Hybrid photoenergy installation development

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Abstract. The current problem is the autonomous supply thermal energy and hot water for civilian and military consumers. The most commonly used for this purpose are installations based on solar thermal collectors, which at the same time require an external power source up to 100 W for electronic control components and a circulating pump, which does not allow them to be fully considered as autonomous. One of the ways to solve this problem is to combine in one installation solar panels and heat collectors. It has been proposed the constructive-technological solution of the hybrid photoenergy system with flexible solar cells based on cadmium telluride, which allows getting the total efficiency of such a system up to 73% for the transformation of solar energy into heat and electric energy.

1. Introduction
The current problem is the autonomous supply thermal energy and hot water for civilian and military consumers. The most commonly used for this purpose are installations based on solar thermal collectors, which at the same time require an external power source up to 100 W for electronic control components and a circulating pump, which does not allow them to be fully considered as autonomous.

One of the ways to solve this problem is to combine in one installation solar panels and heat collectors. Such hybrid thermo-photoenergy installations are usually made from solar cells (SC) based on monocrystalline silicon and their electrical characteristics are much more prevalent [1]. In addition, the silicon based SC, due to the material properties, has an intense absorption of the near-infrared solar radiation component with a wavelength more than 1000 nm. Such absorption is photovoltaically ineffective and leads to parasitic SC heating and decrease efficiency of thermal part such hybrid installation. This necessitates the organization of efficient heat removal from SC to the heat exchanger through intermediate thermo-interfaces, which leads to complication of the installation design. At the same time, the maximum absorption of flexible thin-film SC based on the CdS/CdTe system is concentrated in the range 400-800 nm, and for near-infrared component, they are practically transparent.

Therefore, using such SC in hybrid photovoltaic installations will provide free access to the heat exchanger of the longwave solar radiation component, and efficient heat energy generation [2]. Using flexible thin-film CdS/CdTe based SC on the polyimide substrate in the electrical part of the hybrid installation will allow to mount such SC by gluing on a protective glass directly on the standard solar thermal collectors photoreceiving surface. Therefore, the development of an autonomous hybrid photoenergy installation equipped with flexible CdS/CdTe based SC, adapted for the mounting directly on the protective glass of standard solar thermal collectors, is perspective.
2. Results and their discussion
The main optimization problem for the development of such a system is the determination the level of the collector working temperature influence on the rate of thin film SC efficiency reduction. In order to determine the temperature effect on thin film SC parameters, it has been carried out a study of industrial samples of SC based on CdS/CdTe. For samples of series 1-3 at temperatures from 0 °C to 60 °C, illuminated current-voltage characteristics (CVC) were measured [3]. As a result of further analytical processing such experimental illuminated CVC, the output parameters and light diode characteristics of the SC (Table 1) were determined.

| Table 1. Output parameters and light diode characteristics of thin film SC based on CdS/CdTe at temperature 25°C |
|---------------------------------|-----------------|-----------------|-----------------|
| Output and light diode parameters | Samples serie 1 | Samples serie 2 | Samples serie 3 |
| \( J_{SC} \), mA/cm² | 19.3 | 19.4 | 19.6 |
| \( U_{OC} \), mV | 733 | 756 | 762 |
| \( FF \), rel. un. | 0.59 | 0.51 | 0.58 |
| Efficiency, % | 8.5 | 7.2 | 8.7 |
| \( J_{MR} \), mA/cm² | 19.6 | 19.9 | 19.8 |
| \( R_s \), Ohm·cm² | 5.8 | 8.2 | 8.7 |
| \( R_{SH} \), Ohm·cm² | 2300 | 1520 | 1890 |
| \( A_i \), rel. un. | 2.2 | 1.8 | 1.9 |
| \( J_0 \), A/cm² | \( 1.1 \times 10^{-9} \) | \( 5.9 \times 10^{-9} \) | \( 2.3 \times 10^{-9} \) |

The analysis shows that with temperature increase for all investigated samples, similarly to silicon samples, there is practically a linear decrease of the efficiency (Fig. 1, a). At the same time, the efficiency reduction coefficient, which describes the relative efficiency change when temperature change on one degree, is only \( -0.14 \text{ rel}\%/\text{°C} \), which is much lower than the corresponding parameter for silicon samples [4]. For open circuit voltage and short-circuit current density, there is also a decrease in their values when the working temperature is increased (Fig. 1, b, c). Experimentally it has established that the CVC fill factor practically does not change with temperature increase (Fig. 1, g). The analysis of light diode parameters shown that the observed efficiency decrease is accompanied by an increase of diode saturation current density and by decrease of shunt resistance.

The analysis of the obtained temperature dependences for thin film solar cells shows the traditional decrease of parameters with increasing temperature, which correlates with data of the leading world producers (Calyxo GmbH, Germany). In such solar cells, in comparison with silicon, there are absence of additional mechanisms that can reduce the efficiency with increasing temperature. For the investigated samples of thin film SC based on CdS/CdTe structure, there is no significant decrease in efficiency with increasing temperature up to 60 °C.

Optical studies have shown that the solar energy absorption coefficient for flexible SC based on cadmium telluride in the visible range (400-800 nm) is up to 94-96%, and the reflection coefficient in the infrared part of spectrum does not exceed 7-8% (Fig. 2), which allows excluding the selective coating from collector design.

The conception of a photoenergy system based on a thin film SC is in the development a design solution for the placement of flexible thin film SC based on CdS/CdTe system which adapted for the mounting directly to the plate of solar collector. Such autonomous combined photoenergy installation for military and civilian applications should be based on standard solar thermal collectors. The main part of the installation is the photoenergy module, which is a standard solar thermal collector on the photovoltaic surface of which would be mounted a flexible solar cell based on the CdS/CdTe system.
As a cooling system, it has been proposed the using of standard solar collector plates [5]. To determine the possibility and effectiveness of their using the simulation of thermal processes during the working of such photoenergy system was carried out.

A series of model experiments with different parameters, namely the plate thickness and the coolant flow velocity in the system, were carried out to detect the optimal heat exchange regime between the SC, the plate and the pipe. The aim of this work was the finding out the optimal balance between these parameters, the uniformity of heat transfer and the cost of such system. The thickness of
the plate was changed in the range from 0.5 mm up to 5 mm with increments of 0.5 mm, and at a coolant flow rate from 0.2 m/s up to 1 m/s with increments of 0.2 m/s. An example of temperature distribution visualization along the solar collector plate surface with 1 mm thick and a coolant flow velocity 0.4 m/s is shown on Fig. 3a.

![Distribution of temperatures on the surface of a single-tube (a) and two-tube (b) solar collector plates with 1 mm thick and a coolant flow velocity 0.4 m/s](image)

**Figure 3.** Distribution of temperatures on the surface of a single-tube (a) and two-tube (b) solar collector plates with 1 mm thick and a coolant flow velocity 0.4 m/s

Based on the received visualizations of the temperature distribution along the collector plate surface, we can observe the tendency that with increasing of the plate thickness and coolant flow rate, the temperature distribution over the surface becomes uniform. This is due to the basic physical laws of heat conductivity. The problem is that in order to achieve a coolant flow velocity of more than 0.6 m/s, it is necessary to use a powerful circulation pump, which will result in to unnecessary consumption of electric energy and the impossibility of autonomous installation creating. In addition, if the collector plate thickness is increased up to 2 mm, use of such plate will be inappropriate, because it will have a very large mass and cost.

Therefore, based on this results it has been proposed to improve the system of solar collector plate in such by means the organizing heat exchange between the plate and the system through the two pipes instead one pipe, as it was made in industrial solutions. In this way, a uniform distribution of heat should be achieved without using high velocities of the coolant flow and large thicknesses of the collector plate. This will lead to some increase in the complexity of plant manufacturing due to the failure of the standard plate collector, but will allow to develop the system with maximum efficiency. An example of temperature distribution along the surface of solar collector two-tube plate with thickness 1 mm and a coolant flow velocity 0.4 m/s is shown on Figure 3, b.

Based on the carried out research, a test solar cell based on the ITO/CdS/CdTe/Cu/Au heterostructure was made and mounted through heat-conducting interface on the two-pipe plate of a solar collector. As a heat conduction interface we using a Stars 922, this is a heat conductive adhesive, which has a high thermal conductivity up to 1.2 W/(m·K) and a sufficient strength about 15 kg/cm². Schematic representation and overall view of such plate has shown on Figure 4.

As a result of carried out research of such type collector plate, it was shown that the technology of its manufacture is significantly simple. The proposed design and technological solution of such photoenergy module with flexible SC is optimal and allows getting the total efficiency of such type installation up to 73% for thermal and electric energy [6].
73% for thermal and electric energy. The installation of a solar battery is carried out using conductive adhesive, which has a high thermal conductivity.

## References

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**Figure 4.** Schematic representation (a) and overall view (b) of solar collector plate with mounted SC based on ITO/CdS/CdTe/Cu/Au heterostructure.

3. Conclusions

By the comparison of efficiency temperature dependences for thin film SC based on CdTe compounds produced in laboratory conditions it has been shown that when the temperature of such devices is changed on 50 °C, the efficiency decreases only on 1%, and the relative rate of efficiency decrease is 0.14 rel %/°C. This is significantly less than the similar indicator for other types of solar cells.

After the analytical processing and analysis of light diode characteristics influence on the efficiency of cadmium telluride based SC, it has been established that the temperature stability of their efficiency is ensured by the diode saturation current density. When the temperature rises from 20 °C to 50 °C, the diode saturation current density increases only on 50 % from $1.9 \times 10^9$ A to $2.7 \times 10^9$ A, which is much lower than for silicon SC, for which the diode saturation current increases on 300 %.

The construction-technological solution of the photoenergy system with flexible cadmium telluride based solar cells has been proposed, which allows getting the total efficiency of such type system up to 73% for thermal and electric energy. The installation of a solar battery is carried out by using a heat conductive adhesive, which has a high thermal conductivity up to 1.2 W/(m·K) and a sufficient strength about 15 kg/cm².