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EVALUATION OF ENERGY EFFICIENCY OF PHOTOELECTRIC HEAT BATTERIES WITH MECHANISM OF SOLAR OBSERVATION

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Abstract: *Cooling of the rear surface of photoelectric batteries (PEB) was investigated by attaching a newly designed heat collector made of parallel channel cellular polycarbonate to the rear surface in order to improve the electrical and thermal efficiency in this research work. The experiment was conducted on June 7, 2022 at the Heliopolygon of the Physical-Technical Institute of Tashkent city (latitude: +41,34 (41°20'23"N), longitude: +69,3 (69°17'36"E). 2 340 W monocrystalline silicon PEBs(photoelectric batteries) were used as experimental devices. The rear surface of the first is equipped with a cooling system.*

The second are unadjusted for comparison purposes. A heat collector is attached to cool the back surface of the PEBs(photoelectric batteries), called a photothermal battery (PTB). Water was used as the cooling liquid of the photothermal battery (PTB). The increase in electrical and thermal efficiency depending on the change in the flow rate of the coolant was analyzed. In addition, the dependence of the solar radiation on the frontal surface of the photothermal battery (PTB) on the inclination angles of the flux density enhancing reflectors and the support structure moving in relation to the sun on two axes was also investigated. Electrical and thermal efficiencies were observed for 0,067, 00,1 and 0,2 kg/s flow rates of 21^{0}C water in the consumer pipe to the heat collector.

Keywords: *photoelectric battery, photothermal battery, reflector, cellular polycarbonate, short circuit current, open circuit voltage, heat absorber, thermal efficiency, electrical efficiency.*

INTRODUCTION. Solar energy is considered an important source of all renewable energy sources because it provides clean and unlimited energy. The solar energy can be converted directly into electricity with using PEBs. A small part of this radiation is used to convert solar energy into electricity falling on the frontal surface of PEBs. In practice, only (15-20%) of the incident solar radiation can be converted into electrical energy [1].

As the bulk of the absorbed radiation heats the PEBs, the temperature of the solar elements (SEs) rises. The increase in temperature causes a decrease in the electrical efficiency of the PEB. The electrical efficiency degradation of PEB decreases from 0,25%/°C to 0,5%/°C when the ambient temperature is high [2]. Thus, it is very important to use active cooling methods to increase the electrical efficiency by reducing the PEB temperature. Together with this, the service life of PEBs can be extended [3].

The reduction of efficiency due to the change of the angles of incidence of the solar radiation flux density on the surface of the Earth in the cross-section of seasons on the frontal surface of PEBs which was installed on fixed support structures was considered in previous works [4]. In this research work, the increase in electrical efficiency was achieved by reducing the heat accumulated on the rear surface of the PEB. In addition, thermal efficiency has been increased by intelligently using the heat which was obtained by cooling the rear surface of the PEB. Technical parameters and details of PEB on the basis of the active method of cooling were studied. The electrical efficiency of the used PEBs is equal to 19,89% under standard test conditions (passport data 1000 W/m^2, 25^0 C) [5,16].

MATERIAL AND METHODS. In our experiment, the parameters of PEB and PTB with conventional structure were compared. The measurement results were carried out in sunny weather (daytime air temperature 26-32^0 C, wind speed 0,4-1,6 m/s, solar radiation flux density around 720÷1100 W/m^2).

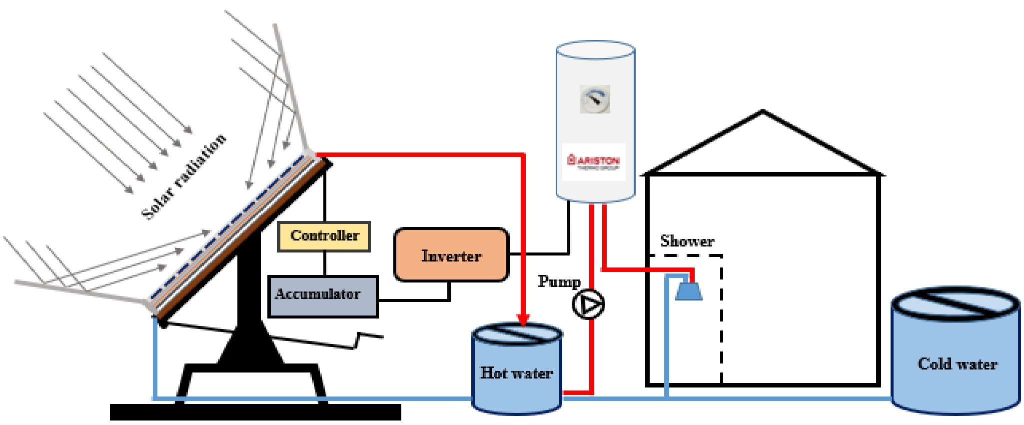

Fig.1. Scheme of the experimental device

Modifications to the sun-concentrating reflectors (which move in relation to the Sun on two axes) on which the PTB is mounted, have also been studied. According to the results of the research, this system is considered a promising technology for rural people in extreme conditions, and it creates ample opportunities for further research.

The increase of current density in solar radiation increases electrical efficiency. Therefore, it is important to keep the PEB temperature lower and the solar radiation flux density higher. A heat collector on the basis of a new technology was attached to the rear surface in order to keep the temperature of the PEB between the passport data and the ambient temperature [6, 10, 11]. New reflectors were installed to increase the flux density of solar radiation which was falling on the frontal surface of the PTB.

In addition, the PTB was installed on a support structure which was moving in relation to the Sun on two axes [7]. The results of our research differ from the results of research which was conducted by other scientists. The absorbers used as heat collectors of the new design which completely cover the back surface of PEBs are made of different material, and the reflectors which increase the solar radiation flux density are used on the frontal surface, and the support structure is moved in relation to the sun on two axes. The scheme of the experimental device is presented in Fig. 1.

Table 1

Mechanical characteristics	
Length, width, height (mm)	1950 x99 x35
Weight (kg)	22,5
The number of solar elements and their arrangement	72(12x6)
Type of solar cell	Mono crystal silicon
Protective glass material and thickness	Low iron tempered glass/3.2mm/4mm
Insulation layer	Ethylene vinyl acetate
Frame material	Anodized aluminum alloy
Cable section	4 mm^2
Electrical characteristics	
Rated maximum power (RM, W).	340
Open circuit voltage ($U_{o.c.v.}$, V)	46
Short circuit current ($I_{sh.c.}$,A)	9
Voltage at maximum power(U_M, V)	38
Short circuit current at maximum power(I_M, A)	8,5
Module efficiency(%)	20
Thermal characteristics	
Temperature coefficient of short circuit current($I_{sh.c}$), α (%/ºC)	0,0118
The temperature coefficient of the open circuit voltage ($U_{o.c.v.}$, V), β (%/ºC)	-0,2627
Temperature coefficient of power(P_M), γ (%/ºC)	-0,3677
Operating temperature range(ºC)	-40÷85

During the experiment, the influence of the environment on the technical parameters of PTB and PEB was studied. It was ensured that the solar radiation flux density fell vertically on the frontal surface of the experimental devices during the day. It was checked that it is possible to save electricity by connecting hot water from PTB to Ariston (Fig. 1). Table 1 below lists the mechanical, electrical, and thermal parameters of the experimental device.

RESULTS AND DISCUSSION. Research work was carried out during 8^{30}÷16^{00}. Figure 3 shows the time dependence of the PTB and PEB voltage. The curve graph in red is considered to be PTB, and the curve graph in green is to PEB. In the graphic line typical of PTB, in the time interval 8^{30}÷9^{45}, it can be seen that the solar radiation current density falls perpendicularly to the frontal surface, the rear surface is covered with a heat collector and insulating layer, and there is not convective heat exchange with the external environment, so it can be seen that the amount of the open circuit voltage is reduced by a large difference.

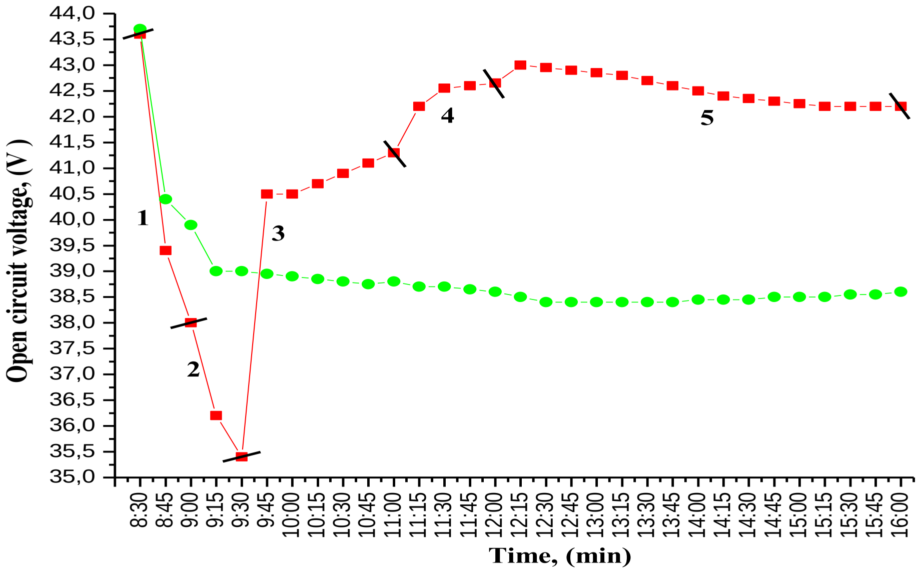

Fig. 2. Dependence of time open circuit voltage of PTB (red curve) and PEB (green curve)

Graphical line characteristic of PEB shows a linear decrease of the walking voltage up to ~10,4% with small differences during the time 8^{30}÷9^{30}. During the day, the ambient temperature varied between 28-35^0 C, and the wind speed index varied between 0-3,8 m/s. Fields 1 and 2 on the PTB graph correspond to the operating modes of PEBs used in extremely hot countries. In the 2nd area, a sharp decrease of open circuit voltage is observed by using reflectors which increase the current density of the solar radiation falling on the front surface of the PTB, and the amount of heat on the rear surface of the PTB increases due to the lack of convective heat exchange with the external environment.

At 9^{30}, water was transferred from the PTB as a coolant under normal conditions of 21 ^{0}C. This case was observed at the output of the heat collector attached to the back surface of the PTB in the field 3, the temperature of the back surface decreased at a current consumption of 0,067 kg/s. The faster the speed of the heat carrier, the faster the rear surface of the PTB module cools, and the higher open circuit voltage. This situation was determined in the case where the speed of water in the field 4 was 0,1 l/s. When the flow rate reaches 0,2 kg/s, the electrophysical parameters of the PTB approach the passport data. After a certain period of time, due to the continuous circulation of the heat carrier, when the temperature of the rear surface of the PTB reaches a minimum value, the open circuit voltage remains stable. This situation is reflected in the field 5 of Figure 2. The rear surface temperature of the PEB decreases until it approaches equilibrium with the ambient temperature. The result of this can be observed in the PEB graph line in Figure 2. 1-side reflector when it is unused; 2 – side reflectors when they are used.

As a result of changing the direction of the reflectors to the sun, the amount of heat energy on the rear surface of the device was also determined. The amount of solar radiation falling on the frontal surface of PTB equipped with reflectors is 720÷1100 W/m^2, and on the frontal surface of PEB with conventional structure it is 720÷775 W/m^2. The accumulated excess heat energy is reduced by passing water through the numerous channels of the heat collector attached to the rear surface of the PTB.

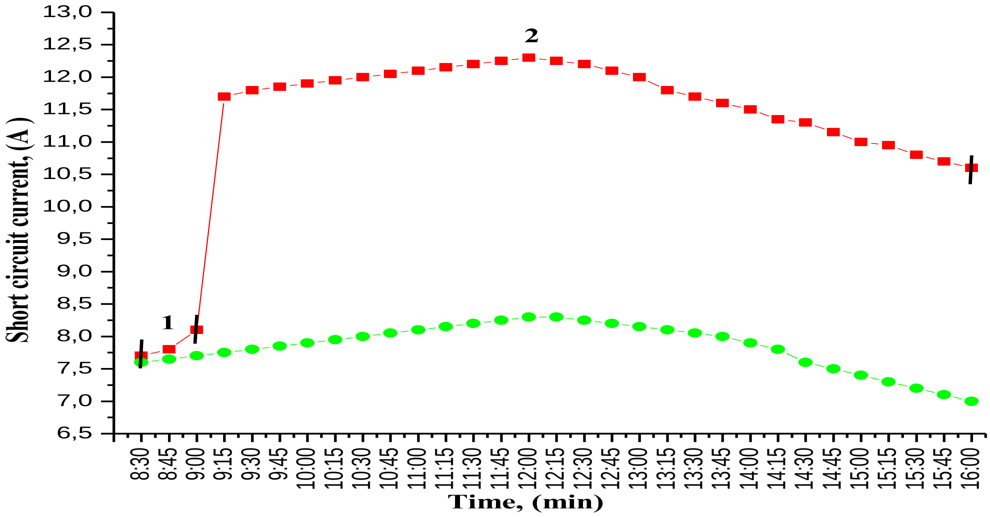

Fig. 3. Time dependence of PTB (red curve) and PEB (green curve) short-circuit current

0,067 kg/s current consumption for cooling the rear surface of PTB from 9^{00}÷11^{00}, the average generated electricity for two hours when the temperature at the inlet of the heat collector was 21^0 C was ~0,68 kWh. The temperature difference of the water at the inlet and outlet of the heat absorber was ~6^0 C, and the water temperature at the outlet was equal to 27^0 C. From 11^{00} to 12^{00}, when the water consumption reached 0,1 kg/s, the temperature of water decreased by 1^0 C, the volume of water coming out of the heat collector was 360 liters, and the produced electricity was 0,82 kWh.

Due to the increase in water consumption in the time interval of 11^{00}÷12^{00} during the day, the thermal efficiency was equal to ~ 24%, and the electrical efficiency was equal to ~ 20%. In the time interval of 12^{00}÷16^{00}, the total volume reached 2880 liters, while the temperature of the water was maintained at a constant flow rate of 0,2 kg/s.

On the basis of the results of the conducted experiments, the electrical capacities of PTB with reflector moving along two axes and PEB with conventional structure are presented in Figure 4. The power of PTB is 1.7 times greater for maximum values than PEB and 1.6 times greater for average.

Economic analysis**.** Using the results of the experiment, the results of the solar radiation flux densities and power values of both devices during the day are given in Figure 4. The developed thermal and electrical energy efficiencies were determined by the experimentally measured values using the following formulas [8,14,15]:

$$\eta_e = \frac{Q_e}{E \cdot S} = \frac{I_m U_m}{E \cdot S} \tag{1}$$

where, I_m, U_m — maximum current and voltage (A, V), E — solar radiation current density (W/m^2), S — PEB surface (m^2).

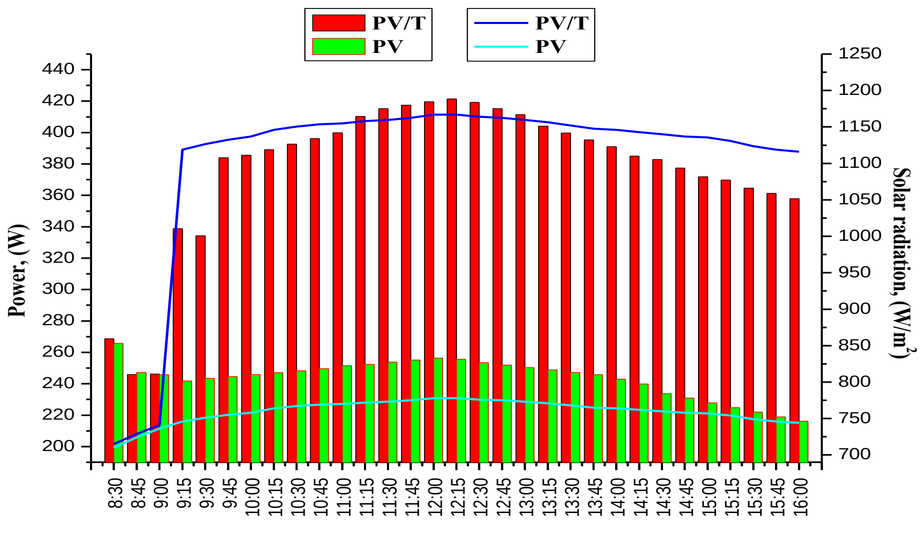

Fig. 4. Daily variation of solar radiation flux densities and maximum power magnitudes in the working area of PTBs and PEBs

$$\eta_e = \frac{Q_{is}}{E \cdot S} = \frac{c \cdot G_{SS} \cdot (T_2 - T_1)}{E \cdot S} \quad (2)$$

where, c – is the comparison heat capacity of the heat carrier (J/kg·K), G_{SS} – the mass consumption of the heat carrier (kg/s), T_1, T_2 – the inlet and outlet temperatures in the heat collector of the heat carrier (K).

A simple payback method can be used to compare PTBs and PEBs economically. Using the simple payback period method, the payback period of devices can be determined from the following formula 3 [9,12,13]:

$$\text{Normal payment term} = \frac{\text{Device price}}{\text{The cost of the energy produced by the device}} \quad (3)$$

It was found that the investment in the development and additional equipment of the new design PTB is 15-20% higher than the investment made in the combination of the conventional PEB with additional equipment. The payback period was shown to be 15% different from each other.

CONCLUSION. In this study, the technical parameters of PTB on the basis of monocrystalline silicon were investigated to increase the power performance by changing the water consumption and solar radiation current density.

Thermal and electrical efficiency is increased by using a heat collector and reflectors which increase the flux density of the solar radiation when the PTB is cooled and on the frontal surface. It has been found that higher efficiency can be achieved if the reflector PTB is always moved perpendicularly to the sun continuously throughout the day.

It was found that the higher the solar radiation current density, the higher the device's power performance. According to the results of the experiment, the electrical efficiency of the PTB reached 35% compared to the PEB with a conventional structure, and the total efficiency (excluding the amount of electrical energy spent on the circulation pump) reached 86%. Currently, the use of the PTB device in extreme conditions is considered a cheap and economical device for the villagers.

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