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Cooling of Photovoltaic Panel Equipped with Single Circular Heat Pipe: an Experimental Study

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Abstract

The cooling process of photovoltaic (PV) panel is one the main issues in the field of solar systems. The temperature of solar cells increases when the solar radiation and also the ambient temperature increase. Increasing the cell temperature reduces the electrical output power of the panels as well as their lifetime. In order to solve this problem, various methods have been provided for cooling the panels. One of these methods is the application of heat pipes. In this research work, a PV panel equipped with thermosyphon heat pipe is introduced. The thermosyphon is connected to the back sheet of the panel in order to enhance the cooling effect of the PV system. Instead of using the polyvinyl fluoride polymer, unlike the conventional panels, an aluminum plate is used to connect the heat pipe to the back of the panel to have a better cooling. In addition, in order to increase the heat transfer area between heat pipe and the back surface of the panel, a special groove is drilled on the aluminum plate. Three different filling ratios (25%, 45%, and 65%) of distilled water, as the working fluid, are used in thermosyphon. The best performance of the systems is obtained at 45% of filling ratio, in which the electrical power of the PV panel equipped with heat pipe is around 3.2% better than the conventional PV panel. In this case, a 6.8 ˚C temperature difference is observed in the water tank connected to the condenser section of heat pipe, which means that 54 kJ heat is transferred to the water in the tank.

Keywords: *Photovoltaic panel, Cooling, Heat pipe, Thermal analysis, Electrical performance.*

1. Introduction

Heat pipes are known as one of the most efficient passive heat transfer technologies. They have a very high thermal conductivity that allows heat transfer along its hot and cold parts. In general, **the** heat pipes are able to transfer large amounts of heat over relatively long distances without moving parts using **the** phase change processes. There are different types of heat pipes such as two-phase closed thermosyphon pipe, loop heat pipe, rotating heat pipes, oscillating or pulsating heat pipes. They can be used for cooling in electronic devices, solar systems**,** and air conditioning systems. Among them**,** two-phase closed thermosyphon or wickless heat pipe is the most widely used **that** works base**d** on gravity.

The application of heat pipe in the solar systems to improve the thermal and electrical performance of solar systems have been investigated by several researchers. Hussein et al. [1] have experimentally studied the effects of the cross-section and filling ratio on a panel equipped with heat pipe. They compared three different cross sections of heat pipe including circular, elliptic, and half-pipe at three different filling ratios of 10%, 20%, and 35%. Rittidech et al. [2] have presented a new design for the conventional heat pipe in flat plate solar collectors. They have proposed a closed oscillating heat pipe charged with R134a. The efficiency of the system was reported to be around 62% in their experiments. One of the influential factors in the heat pipe performance is the type of the working fluid.

Essen et al. [3] have experimentally evaluated the effect of working media on the performance of a flat plate solar collector system. They compared three environmentally friendly fluids: R134a, R407C, and R410A. Among them, R410A showed the best electrical performance. Hussein [4] has studied the effect of wickless heat pipe in a flat plate solar collector theoretically and experimentally in Egypt. According to their results, the optimal number of heat pipes in a flat plate collector was 12. Chougule et al. [5] have handled a set of experimental studies in order to assess the influence of carbon nanotubes (CNTs) in different concentrations on the performance of heat pipes. At 0.6 vol.% of CNTs in distilled water, the best performance of heat pipe was obtained. Zhang et al. [6] have presented a theoretical model for PV panel equipped with heat pipe. The model was able to predict the experimental results well with an average error of 16%. The effects of various parameters including the water flow rate, cell coverage factor, and distance between the heat pipes and also different adsorbent coatings on the polymer plate of panel have been evaluated by Zhang et al. [7]. Moradgholi et al. [8] have used thermosyphon heat pipes to cool the solar panel. 30° and 40° were chosen as the inclination angle of heat pipes. Methanol and acetone were used as the working fluid, and the experiments were done in the spring and summer. The 16.35% and 45.14% thermal efficiency in the spring and summer was reported by them, respectively.

It is worth mentioning that one of the key parameters in the cooling process of panels equipped with heat pipes is the tank volume located in the condenser section. Zhang *et al*. [9] have compared the three different tank volumes of 30 L, 50 L, and 80 L for their system. Among them, the water tank with a capacity of 80 L showed the best performance. In this case, the maximum efficiency of the system was about 67.50%. Hu *et al*. [10] have considered two different types of heat pipes, one with wicks and another with wire meshed. They observed that the performance of the heat pipe with wick was more sensitive than wire meshed on low slopes. Hou *et al*. [11] have developed a cooling method for PV, in which a micro-heat pipe array is connected to the back of the panel. The electrical efficiency of their designed system was about 13%, while the thermal efficiency of the system was around 40% and 20% in the summer and winter, respectively. Habeeb *et al*. [12] have designed and compared two different PV systems including a conventional panel and a PV equipped with four thermosyphon heat pipes. The heat pipes charged with distilled water as the working fluid, the filling ratio was set on 55%, and a volume of tank was about 16.2 L. They found that the PV panel with heat pipes cooled the PV around 15-35% better than the conventional one, and also the electrical efficiency was about 14-11% better. Moradgholi *et al*. [13] have employed the Al_2O_3/methanol nanofluid in (1, 1.5, and 2 wt.% concentrations) in heat pipes with four different filling ratios varied 30-60%, to enhance the cooling of the PV systems.

The optimal performance of cooling was observed for 50% filling ratio and 1.5 wt.% of nanofluid. The electrical power and surface temperature of PV equipped with heat pipes were 1.42 W more and 14.52 °C cooler than the conventional PV at the optimal conditions.

Engin *et al*. [14] have experimentally investigated the cooling effect of PV using thermosyphon heat pipe. Water and ethanol were compared as the working fluid. According to the test results, the highest power values of 10.49 W, 10.56 W**,** and 10.56 W were obtained for simple panel, PV with water heat pipe**,** and PV with ethanol heat pipe, respectively. In a theoretical review, Tawfiq Ibrahim *et al*. [15] have evaluated a cooled photovoltaic panel using a thermosyphon heat pipe using acetone as the working medi**um**. According to their simulation results, the average electrical, thermal**,** and overall efficiency were 12.52**%**, 43.75**%,** and 56.27%. The thermal and electrical efficiencies were 21.9% and 14.2%, respectively**,** better than **the** conventional water-based PVT systems**.**

Al Hasnawi *et al*. [16] have experimentally assessed the effect of two modes, with and without heat pipe technique, on the electrical output of the photovoltaic panel. The application **of** heat pipe was able to increase the power generation of the PV panel by about 7.8% and the efficiency by about 3.3%. Zhang *et al*. [17] have evaluated the effect of inclination angle on the thermal performance of PVT equipped with heat pipe, theoretically and experimentally. The optimal inclination angle was obtained to be 40 degrees in their study.

In the current work, the application of thermosyphon to enhance the cooling ability of PV is investigated. In addition, a new designed of cooling section is presented by application of aluminum plate as the back plate instead of using the conventional polyvinyl fluoride polymer. In order to have a better comparison, the cooling performance of the conventional panel and also panel equipped with thermosyphon, in the same weather conditions are investigated.

2. System Description

In this experimental work, two similar solar panels with the dimensions of 110 × 1200 mm were used. Aluminum sheets were considered to maintain and install the panel on the structure. The net surface area that was directly exposed to the solar radiation was 90 × 1200 mm. The panels were made of three main parts: glass cover, solar cell, and aluminum plate. 21 series of mono-crystalline solar cells with dimensions of 78 × 56 mm were considered for the panel section, and the thickness of aluminum plate was 3.0 mm. In order to intensify the heat transfer between the thermosyphon wall and the panel, a longitudinal groove was drilled up to 1.5 mm of the aluminum plate thickness. Then the heat pipe could be easily placed inside the groove with direct contact by aluminum plate. The layout of heat pipe placed in the groove is shown in figure 1.

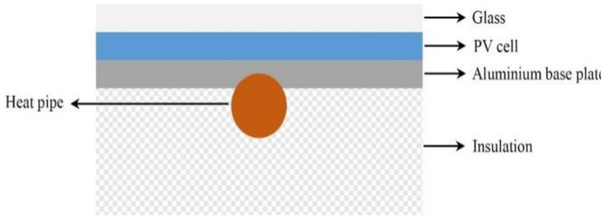

Figure 1. Schematic representation of heat pipe layout in PV system.

The aluminum plate was anodized to increase the surface roughness, and also have a better connection between the plate and the solar cells. This process improves the heat transfer rate in PV equipped with heat pipe. The specifications of the panels is tabulated in table 1.

Table 1. Operational data at STC PV test.

Parameters	Values
Voltage at maximum power point (V_{mp})	11.55 V
Current at maximum power point (I_{mp})	2.4 A
Nominal power	26.5 W
Open-circuit voltage (V_{oc})	13.65 V
Short-circuit current (I_{sc})	2.65 A

The copper thermosyphon heat pipe used is this work had a circular cross-section with 10 mm diameter and 0.7 mm thickness. The total length of the pipe was 1500 mm. The length of the evaporator, adiabatic, and condenser sections of thermosyphon was 1200 mm, 50 mm, and 250 mm, respectively. Two valves were connected to the both ends of the pipe, one for the fluid injection and draining and another for the vacuum process. It should be noted that the sealing and aeration test were performed immediately after the set up construction to ensure about the proper operation of the system.

The condenser section of heat pipe was immerge in a PVC tank with an outer diameter of 110 mm and a thickness of 32 mm. The length of the water tank was set to be equal to the length of the condenser section, 250 mm. For a better contact between the thermosyphon and the panel, silicone paste was used between the pipe and the aluminum surface. In order to minimize the heat loss to the environment, 40 mm of polyethylene insulation was considered in the back of the plate. Also 30 mm thickness of the same insulation was applied around the water tank. The schematic representation of PV panel equipped with heat pipe is depicted in figure 2.

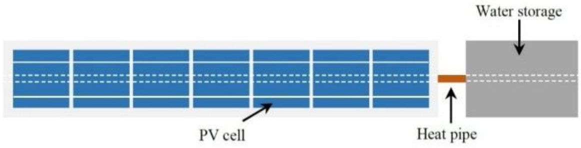

Figure 2. Schematic representation of a PV panel equipped with heat pipe.

In order to investigate the effect of heat pipe on panel cooling, a conventional panel with the same dimensions was considered next to the PV equipped with heat pipe. Both types of constructed PVs were evaluated simultaneously for a better comparison. In figure 3, a photo of conventional PV and PV equipped with heat pipe and their layout on the system are shown.

Figure 3. Pphoto of conventional PV and PV equipped with heat pipe and their layout on system.

All experiments were done in the Shahrood city, Iran. The thermosyphon was evacuated well by a vacuum pump, and then the distilled water as the working fluid was injected into the pipe. Also the PVC tank was filled with 1.9 L of water. In order to measure the solar radiation, a pyranometer with an accuracy of 0.1% was used. The pyranometer was placed on the test structure in line with the solar panel. In addition, in order to measure the wind speed, a wind speed sensor with an accuracy of 2.0% was employed. A digital thermometer model TA-288 with an accuracy of 0.1 °C was used to measure the ambient temperature and water temperature in the tank. Also the amount of voltage and current of the panel was measured and recorded by a digital multimeter.

3. Result and discussion

Three different filling ratios (volume of fluid to volume of the evaporator section) including 25%, 45%, and 65% of distilled water were investigated in this work. Each experiment was performed for a period of 120 minutes. During this time period, the solar radiation varied between 900 W/m^2 and 1000 W/m^2. The temperature difference of the tank water with respect to the initial temperature for different filling ratios of the working fluid in thermosyphon heat pipe is shown in figure 4. The average ambient temperature measured in these experiments were 23 ˚C, 25 ˚C, and 26 ˚C, and the average wind speeds were 1.45 m/s, 2 m/s, and 1.97 m/s, for 25%, 45%, and 65% of filling ratios, respectively. As it could be seen in figure 4, the temperature differences were 6.8 ˚C and 6.4 ˚C for 25% and

45% of filling ratio, respectively. It means that the ability of PV for heat transfer in the case of 25% and 45% filling ratios is similar. However, for the filling ratio of 65%, compared to the other filling ratios, a smaller temperature difference, which was equal to 5 ˚C was observed. From this figure, it can be concluded that the best performance of the system in terms of temperature differences of tank water is observed for the filling ratio of 45%.

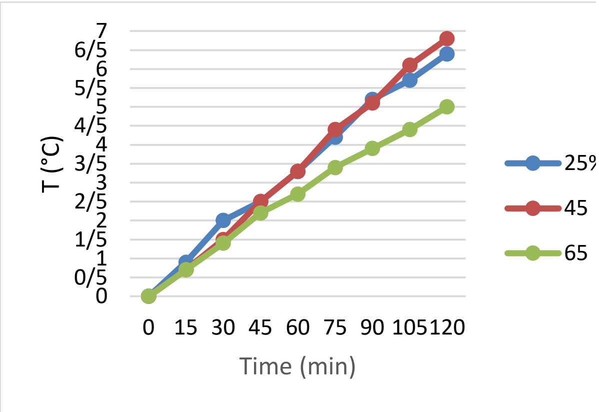

Figure 4. Temperature change of tank water during a period of 120 min with respect to initial temperature for different filling ratios of working fluid.

According to the values of temperature difference obtained from the mentioned experiments, the amount of heat transferred to the water in the tank can be calculated by multiplying the mass and specific heat capacity of water into its temperature differences. As presented in figure 5, the best thermal performance is allocated to the 45% of filling ratio, which is equal to around 54.07 kJ, while 50.85 kJ and 39.7 kJ for 25% and 65% of filling ratio is obtained, respectively. It means that 5.9% and 27.7% decrease in the thermal performance of PV equipped with heat pipe system are observed when 25% and 65% filling ratios are applied, instead of 45% of filling ratio, respectively.

In order to evaluate the ability of PV panel equipped with heat pipe, the output electrical power of both equipped panel and conventional PV for 25% of filing ratio are depicted in figure 6. Since the test panel was not initially at stable electrical conditions, the first 30 min of each experiment was considered for stabilization, and the values of this period were not taken into account in the calculation.

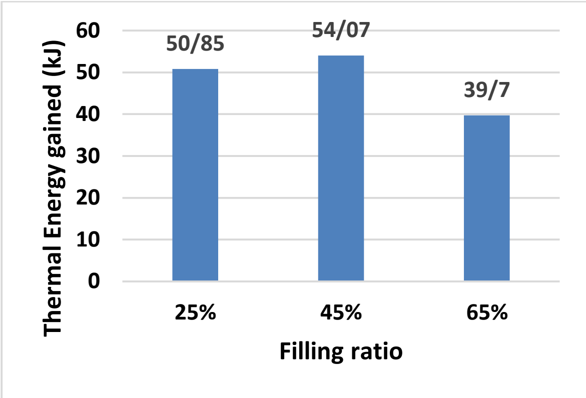

Figure 5. Heat transferred to tank water.

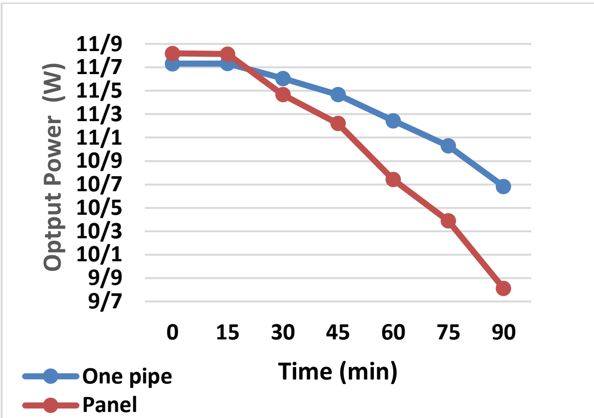

Figure 6. Changes in electrical power for equipped panel with 25% of filling ratio and the conventional one.

The conventional panel was installed without insulation, and the effect of natural convection is important. Thus for the first 15 min, the output electrical power of conventional panel is slightly higher than the equipped one. However, when time passes and cell temperature increases, the output power of conventional panel is decreased and the equipped panel with heat pipe shows a better performance due to the cooling done by the heat pipe in the system. The average electrical powers were 11.03 W and 11.35 W for the conventional panel and equipped panel, respectively, which represents 2.88% improvement in the electrical performance for the equipped panel compared to the conventional one.

The electrical output power of the panels for 45% of filling ratio can be seen in figure 7. The average electrical power of the conventional panel is around 10.94 W. However, when the system is equipped with heat pipe, 11.29 W electrical power is obtained, which shows 3.22% improvement compared to conventional one.

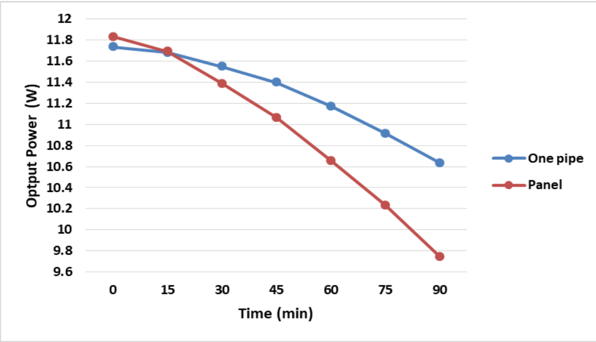

Figure 7. Changes in electrical power for equipped panel with 45% of filling ratio and the conventional one.

The similar results in the electrical power output for the filling ratio of 65% can be seen in figure 8. The average amount of electrical power of the conventional panel is 10.55 W and for the cooled panel with heat pipe is around 10.89 W. 3.17% enhancement in the electrical performance is observed by application of heat pipe in PV. By comparison of the results depicted in figures 6-8, it can be easily seen that the cooled panel at the 45% filling ratio shows the best electrical performance among the others filling ratios.

It should be noted that before performing the main tests, the two panels were inspected under the same conditions, without cooling. A similar electrical performance was observed in both cases. However, as described in figures 6-8, the positive effect of application of thermosyphon heat pipe on the electrical performance of the system compared to the conventional panel is easily observable.

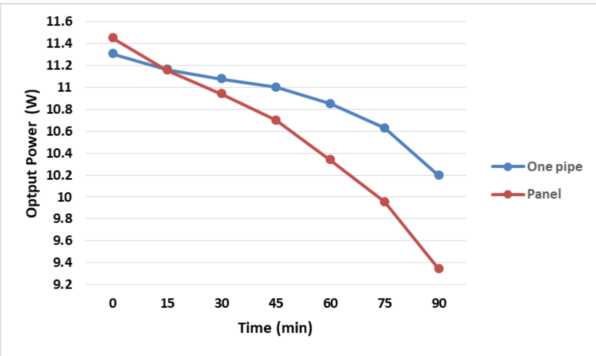

Figure 8. Changes in electrical power for equipped panel with 65% of filling ratio and the conventional one.

Since the best thermal and electrical performance was achieved for 45% of filling ratio, a daily basis experiment was done in the period of 8:00 to 18:00 on July. The inclination angle was set to be 20° relative to the horizon level, and the average wind velocity was 5.6 m/s. The changes of the solar radiation and also the ambient temperature are shown in figures 9 and 10, respectively. The maximum solar radiation was observed at 13:00 and the maximum ambient temperature was about 35.4 °C.

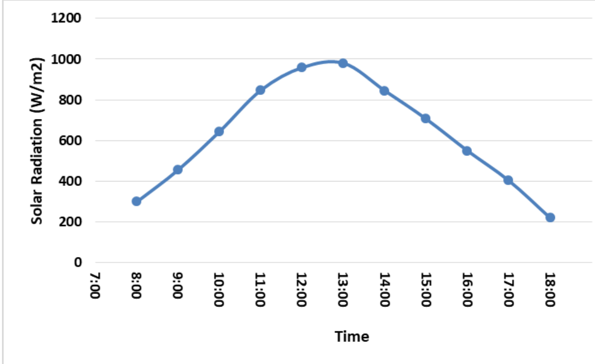

Figure 9. Daily solar radiation changes.

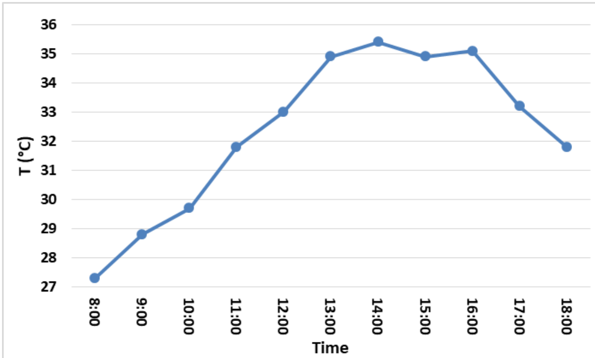

Figure 10. Daily ambient temperature changes.

As shown in figure 11, the initial temperature of the tank water is 27.8 °C, and at the end of the experiments it reaches 38.8 °C . Thus the 11 °C temperature difference was obtained during the test. Although the trend of temperature changes in most of the time intervals is increasing, at the end of the experiment, due to the decrease in the ambient temperature and also heat transfer with the environment, is decreased slightly. 82.71 kJ of heat transfer was obtained during this specific daily test.

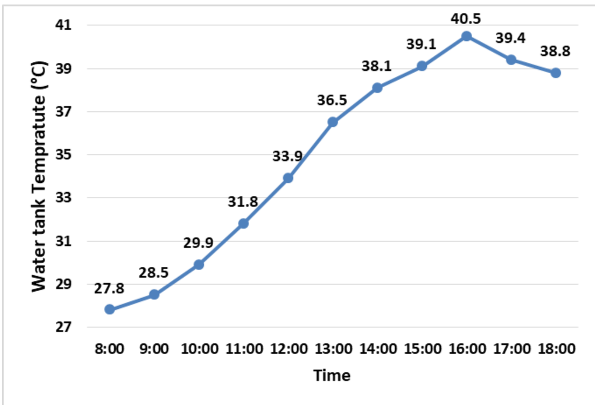

Figure 11. Daily storage water temperature changes for 45% filling ratio.

The output electrical power in the daily test for both the conventional and equipped panels is drawn in figure 12. It is observed that until 13:00, the electrical output power of the conventional panel is higher than the cooled panel. However, after passing this initial time period, the effect of cooling by heat pipe is dominant and shows its ability, Thus the better performance of the cooling panel than the conventional one is observed. By increasing the solar radiation, the temperature of the conventional panel cell is increased too, while in the equipped panel, the cooling of the system by heat pipe occurs, and as a result, the cell temperature decreases compared to the conventional panel.

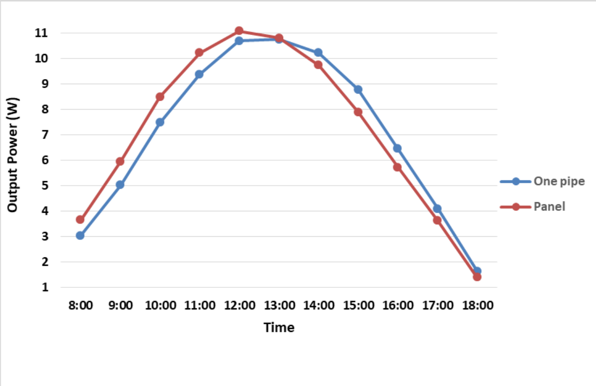

Figure 12. Changes in electrical output power versus time for both conventional and equipped panel at filling ratio of 45%.

It worth mentioning that in this research work, the impact of heat pipes with different cross-sections such as square or triangle was not evaluated. Thus the effect of cooling thermosyphon tubes with different cross-sections on the performance of photovoltaic panels can be investigated in the future to give a better view of the cooling performance in PVs. There is also a need for more economic evaluation in this area.

5. Conclusion

In this work, the photovoltaic panel equipped with a thermosyphon heat pipe was designed and fabricated. The thermal and electrical performance of equipped panel was experimentally compared with the conventional one. In order to have a better contact between the thermosyphon wall and the panel, a longitudinal groove was applied on the panel, which increased the heat transfer between the back sheet of panel and the pipe. A summary of the results obtained can be stated as follows:

1. Three different filling ratios including 25%, 45%, and 65% of distilled water were investigated as the working fluid. The temperature difference values of tank water were 6.4 ˚C, 6.8 ˚C, and 5 ˚C, respectively, which confirmed that the best performance was observed for 45% of filling ratio.
2. The amount of heat transfer between the panel and the water inside the tank was equal to 50.85, 54 kJ and 39.7 kJ for 25%, 45%, and 65% of filling ratios, respectively.
3. Up to 3.22% enhancement in the electrical output power was obtained when the PV panel equipped with heat pipe was used instead of the conventional panel.
4. 11 ℃ temperature change and 82.71 kJ of heat transfer rate could be gained during the daily test for 45% of filling ratio.

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