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The mathematical modeling of concentrated photovoltaic module temperature

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ABSTRACT

In this study, we examined the effect of the use of paraffin wax on the panel temperature of concentrated solar panels. Some tests were performed on various days for three months (including spring, summer, and winter months). With the help of the experimental results, new approaches have been made as concentrator ratio, area ratio, concentrator efficiency and power coefficient. As a result of this approaches the concentrator ratio was found to be 3. When the concentrator ratio was 3, the panel temperature of the system with paraffin was found to be between 80 and 100 °C, while that of the other system was found to be above 100 °C. Panel efficiency might be reduced down to 10% at these temperatures. The study also included the development of a mathematical model of the changes in the panel temperature of the concentrated systems in which paraffin was not used. The temperature at the back of the panels could be calculated by this mathematical model, depending on the ambient temperature and the concentrated solar radiation. The correlation coefficient of the mathematical model was found to be 0.929. The test results of two days, which were not included in the model, were used to determine the reliability of the model, and the panel temperatures were calculated using the correlation coefficients of 0.933 and 0.966.

Introduction

Energy prices have increased around the world due to the gradual decrease in the fossil-based energy resources. Besides, we know that fossil fuels are harmful to the environment. Therefore, countries have changed their energy policies to include renewable energy resources to the extent possible. Among the renewable energy resources, the sun stands out as a limitless source of energy. The number of hot-water and power-generating facilities supported by solar energy is increasing with time. Photovoltaic (PV) systems currently are the most preferred solar energy systems because they are compact and easy to use. However, these systems are subject to inefficient operating conditions during applications with high solar radiation and high ambient temperatures. Du et al. reported that the efficiency of crystal silicon cells was reduced by 0.45%/°C at different temperatures [1]. There have been many studies in which the panel efficiencies of PV/Thermal systems were increased by using active and passive cooling systems [2]. In the studies of active cooling systems, the temperature at the back of the panels was used to heat a fluid so that the heat could be used. In studies of passive cooling systems, the most common application has been to reduce the temperature at the back of the panels by using phase-changing materials. Our literature review of the studies of

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active and passive cooling systems showed that Ceylan et al. used a spiral heat exchanger at the back of the PV panel to reduce the temperature at the back of the panel. They also used the hot water obtained from the heat exchanger for feeding a solar collector, thus producing domestic hot water [3]. A study conducted by Zhongzhu Qiu et al. examined a PV/T system in which paraffin was used as a phase-changing material. As the theoretical part of their study [4], they developed a new mathematical model and a computer program based on the Hottel-Whillier assumption. With this program, they were able to predict the energy performance of the PV/T module system at an accuracy that was within 0.3–0.4% of the performance of a validated model. They reported that laminar flow was not the optimal flow state in terms of the energy efficiency of the PV/T module; instead, turbulent flow was the desired flow state because it had the potential to enhance the panel efficiency. Ceylan et al. [5] designed a spherical structure out of broken solar cells, used a phase changing material, and used the energy obtained from the solar panel in a drying application. Machniewicz et al.'s study [6], in which they sought to stabilize the temperature on the surface of the panel, indicated that the efficiency of the PV panels decreased by 0.5%/K, depending on the temperature. Their aim was to determine the transition temperature of the PCM (Phase Changing Material) layer by avoiding rapid temperature fluctuations on the PV back surface. They modelled the thermal and electrical performance of PV/PCM panels by using ESP-r software. Based on the results they obtained, the efficiency was found to have increased when the PCM transition temperature was about 20 °C. The study by Ciulla et al. [7] aimed to reduce the peak temperatures of PV systems by using phase-changing materials, and they developed a numerical model to describe the behavior of PV-PCM systems and compared their findings with the actual data. Maiti et al. [8] aimed to regulate the module temperature of a PV system. In their study, they added metal turnings to increase the low thermal conductivity of the paraffin wax, and they used a 0.06-m thick metal-wax composition and were able to maintain the module temperature in the indoor experiment, which rose beyond 90 °C within 15 min in the absence of the metal-wax composition, at 65–68 °C for 3 h. The module temperature ranged between 62 and 78 °C when a V-trough concentrator was included in the system. Another way to increase the efficiency of today's PV systems is to increase the amount of solar radiation on the panels using a concentrator, and there are many such studies in the literature. Shanks et al. [9] pointed out different types of concentrated PV systems, their design advantages and limitations, and noticeable trends. Al-Nimr and Dahdolan [10] built a system with a parabolic concentrator and used the thermal energy rejected by the PV cell to distill salt water. Radwan et al. [11] developed a new cooling system using a microchannel heat sink with nanofluids for low concentrated PV/T systems. They used aluminum oxide (Al_2O_3)–water and silicon carbide (SiC)–water nanofluids with different volume fractions and examined the cooling performance of the system. Sharma et al. [12] conducted an experimental analysis of the use of a phase-changing material to increase the performance enhancement of a building-integrated, concentrated photovoltaic system. They proposed a new analytic model and performed in-house, controlled experiments using paraffin wax-based RT42. During the indoor experiments, they used a highly-collimated, continuous light source at 1000 W/m^2. They obtained a 7.7% increase in relative electrical efficiency by incorporating PCM,

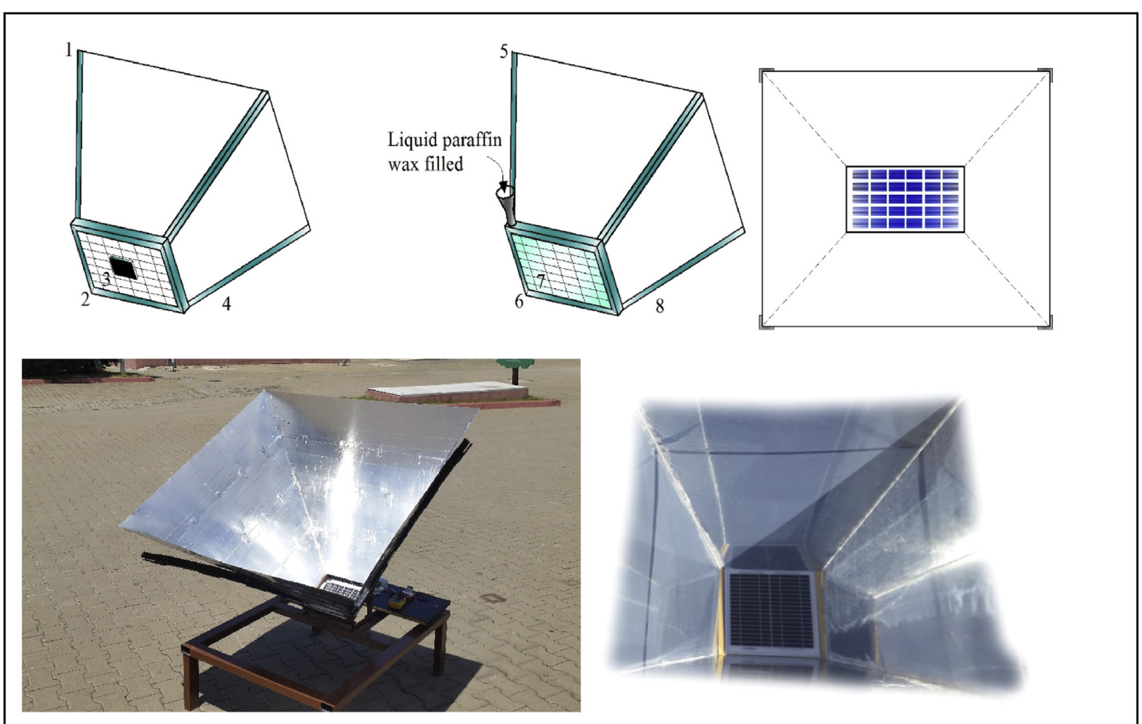

Fig. 1 – The system designed and manufactured within the scope of this study.