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O. Tukfatullin
Institute of Semiconductor Physics and Microelectronics of the National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan, oskar.tukfatullin@gmail.com

R. Muminov
Physical-Technical Institute SPA "Physics – Sun" named after S.A. Azimov of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan

I. Rakhmatullaev
Institute of Semiconductor Physics and Microelectronics of the National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan

I. Abdullaev
National University of Uzbekistan named after Mirzo Ulugbek,

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THE METHOD FOR DETERMINING THE TEMPERATURE OF SOLAR CELLS IN A FLAT PHOTOVOLTAIC/Thermal SYSTEM

O. Tukfatullin\textsuperscript{1}, R. Muminov\textsuperscript{2}, I. Rakhmatullaev\textsuperscript{3}, I. Abdullaev\textsuperscript{4}

\textsuperscript{1,3}Institute of Semiconductor Physics and Microelectronics of the National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan
\textsuperscript{2}Physical-Technical Institute SPA "Physics – Sun" named after S.A. Azimov of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan
\textsuperscript{4}National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan
e-mail: oskar.tukfatullin@gmail.com

Abstract. In the framework of the theory of heat transfer processes in flat solar collectors, a semiempirical method for calculating the temperature of solar cells in a photovoltaic thermal system is considered.

Keywords: solar cell, photovoltaic module, solar collector, photovoltaic/thermal system, temperature.

Among the problems that have a significant impact on the efficiency of conversion of solar radiation (SR) of greatest interest for countries with hot climates, is the problem of reducing the operating temperature of a photovoltaic module [1]. For such operating conditions, one of the promising directions in the field of solar energy is the use of combined photothermal converters [2].

The main structural element of photo heat converter is a photovoltaic module, in which solar cells, a back layer of a sealant and a protective film can in the first approximation be considered as an absorbing surface (AS) of an absorber of a flat solar collector. The combination of photovoltaic module and solar cell allows not only to simultaneously generate electrical and thermal energy, but also to protect the solar cells from excessive heating, thereby increasing their efficiency.

The useful energy $Q_U$ absorbed by the collector part (CP) of the PHC can be determined through the physical parameters of the installation and the environment, as well as the local temperature of the coolant [3]:

$$Q_U = SF_R\left[G\beta - U_L(T_{in} - T_A)\right], \quad (1)$$

where $S$ is the area of the absorbing surface, $F_R$ is the coefficient of heat removal from the CP of the PHC, $G$ is the flux density of SI, $\beta$ is the effective reduced absorption capacity, $U_L$ is the total coefficient of heat loss, $T_{in}$ is the temperature of the coolant at the inlet, $T_A$ is the temperature of the environment.

The $F_R$ coefficient represents the ratio of the actually useful thermal energy of the PHC to the energy of the PHC when the temperature of the AS is equal to the temperature of the coolant at the inlet. For convenience, we represent it in the form of a product

$$F_R = F_1F_2, \quad (2)$$
where $F_1$ is the efficiency of the CP of the PHC, determined from expression

$$F_1 = \left(1 + \frac{U_L}{h_{CT} + \left(1/h_{CT} + 1/h_R\right)^{-1}}\right)^{-1},$$

(3)

and $h_{CT}$ and $h_R$ are the coefficients of convective heat transfer and heat transfer by radiation, respectively. Quantity $F_2$ is the coefficient of the PHC flow rate, which is calculated from

$$F_2 = \frac{\dot{m}C_P}{U_LF_1}\left(1 - e^{-\frac{U_L}{\dot{m}C_P}}\right),$$

(4)

here $\dot{m}$ - the flow rate of the coolant, $C_P$ is the specific heat capacity of the coolant.

Now, having determined the useful thermal energy, we will find the thermal efficiency. The temperature of the coolant at the outlet of the photothermal converters will be

$$T_{out} = T_{in} + \frac{Q_U}{\dot{m}C_P}.\quad (6)$$

With an increase in the flow rate of the coolant, the temperature difference $(T_{out} - T_{in})$ decreases. This leads to a decrease in heat losses to the environment and a corresponding increase in useful energy, since the average temperature of the PHC decreases. An increase in useful energy with an increase in the flow rate of the coolant is manifested in an increase in the coefficient of heat removal from the photothermal converters $F_R$. Note that the $F_R$ coefficient can never be greater than the coefficient $F_1$. With an infinite increase in flow rate, the temperature difference at the inlet and outlet of the PHC tends to zero, but the temperature of the absorbing surface will be higher than the temperature of the coolant.

It should be noted that the method for determining the useful energy and thermal efficiency of the photothermal converters is convenient to use in the study of solar thermal installations, since the temperature of the coolant at the inlet of the installation is usually known.

Let us calculate the characteristics of the photothermal converters at a flux density incident on the AS, equal to 740 W/m$^2$. Ambient temperature - 35°C. Wind speed - 5 m/s. The distance between the front and back sides of the heat-removing channel is 0.07 m. The width and length of the AS are 0.31 and 0.49 m, respectively. The coolant temperature at the inlet is 28.5°C. Heating agent consumption - 6 l/h. The heat carrier used is water. The blackness of the inner surfaces of the channel filled with water is 0.95. The effective reduced absorption capacity of the frontal layer system is 0.85. The angle of inclination is equal to the geographical latitude of the area (41.3°).

Assuming the average AS temperature to be 55°C, using the method [4], we find the loss coefficients through the front surface of the photothermal converters $U_T$, the back surface $U_B$ and the side surfaces of the $U_S$ PHC, which are 2.66, 0.59, and 0.37 W/(m°C), respectively.

Let us also assume that the temperature of the rear wall of the heat removal channel is equal to the temperature of the water at the inlet. When calculating the heat transfer coefficient by radiation between the walls of the channel [5] filled with water, we will take the average temperature equal to the arithmetic mean of the temperatures of the AS and the rear wall of the channel (42°C): $h_R = 6.41$ W/(m°C). The heat transfer coefficients between water and channel...
walls will be assumed to be the same. The presence of thermal insulation of the side walls of the photothermal converters allows us to assume that heat transfer occurs only as a result of free convection. The thermal diffusivity coefficient at an average water temperature $\overline{T} = 40^\circ C$ is equal to $D = 1.53 \cdot 10^{-7} \text{ m}^2/\text{s}$. With a known value of the water temperature between the channel walls, we determine from [5] the Rayleigh number $Ra = 2.14 \cdot 10^6$. The corresponding value of the Nu number is determined for the case when the PHC has a slope of no more than $50^\circ$ $Nu = 0.062Ra^{0.33} = 7.63$ [5]. The characteristic linear dimension is the hydraulic diameter $D_H$, which for the flow between flat surfaces is equal to twice the distance between them [3]. Then the convective heat transfer coefficient is equal according to [5]

$$h_{CT} = Nu \frac{k}{D_H} = 35 \text{ W/(m}^2\cdot{\circ C}).$$

Let us now use expression (3) for the efficiency of the photothermal converters $F_1 = 0.94$. Then, by expression (4) for the coefficient of consumption of photothermal converters $F_2 = 0.92$ and the product $F_1$ and $F_2$ (2) $F_R = 0.87$. In this case, the useful thermal energy of the photothermal converters (1) is $Q_U = 88 \text{ W}$, and the thermal efficiency (5) is then equal to $\eta_T = 76\%$. Finally, according to (6), we find the water temperature at the exit from the photothermal converters $T_{out} = 41^\circ C$

In fig. 1 shows the graphs of the change in the temperature of the water at the outlet of the photothermal converters (straight line 2) versus the temperature of the water at the inlet (straight line 1) obtained during the operation of the installation described in [6].

![Fig. 1. Dependence of the temperature of the protective glass of the photothermal converters (PTC) on the temperature of the water at the inlet (1) and at the outlet (2) of the photothermal converters](image-url)
The calculation results are presented by straight line 3. This straight line is close to the values obtained in natural conditions, and this allows us to conclude that the processes occurring in the photothermal converters system can be considered within the framework of the above concepts.

Fig. 2. Dependence of the absorbing surface temperature of the PTC on the protective glass temperature of the PTC.

Thus, our studies have shown that, on the basis of experimental data on the surface temperature of the protective glass of the photothermal converters, it is possible to effectively apply the proposed method to determine the temperature of the solar cell in the composition of the photothermal converters under known environmental parameters (air temperature, SI intensity, etc.) and given conditions operation (water temperature at the inlet and outlet, productivity, etc.).

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