Testing the Energy Efficiency of a New Type of Photothermal Device in Dry Climate Conditions

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Abstract: The results obtained on the photoelectric battery (PVB) and photothermal battery (PTB) based on a new type of autonomous moving cooling system photothermal devices (PTD) are presented in this research work. This new type of device (PTD) is self-cooling and has the ability to provide hot water for the village residents while increasing the efficiency of the PTB. There was created a new experimental copy of the device with a power of 300 W based on the design of the PTD with a new type of cooling system with a power of 60 W mentioned in previous scientific research. It consists of a 180 W PVB, a 60A·h battery, a 2kW inverter, a 50A controller, a radiator for cooling hot water, 5 cooling fans, a pump, and a cart-shaped structure for their installation. It is possible to get results in two different situations in the experimental copy with a new type of cooling system. It is possible to increase the efficiency of PTD by fully using the cooling system, and to obtain hot water for the household without a sharp decrease in efficiency by partially using the cooling system. There is mentioned a study of hot water regimes with a temperature of 40-50 ^{0}C for the agricultural sector, depending on the intensity of solar radiation and ambient temperature. Preliminary tests showed that the power of the PTD differs from the power of the PVB by up to 70 W. This new PTD showed that it is possible to use it in many other cases, such as water supply, lighting, watching TV, listening to the radio, using a refrigerator, charging computers and phones in rural areas.

1 INTRODUCTION

It is clear to all of us that our need for electricity on a global scale is increasing day by day. If we take the last five years, the world’s electricity demand is increasing by 50% every year. This requires the increase and development of alternative energy types. If we pay attention to the information of the International Energy Agency, if the use of solar energy develops at such a pace, by 2050, it will be possible to meet 25% of the world’s electricity needs at the expense of solar energy, and it will be possible to reduce carbon dioxide gas released into the environment by 6 billion tons per year [1]. It is clear from this that it is necessary to switch to renewable energy sources. Solar energy is the most widely used renewable energy source. We use PVBs to convert solar energy into electricity. It has been noted in many works that the use of PVBs without taking into account climatic conditions greatly affects their efficiency [2]. Especially in conditions of high atmospheric temperature, the efficiency of PVB decreases rapidly [3]. To study the phenomenon of decreasing efficiency of PVBs made of silicon-based solar cells (SC), which convert solar energy into electricity, with increasing temperature, to analyze the process of PVB efficiency decreasing to 40% when the atmospheric temperature exceeds 50^0 C, and to prevent the phenomenon it is desirable to study the possibilities. Employees of the Institute of Physics and Technology have studied this phenomenon for 15-20 years, and in order to increase the efficiency of PVBs, they have been offered cooling devices using air or water. As a result, new constructions with 20-30% more efficiency than PVBs produced in foreign countries were created in hot climates [4]. There was studied the supply of low-power household consumers (TV, light-emitting diode lamps, laptop, telephone) with the help of an efficient small-power autonomous portable photothermal device for dry climate without water, the use of new types of photothermal devices in extremely dry areas with water shortages, The electricity generated by this device is used in desert areas. The new type of devices that we are looking for are created for these purposes. There was created a laboratory copy of PTD with a new type of cooling system of small capacity at the Institute of Physics and Technology, and based on the results, a new PTD was created for rural and water-scarce areas with a large capacity. The difference of this new type of PTD from other photoelectric devices is that it does not require a lot of water for cooling and operation in extremely dry climates.

2 EXPERIMENTAL DEVICE AND RESULTS

A crystalline silicon-based PVB with a power of 180 W was selected for the experimental tests. A photothermal device, based on the concrete PVB, was created. There was used cellular polycarbonate with 1.5 times the geometric dimensions (width and height) of parallel channels based on polycarbonate, as presented in [5-6], in order to ensure the maximum cooling of the rear surface of the PTB. This created conditions for increasing the rate and volume of water discharge from the collector and, as a result, reducing the temperature of the PVB [7-8]. With the help of an efficient small-power autonomous portable photothermal device for a dry climate without water, funds are saved from the economic side in providing the households of rural residents with the necessary electricity and partial hot water, and in order to do this, there is used a cart with a new type of collector photothermal battery, radiator, pump, water storage tank, controller, accumulator, inverter and their connecting structure. Table 1 shows the geometric dimensions, physical and technical parameters of 180 W PTB parts.

Table 1: Physical and technical characteristics of 180 W PTD parts.

Parameter	Parameter
Maximum power of PVB, P_{max}	150W
Open circuit voltage of PVB, U_{oc}	22.80V
The short circuit current of PVB, I_{sc}	10.34A
Filling factor of VAC of PVB, f_f	0,71-0,73
Reflection coefficient of the reflector, R	0,5
Water capacity of polycarbonate heat collector, V	10 l
Thermal conductivity of polycarbonate	0,2-3,9W/m·ºC
Cooling radiator, dimensions (cm)	35÷45cm
Fan, power (W)	3.6W
Water storage tank, volume (V)	20 l
Water pump, power (W)	5W
Cart, dimensions (cm)	Width 80 cm, length 100 cm, height 70 cm
Water circulation hose, dimensions (cm)	Diameter 1 cm, length 300 cm
Maximum power of PVB, P_{max}	150W

Figures 1 and 2 show a view of a new type of photothermal device that enables efficient operation in dry climate conditions made by scientists of the Institute of Physics and Technology.

Figure 1: A preview of a new type of PTD.

Figure 2: Rear view of the new type of PTD.

The parts that make up the cooling system of the new type of PTD perform the following tasks:

- - a new type of heat collector ensures reduction of energy losses of the photothermal battery.
- - the fan is installed on top of the radiator and serves to increase the efficiency of the radiator with the help of wind.
- - the pump passes the heated water in the new type of collector through the radiator and ensures that it enters the collector again.
- - the water tank serves to store up to 20 liters of warm water and for the good operation of the pump;
- - a small portable structure is used to place the radiator, fan, pump, water storage tank, controller, battery and inverter in the photothermal battery and connect them to each other by switching, and when moving them from one place to another, the mobile structure acts as a mechanical protection.

The results obtained from PTB and PVB were tested at the Heliopolygon of the Institute of Physics and Technology. The new cooling system, designed to adapt to different conditions, was tested in April and May 2024 in different modes for short-circuit voltage, short-circuit current, and device power at different values of solar radiation intensity.

The new type of PTB cooling system is based on the principle of the internal combustion engine cooling system, and cooling is provided by the circulation of water through a special radiator. In order to increase the efficiency of the radiator, heat transfer from the radiator is provided with the help of an additional fan. A cooling radiator is a device designed to cool the engine system and maintain normal temperature conditions. Such a simple, uncomplicated tool is the key to long-term and reliable operation of the engine [9-10]. Not using the fan installed on the radiator of the new type of cooling system is accepted by us as the mode when the cooling system is not fully used. If all components of the cooling system, including the fan, are used, the cooling system is considered to be fully used. The efficiency of the photovoltaic battery was studied when the cooling system was not fully used and when it was operating.

Figure 3 shows the results of comparison of operating voltages of PVB when the cooling system of the PTB is fully used.

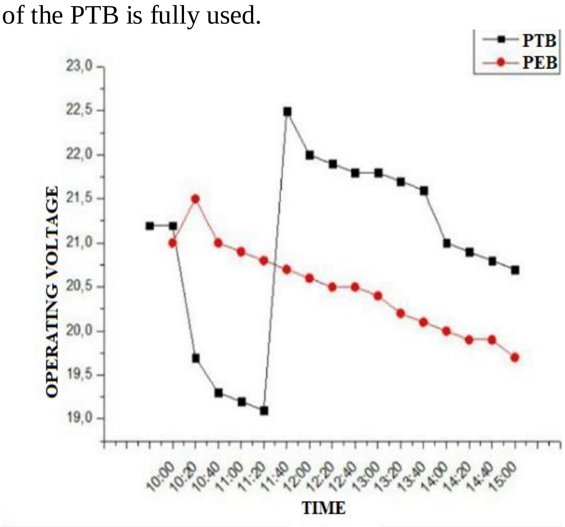

Figure 3: Time variation of the operating voltage of PVB when the cooling system of the PTB is fully used.

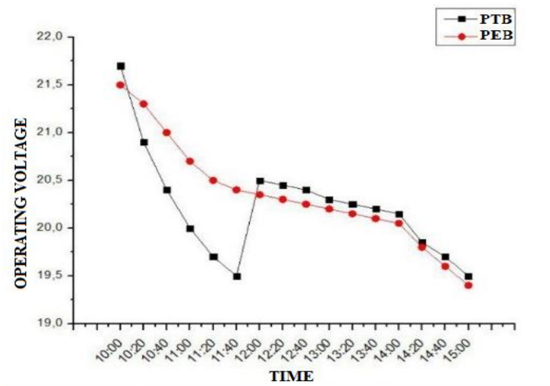

Figure 4: Time variation of the operating voltage of PVB when the cooling system of the PTB is not fully used.

Figure 3 shows the operating voltages of the PVB when the cooling system of the PTB is fully used. The black line is the value of PTB and the red line is the value of PVB. The test experiment was taken from 10:00 a.m. on April 2024 at the Heliopolygon of the Institute of Physics and Technology. Based on the graphs in Figure 3, we can see a linear decrease in voltage at PVB over time during the day. That is, the voltage of PVB has decreased over time. The main reason for this is the increase in air temperature, low wind speed (3-5 m/s), and the fact that the direction of the PTD does not correspond to the south. To overcome this loss, a heat collector based on cellular polycarbonate was installed in full thermal contact with the rear surface of the PVB (the PTB was made from the PVB) and attached to the cooling system. The results of the PTB based on this system are shown by the black line in Figure 3. Results for both PTB and PVB were taken at the same start time at 10:00 a.m. With no cooling system connected, it can be seen that the operating voltage of PTB decreases faster with time than the operating voltage of PVB. The reason for this can be explained by the fact that the heat collector is isolated from the external environment, and as a result, the temperature is maintained in a completely closed environment. As a result, at 11:20 a.m, operating voltage value of PTB decreased to 19 V, at this time, a new type of cooling system was put into operation, and at 11:40 a.m., operating voltage value of PTB increased to 22.8 V. The value of operating voltage of PVB is 20.8 V, i.e. it changes very little. Figure 4 presents the values of operating voltages of PTB and PVB when the cooling system of the new type of the PTB is not fully used. It can be seen that the graph of operating voltage of PVB is almost the same in Figures 3 and 4. When the cooling system of the new type is not fully used, the operating voltage of PTB showed higher values than the operating voltage of PVB. That is, the new type of cooling system reduces the heat accumulated in the rear part of the PTB, while reducing the operating voltage, it also allows to get hot water. Information about the hot water obtained when the new type of cooling system is fully used and when it is not fully used is presented in Figure 7.

Reflectors were installed on the sides of the new type of PTD to increase the intensity of the solar radiation current, and the short-circuit currents over time were compared with the short-circuit currents of the PVB over time.

Figures 5 and 6 show the time variation of the short-circuit current between 10:00 a.m. and 15:00, with PTB and PVB installed side by side. At 11:20 a.m., it was noted that the short-circuit current value increased from 8 A to 11 A by increasing the intensity of solar radiation by directing the reflectors to the two sides of the PTB. We can see from Figure 5 that when the natural solar radiation current intensity increases with time, the short-circuit current of PTB increases proportionally. When the sun reaches the solstice, the values of the short-circuit currents of PTB and PVB are 11.8 A and 8.2 A respectively. Figures 5 and 6 show the difference in short-circuit current values of PTB with time when the new type of cooling system is fully used and when it is not. That is, by fully using the new type of cooling system, the short-circuit current was partially increased.

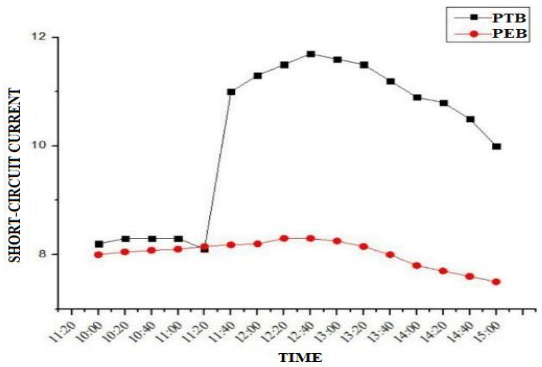

Figure 5: Time variation of short-circuit currents of PTB and PVB when the new type of cooling system is fully used.

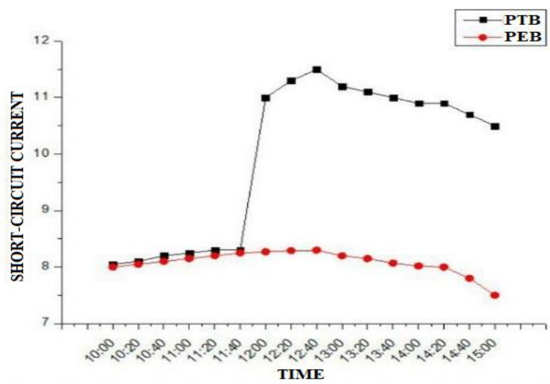

Figure 6: Time variation of short-circuit currents of PTB and PVB when the new type of cooling system is not fully used.

This new type of cooling system, along with increasing the physical parameters of PTB, allows obtaining hot water even in remote areas. PTD is equipped with a 20-liter water storage tank, and the water is collected in the storage tank by absorbing the heat accumulated in the collector mounted on the back of the PTB. This heated water cools again through the radiator and goes to the collector, and the process continues over and over again. The hot water collected in the storage tank can be used by the village residents for many purposes (laundry, washing dishes, taking a shower, etc.). Figure 7 shows the values of the change of water temperature in the storage tank over time

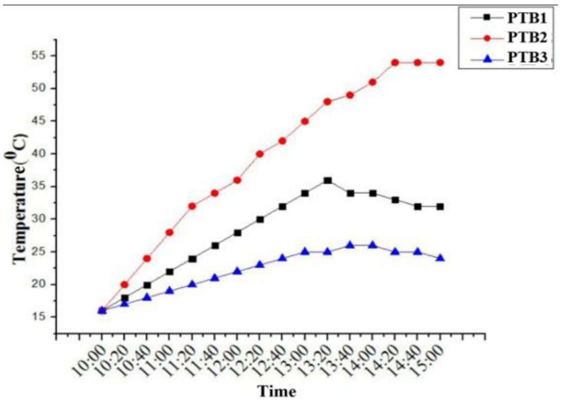

Figure 7: The values of the temperature change of hot water obtained: PTB 1 - when the new type of cooling system is fully used, PTB 2 - when the new type of cooling system is not fully used, PTB 3 - by conventional cooling.

PTB1 graph in Figure 7 shows the hot water temperature change obtained when the new type of cooling system of PTB is fully used. The temperature of the water in the water storage tank at 10:00 a.m. was 16^0 C. Gradually, as the intensity of solar radiation increases, the temperature of the water in the storage tank also rises. At 13:20, the water temperature showed its maximum value of 36^0 C. Later, the hot water temperature showed a value of 32^0 C at 15:00. The PTB2 graph also shows the values of the hot water temperature when the new type of cooling system of PTB is not fully used. At 10:00 a.m., the temperature of hot water was 16^0 C, and with the change of time, the water temperature rose to 54^0 C at 15:00. And the PTB3 graph shows the hot water temperature values obtained by conventional cooling of the PTB. The conventional method of cooling the PTB is to connect cold water to the bottom of the collector and hot water from the top of the collector. But cooling the PTB in this way brings a number of inconveniences. Firstly, it is difficult to find running water at a constant pressure in extremely dry areas. Secondly, after using the required part of the hot water from the collector, there is a problem of using the remaining part. The fact that the PTD with the new type of cooling system offered by us does not need a large amount of water for cooling, and the fact that the hot water is used as needed and the rest is not wasted, proves the efficiency of this device. But it can be seen from Figure 8 that the power of PTB cooled by conventional method is higher than the power of PTB cooled by other methods.

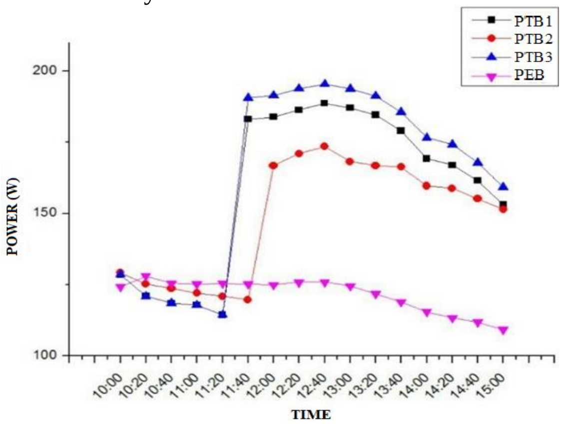

Figure 8: The values of power change over time when the new type of cooling system of PTB is fully used and is not fully used, when PTB is conventionally cooled and for PVB.

Figure 8 shows the results of power change of PVB. The natural solar radiation intensity reduced to PVB and the produced power are given. It can be seen from Figure 8 that the power values obtained in PVB showed much lower efficiency than the power values obtained in PTBs. The maximum power of PVB was 125 W. The PTB2 graph shows the power values obtained by partially using the new type of cooling system. Based on the data presented in Figure 7, it has been proven that hot water with a high temperature can be obtained with the improvement of the power of PTB compared to PVB, even with the partial use of a new type of cooling system. By partially using the new type of cooling system, it is possible to save the power required for the consumption of fans. The maximum power of PTB2 was 170 W. In Figure 8 PTB1 graph shows the results of power changes obtained when the new type of cooling system is fully used. It can be seen from the difference between the graphs PTB1 and PTB2 in Figure 8 that when the new type of cooling system is fully used the power changes have higher indicators than when the system is not fully used. The maximum power of PTB1 was 188 W.

The PTB3 graph is conventionally cooled and shows the obtained power values. The maximum power of PTB3 was 195 W. It can be seen from Figure 8 that when the PTB is cooled by continuous cold water inflow, the power values are more efficient than in all other cases. PTD with the new type of cooling system that we offer can be cooled in all three ways mentioned above. This depends on whether the PTD is installed in a very dry area or a place with a lot of water.

3 CONCLUSIONS

In this paper, it was shown that the power of PTB with a new type of cooling system is 35% to 50% more than the power of PVB. We can conclude the changes and values of other physical parameters based on the given results. By fully and partially using a new type of cooling system PTB, hot water of different temperatures was obtained. The ability to obtain hot water from 25^0 C to 55^0 C on average using the new type of cooling system was demonstrated. In the next researches, it is planned to see the possibility of developing mobile devices with sufficient capacity of PTD with a new type of cooling system to provide separately located rural facilities with electricity and partly with hot water

REFERENCES

[1] IRENA, Renewable Energy Statistics 2024, Int. Renewable Energy Agency, Abu Dhabi, 2024. ISBN: 978-92-9260-614-5. [Online]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Jul/IRENA_Renewable_Energy_Statistics_2024.pdf.

[2] M.J. Elswijk, M.J. Jong, K.J. Strootman, J.N.C. Braakman, E.T.N. De Lange, and W.F. Smith, “Photovoltaic thermal collectors in large solar thermal systems,” in Proc. 19th European PV Solar Energy Conf. and Exhibition, Paris, France, June 2004, pp. 7–11.

[3] B. Yuldoshov, E. Saitov, J. Khaliyarov, S. Toshpulatov, and F. Kholmurzayeva, “Effect of temperature on electrical parameters of photovoltaic module,” Proc. Int. Conf. Appl. Innovation IT, vol. 11, no. 1, 2023, pp. 291–295. doi:10.25673/101957.

[4] M.N. Tursunov, Kh. Sabirov, I.A. Yuldoshev, B.M. Turdiev, and I.M. Komolov, “Different constructions of photothermal batteries: comparative analysis,” Heliotechnika, no. 1, 2017, pp. 26–29.

[5] J.S. Akhatov, I.A. Yuldashev, and A. Shalimov, “Experimental investigations on PV-T collector under natural condition of Tashkent,” Energy Procedia, vol. 39, 2013, pp. 2327–2336, Proc. ISES Solar World Cong., Mexico.

[6] I.R. Jurayev, I.A. Yuldoshev, and Z.I. Jurayeva, “Experimental study of a thin-film photovoltaic thermal battery in natural conditions,” Appl. Solar Energy, vol. 59, no. 4, 2023, pp. 498–506. (CiteScore, IF=2.5).

[7] A.M. Elbreki, K. Sopian, A. Fazlizan, and A. Ibrahim, “An innovative technique of passive cooling PV module using lapping fins and planner reflector,” Case Stud. Thermal Eng., vol. 19, 2020. doi:10.1016/j.csite.2020.100607.

[8] I. Jurayev, I. Yuldoshev, and Z. Jurayeva, “Effects of temperature on the efficiency of photovoltaic modules,” Proc. Int. Conf. Appl. Innovation IT, vol. 11, no. 1, 2023, pp. 199–206. [Online]. Available: https://doi.org/10.25673/101938.

[9] I. Jurayev, I. Yuldoshev, and Z. Jurayeva, “Results of study of photovoltaic thermal battery based on thin-film module by modeling and computational methods,” Proc. Int. Conf. Appl. Innovation IT, vol. 12, no. 1, 2024, pp. 243–249. [Online]. Available: https://doi.org/10.25673/115707.

[10] I.A. Hassan, S.R. Fafraj, and A.J. Kadem, “Enhancing photoelectric conversion efficiency of photovoltaic panel using cooled water by evaporation,” Eng. Technol. J., vol. 35, part A, no. 5, 2017, pp. 525–531.