EUROPEAN MECHANICAL SCIENCE
e-ISSN: 2587-1110

Research Paper

An Experimental Study on the Effect of Fluid Temperature on the Performance of a PV-T Collector

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Abstract

Nowadays, heat energy and the photovoltaic (PV) principle are widely used for generating electric power. PV panels can convert a limited portion of the solar radiation falling on them into electric power. Photovoltaic-thermal (PV-T) systems are used in order to remove and evaluate the heat load caused by the solar radiation. In this study, an experimental setup was developed to compare PV and PV-T collectors. Through the experimental study, not only the collectors were compared but also the effect of the circulating water temperature on PV-T collector was investigated. The working fluid used in the PV-T collector was water. The results obtained from the experiments have shown that the electrical and thermal efficiency of PV-T collector is higher than that of the PV collector under the climatic conditions in Adana, Turkey, and that solar radiation has a significant impact on the performance of the collectors, and that the decrease in water temperature used in the PV-T collector has increased the electrical generation capacity, electrical energy efficiency as well as total efficiency.

Key Words: Photovoltaic, Photovoltaic-Thermal, Fluid Temperature, Experimental

1. INTRODUCTION

Energy, which is one of the most important sources necessary for the survival of human beings, is defined as the capacity to do work. It is one of the cornerstones of economic and social development as a necessary input for production processes and as a service tool for increasing the welfare of societies. Especially for countries that are dependent on imported sources as a result of having limited sources of energy and insufficient foreign currency revenues, energy planning is regarded as a useful and compulsory means since this is an era when conventional sources of energy tend to be exhausted, energy prices are expected to increase and environmental problems arising from energy use are growing, though, energy is a necessary input for economic development and modern life. Energy emerges in different forms such as heat energy, light (radiant energy), mechanical energy, electrical energy, chemical energy and nuclear energy. Energy sources can be classified under two groups as renewable and non-renewable. Renewable energy is presumed as inexhaustible energy that can be used continuously and repeatedly [1].

Most of the energy needed today is derived from fossil and nuclear fuels. Both the damages these fuels cause to the environment and the limited accumulation have led to the search for alternative sources of energy. In other words, it has become crucial to develop and use alternative sources of energy in order to protect the environment and prevent future threats to human life and to environmental balances. Thus, research and development studies on alternative sources of energy such as solar, wind, geothermal, biomass, and hydrogen have been intensified depending on the need to meet energy. The most important source of energy for earth is the Sun [2].

Solar panels (collectors) called photovoltaic (PV) are used to generate electrical energy directly from sunlight. Photovoltaics, consisting of semiconductor plates, are based on the principle of generating electrical current via a process in which, through electromagnetic waves in sunlight, electrons travel from one layer of the semiconductor plate to another [3]. During the generation of electricity from solar energy, surface temperatures of solar panels increase, which affects solar panel efficiency negatively. In order to decrease the surface temperature of the PV panels, liquid or gas fluid is circulated along the lower surface of the panel at a lower temperature than the panel surface temperature. In this way, the surface temperature of the panel is lowered, while the fluid is heated simultaneously to obtain heat energy.

These systems, which obtain electrical and heat energy simultaneously from solar energy, are called Photovolta-

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European Mechanical Science, December 2019; 3(4): 153-158
doi: https://doi.org/10.26701/ems.619874
Received: September 13, 2019
Accepted: September 24, 2019

ic-Thermal (PV-T) systems (collector). There are many experimental and theoretical studies on PV and PV-T systems in the literature [4-7]. Al-Waeli et al. [8] conducted literature research on various aspects of PV-T systems. They examined PV-T systems both in electrical and thermal respects. In this study, various system applications such as analysis of solar thermal systems, air, water, air / water, phase change materials (PCM) and nanofluid systems have been summarized and the importance of focusing on thermal rather than electrical power has been mentioned in the light of many attempts to develop PV-T system. In a study by Huang and Huang [9], the authors made the simulation model of the PV-T collector through the TRNSYS program. The simulation model was reported to provide temporary and long-term evaluation to estimate system performance under different weather conditions. The researchers evaluated the PV-T collector with a capacity of 1.44 kW in different regions in Taiwan and concluded that the electrical and thermal efficiency of the system was 11.7-12.4% and 26.78-28.41%, respectively. Ooshaksaraei et al. [10] conducted an experimental study to evaluate the PV-T air collector in terms of the first and second law of thermodynamics. They designed four different air-based photovoltaic thermal panels, namely unidirectional flow, bidirectional parallel flow, bidirectional counter flow and bidirectional return flow according to the PV cell requirements. As a result, in comparison to the other three models in terms of energy efficiency, the best efficiency was in the bidirectional parallel flow PV-T collector at 57-61%. On the other hand, they showed that it could be preferred in terms of exergy efficiency values in the range of 4.43-10.15% in unidirectional air flow system. The authors concluded that unidirectional air flow PV-T was favourable in systems where electric power generation was in the foreground whereas bidirectional air flow PV-T collectors were preferable in systems with energy efficiency in the foreground. In his experimental study, Ömeroğlu [11] investigated the thermal and electrical performance of an air PV-T system under the solar radiation intensity of 900 W/m^2. The experimental results were compared with the analyses obtained from "Computational Fluid Dynamics (CFD)" to confirm their accuracy. The author performed experiments at different air velocities and different surface configurations. Copper fins were used as heat transfer elements. The results demonstrated how the electrical and thermal efficiency of the photovoltaic panel is improved by active cooling.

In this study, photovoltaic (PV) and photovoltaic thermal (PV-T) collectors with identical powers were compared experimentally with an experimental setup under the climatic conditions in Adana, Turkey, and the effect of circulating water temperature on PV-T collector was investigated.

2. MATERIALS AND METHOD

An experimental setup was designed to compare PV and PV-T collectors experimentally [12]. Figure 1 and Figure 2 show the actual picture and the schematic diagram of the test setup installed at the Kastamonu Integrated Wood Industry Inc. MDF Plant in Adana. As can be seen from the figures, the experimental setup consists of two panels in PowerVault series by Solimpeks at identical powers of 190 W. Water was circulated through one of the PV-T panels. In the other one, the lower insulations were removed and the liquid flow was prevented and it was turned into a PV panel. The panels are installed at an angle of 20° considering the latitude degree of Adana province. In the experimental setup, water for PV-T collector is provided from the absorption chiller and the raw water line where the water with different temperatures circulates in the plant. Separate shut-off valves are used for each line so that the lines do not interfere with each other. The water flow at the PV-T collector inlet is adjusted by the valve placed on the line [12].

In order to observe the performance of the panels and conduct a detailed energy analysis, the measurements were performed on the experimental setup for solar radiation, temperature, wind speed, current, voltage and flow rate. Fronuis PT1000 with ± 0.8 °C of accuracy was used for measuring the ambient temperature in the test setup, Elimko thermometer with ± 0.15°C of accuracy was used for measuring water inlet and outlet temperature, Fronius self-adhesive surface temperature sensor with ± 0.45 °C of accuracy was used for measuring panel surface temperature, Tritec solar radiation sensor with ± 5% accuracy was used to measure solar radiation, and Emerson flow meter with 0.05% accuracy was used to measure water flow. In the experimental setup, the different parameters measured were recorded every 20 minutes using the control panel in which the PLC and the data logger were located [12].

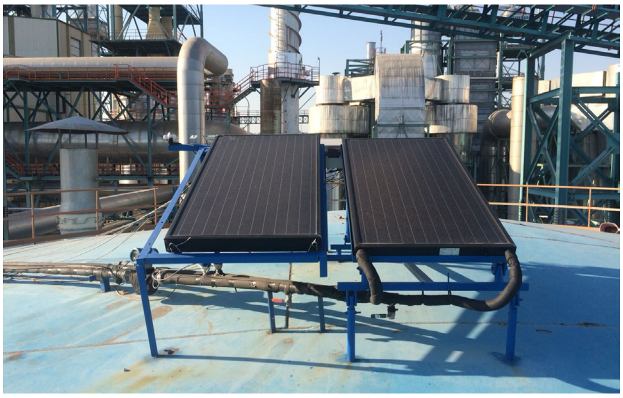

Figure 1. The Picture of the Experimental Setup [12]

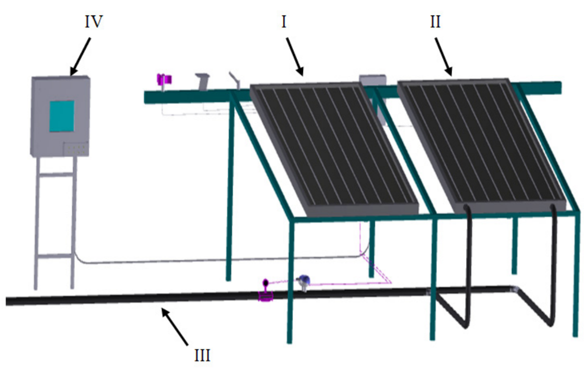

Figure 2. The Schematic Diagram of the Experimental Setup (I: PV Panel, II: PV-T Panel, III: Water Line, IV: Control Panel)

doi: https://doi.org/10.26701/ems.619874

The following equations are used to determine the performance of PV and PV-T panels.

PV panel energy balance can be expressed as follows [4,13]:

$$E_{PV} = E_{PV,e\leq c.} + E_{PV,ther.} \tag{1}$$

E_{PV} refers to the electrical and thermal power (W) of the PV panel. $E_{PV,elec.}$ refers to the electricity generation (W) of the PV panel and refers to the heat losses (W) from the PV panel. The electrical power of the PV panel is found using the following equation:

$$E_{PV,elec.} = V_{oc} I_{sc} \tag{2}$$

In Equation 2, V_{oc} shows the open circuit voltage, while I_{sc} shows the short circuit current. Heat losses from the PV system to the environment $(E_{PV,ther.})$ are given in Equation 3:

$$E_{PV,ther.} = h_{ca}.A_c.(T_c - T_a) \tag{3}$$

Here, T_c and T_a stand for cell and atmospheric temperature (K), respectively, and h_{ca} (W/m^{2}K) stands for convective and radiative heat transfer coefficient from the PV cell to the environment, and A_c stands for the panel surface area (m^2). The heat loss coefficient from the PV cell to the environment is given in the following equation, depending on the wind speed [4,13]:

$$h_{ca} = 2{,}8 + (3.0v_r)\, için\ 0 \leq v_r \leq 7ms^{-1} \tag{4}$$

Here, v_r is the wind speed measured on the PV panel. As a result, the total energy balance of the PV panel can be given as follows:

$$En_{PV} = V_{oc}I_{sc} + h_{ca}A_c(T_c - T_a) \tag{5}$$

The efficiency of a PV panel (n_{PV}) is defined as the ratio of the output energy (electrical and thermal energy) of the system to the input energy (solar radiation / energy) reaching on the PV surface (Equation 6):

$$n_{PV} = \frac{E_{PV}}{I_s A_c} = \frac{(V_{oc}I_{sc} + h_{ca}A_c(T_c - T_a)]}{I_s A_c} \tag{6}$$

The electrical efficiency of the PV panel ($n_{PV,E}$) is defined as follows [4]:

$$n_{PV,E} = \frac{E_{PV,E}}{E_s} \tag{7}$$

Here, $E_{PV,E}$ represents the total electrical energy (W) generated by the PV system throughout the day, and represents the solar radiation energy (W) that comes to the surface of the panel during the day [4].

PV-T panel energy balance can be expressed as follows:

$$Q_{u,PV-T} = Q_T - Q_L \tag{8}$$

$$Q_{u,PV-T} = A_c F_R[(\tau\alpha)_{eff} I_S - U_L(T_i - T_a)] \tag{9}$$

Here, $Q_{u,PV-T}$ stands for the total useful heat, Q_T for the absorbed solar heat, Q_L for the heat losses, F_R for the heat gain factor, $(\tau\alpha)_{eff}$ for the effective transmittance, U_L for the overall heat loss coefficient (W/m^{2}K), and T_i is the temperature of the working fluid at the panel inlet. The collector heat gain factor is given as follows [4,5,14]:

$$F_R = \frac{\dot{m}C_p}{A_c U_L}\left[1 - \exp\left(-\frac{A_c U_L F'}{\dot{m}C_p}\right)\right] \tag{10}$$

Here, F' is the panel efficiency factor and expressed as follows:

$$F' = \frac{\frac{1}{U_L}}{W\left[\frac{1}{U_L[D+(W-D)F]} + \frac{1}{Cb} + \frac{1}{\pi D h_f}\right]} \tag{11}$$

In Equation 11, W represents the space (m) between the pipes through which the heat transfer fluid passes, D is the inner diameter (m) of the pipe, F is the standard fin efficiency, C_b is the conductance of the bond between fin and pipe, and h_f is the heat transfer coefficient inside the pipes. The thermal performance of the PV-T panel depends on the water inlet and ambient temperature, the intensity of the sun rays falling on the panel and the reflector. The thermal efficiency of the PV-T panel $n_{PV-T,T})$ is calculated using the following equation:

$$n_{PV-T,T} = \frac{Q_{u,PV-T}}{I_s.A_c} = \frac{F_R[(\tau\alpha)_{eff} I_s - U_L(T_i - T^a)]}{I_s} \tag{12}$$

Daily total efficiency of the PV-T panel (n_{PV-T}) is expressed as follows similar to electrical and thermal efficiency [4,5,15]:

$$n_{PV-T} = \frac{n_{PV,E}}{n_{pow.}} + n_{PV-T,T} \tag{14}$$

Here, n_{pow} is the electrical efficiency for a power plant in operation and the value can be taken as 0.38 [16]. In this study, the collector heat loss coefficient is (U_L) 4 W/m^{2}K, the average value for F' is 0.925 [17] and the effective transmittance $(\tau\alpha_{eff})$ is taken as 0.53 [18].

3. RESULTS AND DISCUSSION

In order to compare the performance of PV and PV-T collectors and to determine the effect of fluid temperature on the performance of a PV-T collector, experiments were carried out using the experimental setup in the summer season of 2018 under the climatic conditions in Adana, Turkey. The experiments continued for an average of 11 hours between 8 a.m. - 7 p.m., when the solar radiation is effective. The study included the experiments carried out on June 28th, 2018 and July 13th, 2018 when there were similar outdoor conditions in order to see the effect of water temperature on the collectors. In this context, water at temperatures of 10°C and 26°C with 1000 kg/h flow rate was circulated through the PV-T collector on June 28th, 2018 and July 13th, 2018 so that the performance analysis of PV and PV-T collectors was carried out. Figure 3-8 show the graphs representing the changes in solar radiation, ambient air and surface temperatures, power, electrical and total efficiency over time, respectively, which were observed in the experiments conducted on June 28th, 2018 and July 13th, 2018.

Figure 3 shows that the amount of solar radiation varied between 10 and 1050 W/m^2 during the day and reached its highest value at midday hours in the experiments conducted on June 28th, 2018 and July 13th, 2018. The total daily solar radiation amounts were 8033 and 7066 W/m^2.day, respec-

doi: https://doi.org/10.26701/ems.619874

tively. Figure 4 shows the variation of air temperature with time. The air temperature varied between 29-42°C and 30-40°C during the day, respectively. Figures 3 and 4 show that the days of June 28th, 2018 and July 13th, 2018 had approximately the same climatic conditions and were assessed for comparing water temperature. Figure 5 shows that when the water was circulated at two different inlet temperatures (10°C and 26°C) at a flow rate of 1000 kg / h on June 28th, 2018 and July 13th, 2018, the surface temperatures of PV and PV-T collectors reached the highest values at midday hours. In the experiment carried out on June 28th, 2018, a difference of 5-15 °C was observed between the surface temperatures of the PV-T collector and PV collector during the day, while the difference was found to be 10-21°C in the experiment carried out on July 13th, 2018. The difference between PV and PV-T surface temperatures increased with decreasing water inlet temperature.

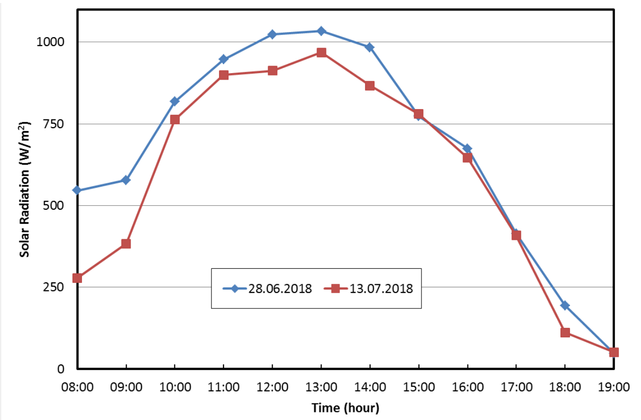

Figure 3. Variation of solar radiation with time in the experiments carried out on June 28th, 2018 and July 13th, 2018

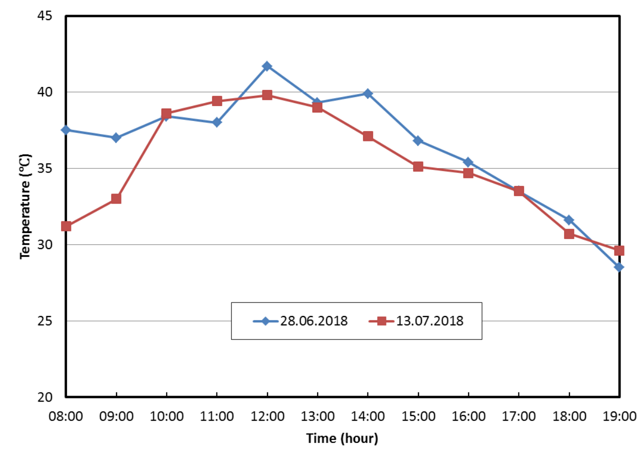

Figure 4. Variation of ambient temperature with time in the experiments carried out on June 28th, 2018 and July 13th, 2018

Figure 6 shows the change of electricity generation of PV and PV-T collectors over time. It is seen from the figure that the power generated by PV and PV-T collectors on June 28th, 2018 and July 13th, 2018 changed during the day depending on the solar radiation, and reached its highest value at midday hours. In the experiment carried out on June 28th, 2018, the electricity generated in PV and PV-T collectors was in the range of 0-127 W and 0-137 W respectively, while in the experiment conducted on July 13th, 2018, it was in the range of 0-130 W and 0-140 W. Figure 6 shows that at different inlet temperatures, the PV-T collector generated more electricity if its surface temperature was adjusted to lower temperatures than that of the PV collector. As the cold water circulating in the PV-T collector decreased the surface temperature of the collector, the electrical efficiency of the PV-T collector increased (Figure 7) and thus more power was generated than it was from the PV collector. In addition, in the experiment carried out on June 28th, 2018, the daily electrical power produced in the PV-T collector was 6.3% higher compared to that of PV, while in the experiment carried out at a low temperature on July 13th, 2018, this ratio was 9.67% (Figure 6). As shown in Figure 7 and Figure 8, the average daily electrical efficiency of PV and PV-T collector was 7% and 7.43%, respectively, on June 28th, 2018, while the average total efficiency was 27.26% and 57.66%, respectively. On the other hand, in the experiment carried out on July 13th, 2018, the daily average electrical efficiency of PV and PV-T collector was 6.83% and 7.63%, respectively, while the average total efficiency was 32.48% and 68.36%, respectively. These results have revealed that decreasing the surface temperature of the PV collector can increase the electricity generation capacity and electrical efficiency in line with the decrease in water temperature, and that there is an inverse ratio between the inlet water temperature and the total efficiency of the PV-T collector under the same environmental and process conditions, as expected.

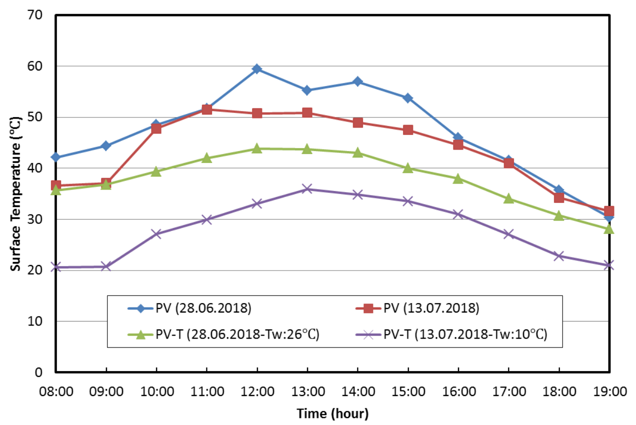

Figure 5. Variation of surface temperature with time in the experiments carried out on June 28th, 2018 and July 13th, 2018

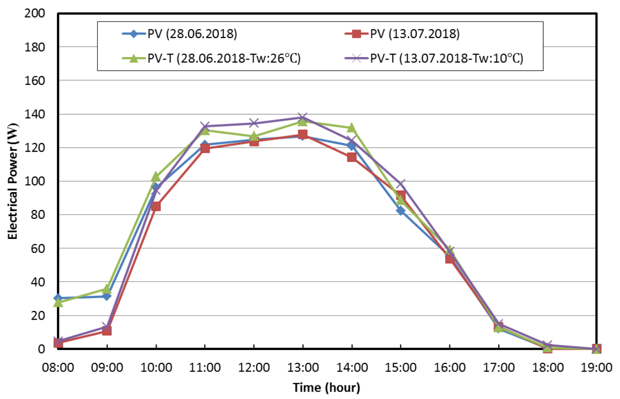

Figure 6: Variation of electrical power with time in the experiments carried out on June 28th, 2018 and July 13th, 2018

doi: https://doi.org/10.26701/ems.619874

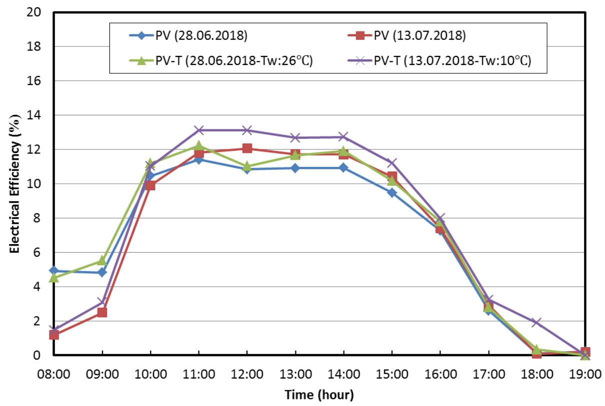

Figure 7. Variation of electrical efficiency with time in the experiments carried out on June 28th, 2018 and July 13th, 2018

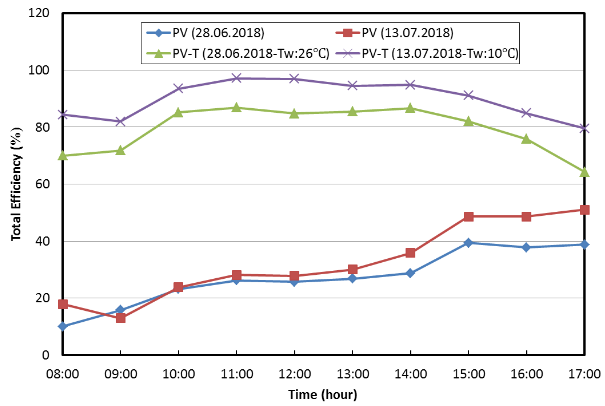

Figure 8. Variation of total efficiency with time in the experiments carried out on June 28th, 2018 and July 13th, 2018

CONCLUSION

The use of photovoltaic thermal (PV-T) collectors has become widespread in recent years in order to prevent the loss of efficiency due to the increase in panel surface temperatures while generating electricity from solar energy with the help of photovoltaic (PV) panels. In this study, a PV and PV-T collector were compared using an experimental setup, and the effect of fluid temperature on the performance of the PV-T collector was investigated. At the end of the study, it was observed that outdoor weather conditions, especially solar radiation, had a significant effect on the performance of the collectors. As the water circulating in the PV-T collector decreased the collector surface temperature, the performance parameters of the PV-T collector, such as electrical efficiency, electricity generation capacity and total efficiency were higher than those of PV collectors. It is clearly observed that the decrease in the temperature of the water used in the PV-T collector increases the electricity generation capacity, electrical and total efficiency and makes these collectors more advantageous than PV collectors. In this study, the effects of solar radiation intensity and surface temperature on PV and PV-T collectors have been examined in detail, and performance declines have been observed with the increase in cell temperature depending on the amount of solar radiation. This study has revealed the necessity of cooling the collector surface in order to increase the efficiency of PV panels, and accordingly, the importance of the use of PV-T collectors.

ACKNOWLEDGEMENT

This study was supported by Osmaniye Korkut Ata University Scientific Research Projects Unit (OKÜBAP) within the scope of the project, OKÜBAP-2017-PT3-027. We would like to thank OKÜBAP for their support. We also thank Kastamonu Integrated Wood Industry Inc. for its material and moral support in the preparation of the experimental setup used in this study.

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