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STUDY OF THE EFFICIENCY OF PHOTOTHERMAL DEVICES OF DIFFERENT CAPACITIES WITH A NEW TYPE OF COOLING SYSTEM DESIGNED FOR DRY CLIMATES WITHOUT WATER

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Abstract. *The article studies the efficiency of photovoltaic thermal of different capacities with a new type of cooling system designed for an arid dry climate. There are presented the results obtained on a 1 kW photovoltaic thermal device. To begin with, the article presents the efficiency of photovoltaic thermal based on 60 W and 180 W photovoltaic batteries and the results obtained on a 1 kW photovoltaic thermal. Several factors should be taken into account when using renewable energy sources in extremely dry regions of our republic including extremely high temperatures. At such high temperatures (40℃ and above in the shade) the efficiency of photovoltaic batteries decreases, some of the energy we need is lost. In order to decrease these losses, it is important that water is not constantly needed to cool the photovoltaic thermal. The new type of cooling system that we offer has no analogues in the world. In further scientific research, the goal is to further improve new type of cooling system and transfer it to work in an autonomous manner.*

Keywords: photovoltaic thermal device, new type of cooling system, collector, reflector.

1. Introduction

Modern industrial-scale monocrystalline and polycrystalline silicon solar cells have a flat construction and an absorption coefficient of 95 %, while their efficiency factor ranges between 18 and 20 %. In solar cells, about 80 % of the absorbed radiation energy is primarily spent on heating the element, which negatively affects its performance. When solar cells are placed on the surface of a heat collector absorber and ideal heat exchange is achieved, the overall efficiency of the system increases significantly [1].

Scientists at the Institute of Physics and Technology are conducting a series of scientific studies to improve the efficiency of photovoltaic-thermal (PV/T) batteries. In particular, the efficiency of photovoltaic-thermal (PV/T) batteries is being investigated using thermal collectors. For arid and water-scarce climates, an efficient, low-power, autonomous, and portable photothermal system helps supply rural households with the necessary electrical energy and partial hot water, reducing economic costs. The implementation of this system relies on a newly developed heat collector-integrated photo-thermal, a radiator, a pump, a water storage tank, a controller, an inverter, and a mobile supporting structure [2].

In the newly developed cooling system, water is used as the working fluid for cooling PV/Ts, and experimental studies are conducted to analyze the results. It is determined that the PV/Ts we developed produced 50–60 % more power than conventional photovoltaic panels [3]. In this study, a new cooling system has been introduced, utilizing water as the working fluid to improve the efficiency of PV/Ts.

PV/Ts systems generate both electrical and thermal energy simultaneously, increasing overall efficiency while minimizing environmental impact [4–6]. In arid and water-scarce climates, researchers are addressing cooling challenges by exploring heat transfer fluids with significantly improved thermal conductivity [7–10]. Advanced materials such as nanofluids are widely used by researchers worldwide to enhance heat transfer rates and improve the efficiency of photovoltaic systems, including PV/Ts [11–14]. Innovative designs of thermal collectors optimize heat dissipation from photovoltaic cells, which is crucial to preventing overheating and reducing efficiency losses.

2. Materials and methods.

The methods of cooling PV/Ts are very diverse, and many scientists are conducting research in this direction. Some studies have found that PV/Ts cannot be used in extremely dry areas, and a constant amount of water is needed to cool the PV/Ts. Considering these shortcomings, the PV/T with new type of cooling system (NTCS) has been created. The photovoltaic thermal device (PV/TBD) with NTCS is designed for use in extremely dry areas without water, self-cooling and providing electricity and hot water without of efficiency. The parts that make up the PV/TBD with NTCS perform the following tasks.

- a new type of heat collector ensures reduction of energy losses of the photo-thermal;
- the radiator serves to cool the hot water collected in the heat collector;
- the fan is installed above the radiator and serves to increase the efficiency of the radiator with the help of wind;
- the pump passes the heated water through the radiator in the new type of collector, and ensures that the cooled water enters the collector and circulates the water;
- the water tank is used for storing hot water and for good operation of the pump;
- mobile construction.

Placing and switching together the radiator, fan, pump, water storage tank, controller and inverter in the PV/T, and ensuring that the portable structure performs the function of mechanical protection when moving them from one place to another.

The new type of PV/T cooling system is based on the principle of the cooling system of internal combustion engines, and cooling is provided by the circulation of water through the radiator. The heat accumulated in the rear part of the PV/T is transferred to the water in the collector, and the heated water is transferred to the cooling radiator using a pump. This process continues continuously. And the liquid that has passed through the cooling radiator is returned to the collector. A fan is installed on it for better cooling of the liquid that has passed through the cooling radiator. The pump and fan in the cooling system of this device are low-power and do not negatively affect the energy produced by the PV/T.

Figures 1 and 2 show the front and rear views of the PV/TBD made on the basis of a 60 W PV. Figure 2 shows the components of PV/TBD: 1) photothermal, 2) accumulator battery, 3) inverter, 4) controller.

Fig.1. Fig. 1. Front view of the device with PV/T.

Fig.2. Rear view of the device with PV/T.

Table 1 shows the characteristics of photovoltaic cells with different capacities and the equipment of the new type of cooling system.

Figures 3 and 4 show the front and rear views of the PV/TBD made on the basis of the 180W PV. Figure 4 shows the components of PV/TBD with a new type of cooling system: 1) controller, 2) amperemeter, 3) inverter, 4) radiator, 5) fan, 6) Accumulator battery, 7) reserve water storage (capacity 20 liters), 8) pump, 9) Electronic thermometer 10) switch.

Table 1. Physical and technical characteristics of different power photothermal devices with a new type of cooling system.

Name	PV/T 1	PV/T 2	PV/T 3
Maximum power of PV, $П_{max}$	60 W, 1 pc.	180 W, 1 pc.	350 W, 2 pc.
Efficiency factor of PV, η	19.9%	19.9%	19.9%
The operating voltage of the PV, $У_{oc}$	21,6 V	22.80 V	22,3
Short circuit current of PV, $И_{sc}$	3.53 A	10.34A	8.6 A
Fill factor of the VAC of PV, *ff*	0,71-0,73	0,71-0,73	0,71-0,73
Reflection coefficient of the reflector R, size in cm, pieces.	05, width 67, height 54, 2 pc.	0,5 , width 145, height 60, 2 pc.	0,5 , width 180, height 80, 2 pc.
Water capacity of the polycarbonate heat collector	3 l	10 l	7x2=14 l
The radiator is made of which material, size in sm	Aluminium, width 15, height 15	Aluminium, width 30, height 60	Aluminium, width 30, height 60, 2 pc.
Fan power W, pc.	3,6 , 1 pc.	3,6 , 5 pc.	3,6 , 12 pc.
Pump power, W	5	5	60
BB, A/h	20, 1 pc.	65, 1 pc.	200, 2 pc.
Inverter, W	300,	300	3000
Controller, A	10	20	-

Fig. 3. Front view of the new type of PV/TBD.

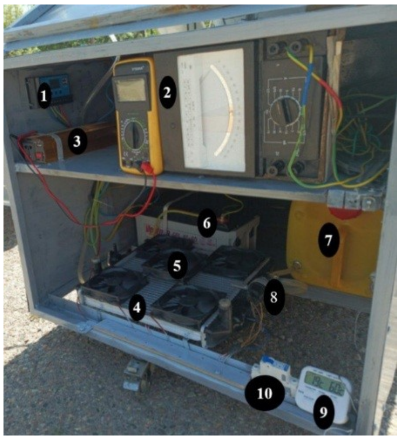

Fig. 4. Rear view of the new type of PV/TBD.

Figures 5 and 6 show the external view of a large capacity PV/TBD with a new type of cooling system. A large-capacity PV/TBD with a new type of cooling system was created to meet the needs of rural residents for electricity and hot water.

Fig. 5. Front view of a 1kW PV/TBD with a new type of cooling system.

Fig. 6. Rear view of a 1kW PV/TBD with a new type of cooling system.

3. Results and analysis

This paper presents the power efficiency of PV/TBDs with NTCS based on 60 W and 180 W PVs. These results were obtained in May and June, respectively. On September 7, 2024, experimental tests were carried out at the high-power PV/TBD with NTCS at the Helio polygon of the Institute of Physics and Technology. Figure 7 shows the time variation of the power values of 60 W PV based on PV/T. The black line of PV1 is the maximum power that the 60 W PV can deliver. The PV/T red line is the power results obtained on a typical 60 W PV. It can be seen from Figures 7 and 8 that due to external influences, PV cannot reach the values indicated in the nominal data. The PV/T blue line shows the power values of a PV/T based on a 60 W PV with NTCS. Reflectors are installed on the side of the PV/T, aiming to increase the solar radiation flux density. Since the short-circuit current (SCC) is directly proportional to the solar radiation current density (SRCD), the SCC of the PV/T is increased [15]. At 10:20, two reflectors were installed on the sides of the PV/T and the NTCS was launched. As a result, the power of the PV/T increased from 46 W to 69 W, as shown in Figure 7. When the solar radiation current density (SRCD) reaches its maximum value, the power of the PV/T reaches 84 W.

The power values of PV/T are always below the PV1 line, that is, they never reach the maximum value. 60 W and 180 W PV-based PV/Ts require 9.6 W and 24 W of additional power to power the NTCS for cooling, respectively. It was mentioned above that the additional useful power provided by PV/T is 2-3 times greater than these powers. Figure 8 shows the time variation of power values of PV/T and PV. It can be seen from Figure 8 that the power values of PV are below the black line of PV1, that is, they have reached values smaller than the maximum power of PV. To increase the efficiency, it is necessary to increase the SCC with the help of reflectors to the PV/T, to prevent a sharp decrease in the operating voltage (OV) with the help of NTCS. Figure 8 shows that the power of PV/T reaches values greater than the maximum power of PV. Solar radiation is absorbed in the surface area of the solar cell. The greater the amount of Sunlight absorbed, that is, in the broad wavelength range of radiation, the greater the efficiency of the element [16-17]. The SCC increase of PV/T using reflectors is shown in Fig. 9. The increase of SRCD through the reflectors also causes an increase in heat in the rear part of the PV/T.

A sharp increase in SRCD leads to an increase in temperature in the back of the PV/T. This causes a decrease in OV, because the parameter most dependent on temperature change is OV. This phenomenon is explained as follows. A solar cell (SC) based on crystalline silicon decreases OV by 0.002 V (0.4 %/degree) at a temperature of 1 degree above 25^{o} C (certification AM 1 reference temperature). Heating of SC on an open sunny day (in the summer months) can reduce OV by 0.07 - 0.09 V. This is the main reason why SC has reduced the efficiency factor (EF). The temperature reduction of the voltage obtained from the SC has been observed in scientific research [18]. A new type of self-cooling, i.e., a new type of cooling system was used to prevent the reduction of the OV of the PV/T. Figure 10 shows the increase in OV of PV/T.

Figures 9 and 10 show the change of PV/T SCC and OV over time. Results started at 10:00 a.m. At 12:00, reflectors were installed on the side of the PV/T. Figure 9 shows that the value of SCC has been increased from 15 A to 22 A. Through reflectors, the SCC has been increased to 50%. Figure 10 shows the decrease of PV/T OV under the influence of heat. OV values of PV/T have been increased since 12:00 when the new type of cooling system was put into operation. PV/T's OV was 44 V at 11:40 a.m., and 46.5 V at 12:00 p.m. when the new cooling system was put into operation.

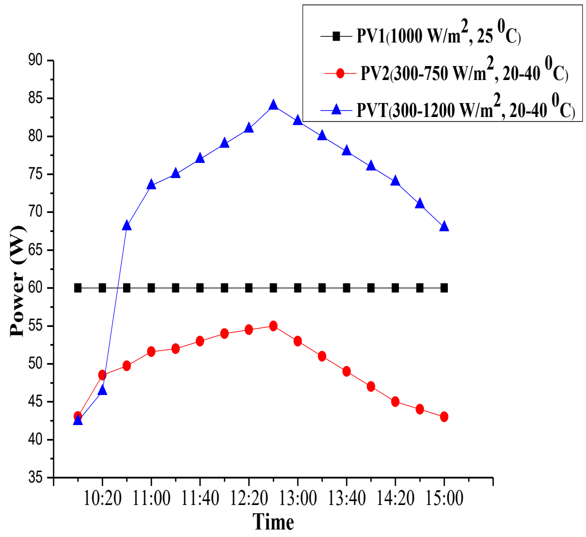

Fig. 7. Power values of 60 W PV based on PV/T with NTCS and 60 W PVB depending on time.

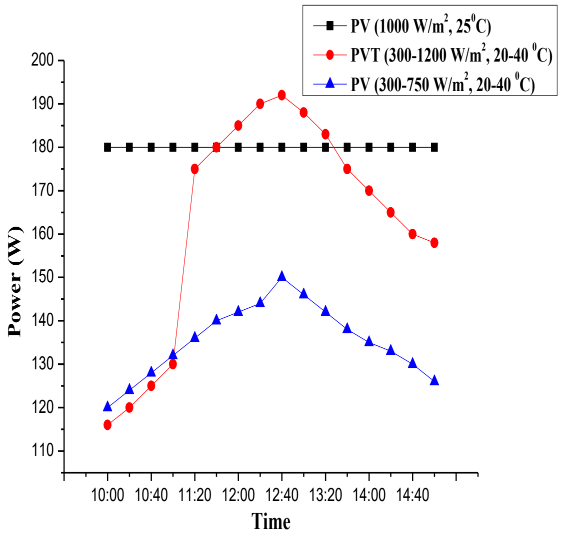

Fig. 8. Power values of 180 W PV based on PV/T with NTCS and 180 W PVB depending on time.

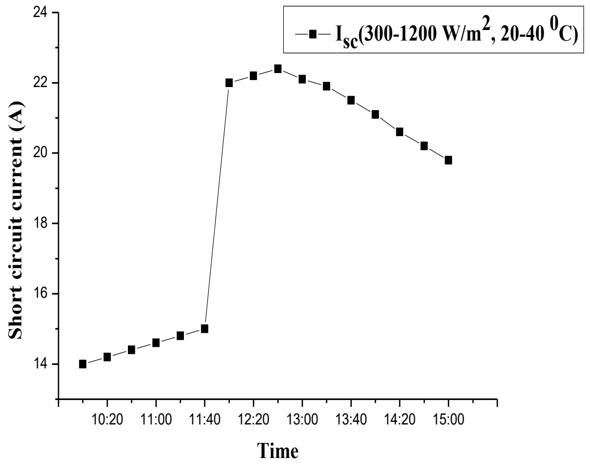

Fig. 9. Time variation of PV/T TB SCC per 1 kW power.

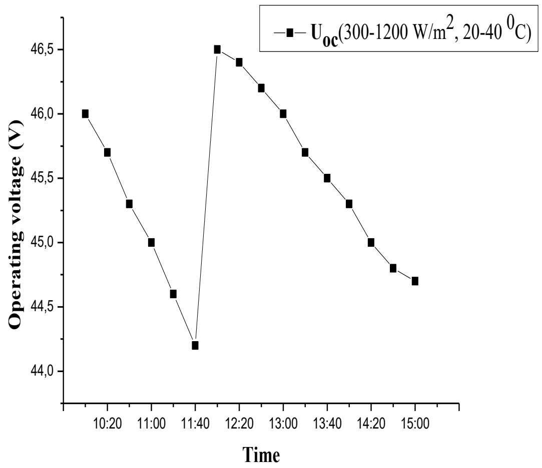

Fig. 10. Time variation of PV/T OV per 1 kW power.

Figure 11 compares the power values of PV/T with the maximum values of PV. Figure 11 shows that the power of PV/T is greater than the maximum power of PV up to 152 W. 100 W of additional energy is required to power the new type of cooling system. Our proposed PV/TBD provides additional useful energy along with providing energy to NTCS. Since the results are received in September, the efficiency of PV/T is slightly less. Because in Based on this, in the summer months, the efficiency of PV/Ts with large capacity NTCS reaches even greater values. The decrease in SRCD is shown in Figure 12. this month, SRCD is slightly lower than in the summer months.

Figure 12 shows the values of SRCD. At 11:40 a.m. SRCD was increased by reflectors to PV/T. That is, up to 30% increase in radiation has been achieved. But these increased values were smaller than AM 1.

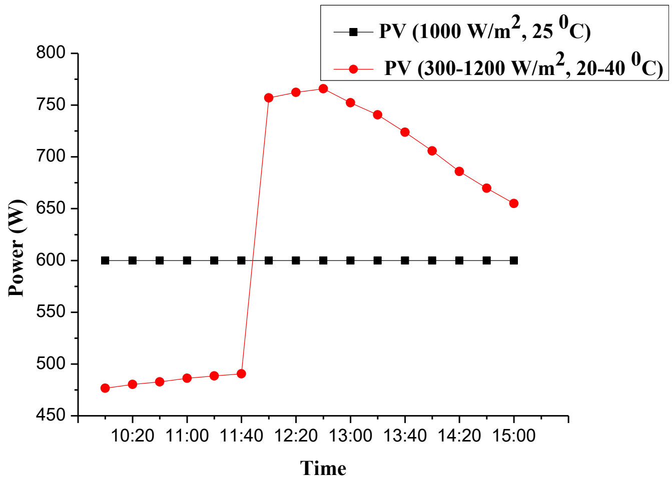

Fig. 11. Time variation of PTB power values with NTCS providing power up to 1 kW.

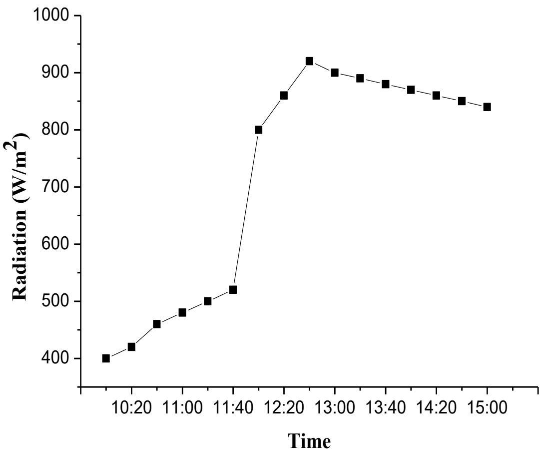

Fig. 12. Time variation of the value of SRCD.

4. Conclusion

In this research work, it was found that the efficiency of PV/TBDs with NTCS based on 60 W and 180W PV was increased to 50% and 30%, respectively. And a new type of cooling system was tested to improve the efficiency of high-power PV/Ts. The experiments showed that the SCC of PV/T was up to 50%, and a sharp decrease in the values of OV was prevented. With a large-capacity new type cooling system, PV/TBD can provide electricity and hot water for rural residents and extremely dry areas. The PV/TBD we offer provides power to water pumps and similar equipment. This device can be used to get up to 100 l of hot water for household needs of villagers. In further scientific research, it was aimed to develop new, more convenient and more efficient versions of PV/TBDs with a new type of cooling system with a large capacity.

The power consumption of the water pump and fan in the new PV/T cooling system is 5 W and 0.36 W, respectively. Under natural conditions, a 60 W PV generates 40–50 W, while a 180 W PV produces 110–140 W. In contrast, PV/Ts with the same power ratings generate 70–80 W and 170–190 W, respectively. Thus, the useful energy output of PV/Ts is several times greater than the energy consumed by the new cooling system. Further scientific research aims to evaluate the efficiency of the cooling system's working fluid by testing nanofluids alongside water.

Conflict of interest statement

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

CRediT author statement
Tursunov M.N.: Conceptualization, Methodology, Validation, Writing - Original Draft; **Sabirov Kh.:** Conceptualization, Methodology, Data Curation, Investigation, Writing – Review & Editing; **Alikulov R.B**.: Methodology, Software, Investigation, Writing - Original Draft; **Kholov U.R**.: Data Curation, Visualization; **Eshmatov M.M**.: Formal analysis, Funding acquisition, Writing-Review & Editing. The final manuscript was read and approved by all authors.

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