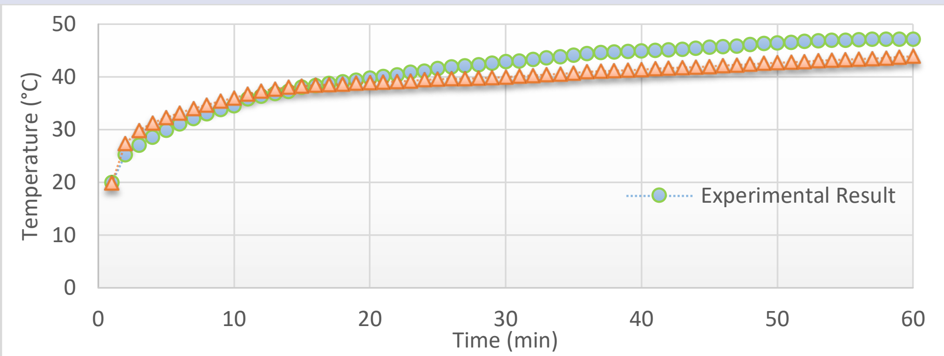

Figure 5. Comparison of experimental and CFD analysis of PV panel surface temperatures

Conclusion

2-dimension CFD analysis A PV-PCM model was created in ANSYS Fluent 18.2 to be compared with the 1-hour experimental study carried out in laboratory conditions. Mesh independence tests were performed and the model with 20000 mesh numbers was found to be sufficient. While temperature of PV panels' average surface was calculated as 39.18 °C with numerical analysis, this value was found to be 40.92 °C in the laboratory environment experimental results. The difference between the study results was calculated as 4.25%. In addition, the analyzes were repeated with different combinations of radiation and initial ambient temperature values, and the values closest to the experimental data were reached with 20 °C initial ambient temperature and 1200 W/m^2 radiation values. In future studies, the effect of the phase change material on the melting solidification process can be investigated by using different structures of the fin geometry.

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