UDC 620.92: 536.242 (045)

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REDUCING THE INFLUENCE OF THE PHOTOCELL'S SURFACE HEATING ON ITS PERFORMANCE

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Abstract. *The incident solar radiation is converted by the photocell not only into electrical energy, but also into thermal energy, that heats its surface. Only 6 – 20% of the incident solar radiation is used by photocell to produce electricity. The remaining energy, mainly, goes into heating the photocell. The solar energy conversion efficiency of photocells decreases in case of temperature increasing. This work is devoted to reduce the photocell's heating effect on its solar energy conversion efficiency by installing it on additional cooling surface, which serves as a radiator. Data about the amount of solar radiation, that falls per unit area of the photocell, the ambient temperature and wind speed is taken for Simferopol city. Based on the simulation results the area of an additional cooling surface is calculated. The area of additional cooling surface A' during the year changes insignificantly, and 2 – 2.2 times bigger than the area of the photocell A. The simulation data was obtained for the ratio of additional cooling surface area to the area of the photocell A'/A. This information, according to the authors, is representative, universal and suitable for further analysis.*

Keywords: efficiency of the photocell; heating of the photocell; photocell size optimization

1. Introduction

The incident solar radiation is converted by the photocell not only into electrical energy, but also into thermal energy, that heats its surface.

There are a number of works devoted to the study of photocell's surface temperature effect on the efficiency of its work [1 – 4]. In them, in particular, noted that only 6 – 20% of the incident solar radiation is used by photocell to produce electricity. The remaining energy, mainly, goes into heating the photocell.

2. Analysis of publications

The solar energy conversion efficiency of photocells based on silicon, which is currently one of the most popular material used in the photocells, reaches its maximum value at a temperatures – 150 ÷ – 100 °C and is about 17%. With temperature increasing, it decreases and at 50 °C falls to 9% [1]. Energy conversion efficiency falling speed at a temperature close to 25 °C is 0.05% / °C. The maximum efficiency of photovoltaic cells based on GaAs corresponds to higher temperatures (from – 100 to – 50 ° C) and at a temperature near 25 °C, the efficiency decreases with a rate 0.033% / ° C [1].

The question of photocell's surface temperature effect on the efficiency of its work is very important in the various methods and devices that enhance (concentrate) the solar radiation that falls on the photocell's unit area [5 – 8]. Along with increasing the efficiency of solar energy conversion by photocell there is a significant increase of photocell's surface temperature, which in turn adversely affects on its operation.

3. Purpose and mission statement

This work is devoted to reduce the photocell's heating effect on its solar energy conversion efficiency by installing it on additional cooling surface, which serves as a radiator.

4. Research methodology

Work of flat-plate solar collector is described by energy balance equation, which characterizes the conversion of incident solar radiation into useful energy, thermal and optical losses [5]:

$$Q = A\left[S - U_L\left(T_p - T_a\right)\right], \qquad (1)$$

where A is an area of the collector absorber, m^2;

S is a solar radiation absorbed by a collector per unit area of absorber, W/m^2;

U_L is a coefficient of heat transfer by convection, radiation and conduction, W/(m^2·^{o}K);

T_p is the absorber plate temperature, ^{o}K;

T_a is the ambient temperature, ^{o}K.

In this work, the expression (1) was used to calculate the area of the additional cooling surface, which is used to compensate the photoelectric converter's heating.

For photocell with a single layer of protective coating (1) is transformed into:

$$Q = AS - AU_L(T_p - T_a) - A'U'_L(T_p - T_a), \quad (2)$$

where A here is an area of the photocell, m^2;

U_L, U'_L are the coefficients of heat transfer by convection, radiation and conduction, W/(m^2·^{o}K);

A' is an area of the additional cooling surface, which is used to compensate the photoelectric converter's heating, m^2;

T_p here is the temperature of the photocell, ^{o}K.

In (2) the AS product characterizes the solar radiation absorbed by the photocell. The rest of the equation (2) gives information about the heat loss by the surface of the photocell, i.e., about its cooling due to heat transfer by convection, radiation and conduction. Thus, $AU_L(T_p - T_a)$ describes the heat transfer between the photocell and the environment through the protective coating, $A'U'_L(T_p - T_a)$ – the heat transfer between the photocell and the environment through the additional cooling surface.

In this work, the optical losses were not taken into account and it was thought that all solar radiation that falls on the surface of the photocell is converted into heat energy.

With full compensation of the photocell's surface heating Q=0. In this case, the area of the additional cooling surface can be determined from (2):

$$A' = A\frac{S - U_L(T_p - T_a)}{U'_L(T_p - T_a)}.$$

Heat transfer coefficients can be found from the following expressions [5]:

$$U_L = \left[\frac{1}{h_{c,p-c} + h_{r,p-c}} + \frac{1}{h_w + h_{r,c-a}}\right]^{-1}; \quad (3)$$

$$U'_L = \left[\frac{1}{h_{c,p-c'} + h_{r,p-c'}} + \frac{1}{h_{w'} + h_{r,c'-a}}\right]^{-1},$$

where $h_{c,p-c}$ is a coefficient of heat transfer between the photocell and a protective coating by convection, W/(m^2·^{o}K);

$h_{r,p-c}$ is a coefficient of heat transfer between the photocell and a protective coating by radiation, W/(m^2·^{o}K);

h_w is a wind-induced coefficient of heat transfer between the protective coating and the atmosphere by convection, W/(m^2·^{o}K);

$h_{r,c-a}$ is a coefficient of heat transfer between the protective coating and the atmosphere by radiation, W/(m^2·^{o}K);

$h_{c,p-c'}$ is a coefficient of heat transfer between the photocell and the additional cooling surface by convection, W/(m^2·^{o}K);

$h_{r,p-c'}$ is a coefficient of heat transfer between the photocell and the additional cooling surface by radiation, W/(m^2·^{o}K);

$h_{w'}$ is a wind-induced coefficient of heat transfer between the additional cooling surface and the atmosphere by convection, W/(m^2·^{o}K);

$h_{r,c'-a}$ is a coefficient of heat transfer between the additional cooling surface and the atmosphere by radiation, W/(m^2·^{o}K).

The expressions for the heat transfer coefficients, which are included in (3), are given in [5].

The formulas for calculating the temperature of the protective coating T_c and additional cooling surface $T_{c'}$ are [5]:

$$T_c = T_p - \frac{U_L(T_p - T_a)}{h_{c,p-c} + h_{r,p-c}};$$

$$T_{c'} = T_p - \frac{U'_L(T_p - T_a)}{h_{c,p-c'} + h_{r,p-c'}}.$$

The change of the photocell's surface temperature T_p modeled using the Ross temperature model presented in [9]:

$$T_p = T_a + kG_T,$$

where k=0,02 – 0,04 ^{o}K m^2/W.

Data about the amount of solar radiation G_T, that falls per unit area of the photocell, the ambient temperature T_a and wind speed V_W is taken from [10] for the Simferopol city, located at 44^o 57' N. In the simulation, the value of the solar radiation G_T taken as the sum of direct and scattered radiation that falls per unit area of the photocell which is situated horizontally relatively to the ground surface in the clear day.

It was assumed that the emissivity of the upper and lower surfaces of photocell is 0.95 and 0.09 respectively, of the protective coating from glass – 0.88, of the additional cooling surface from plastic – 0.91 [5].

Fig. 1 – 3 show the results of simulation.

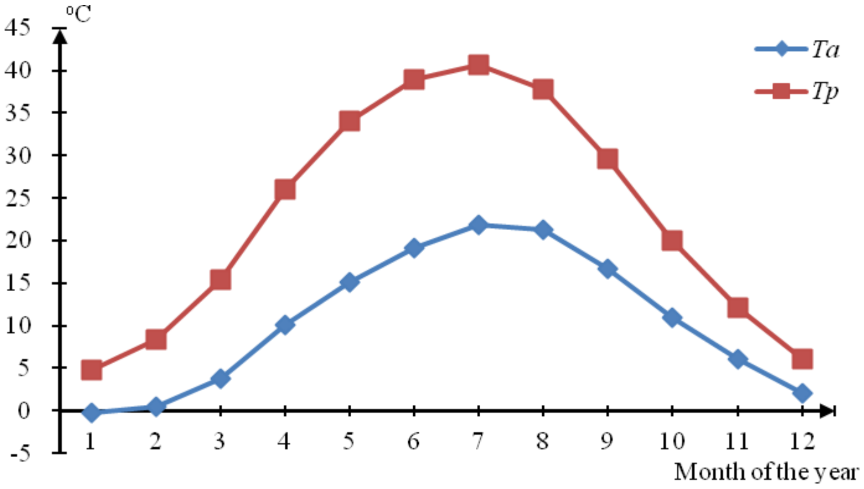

Fig. 1. Dependence of the photocell's surface temperature T_p and the environment temperature T_a on time of the year

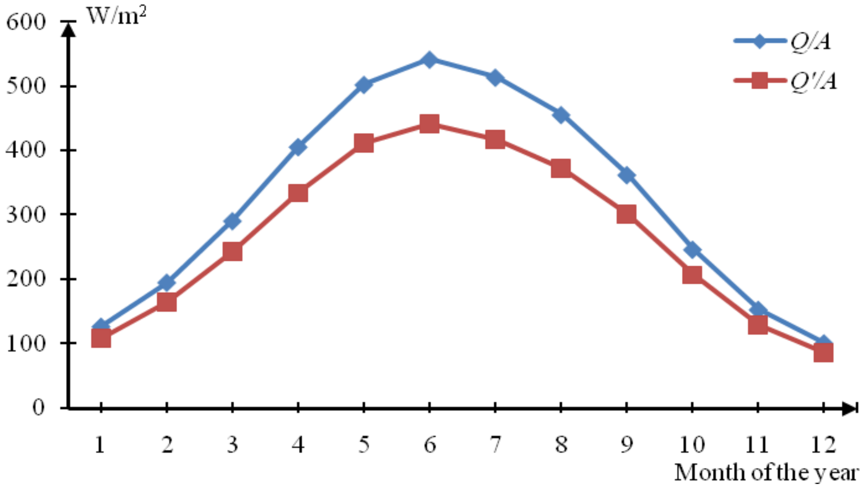

Fig. 2. Dependence of the photocell's surface heating on time of the year in case of the absence (Q) and the presence (Q') of an additional cooling surface

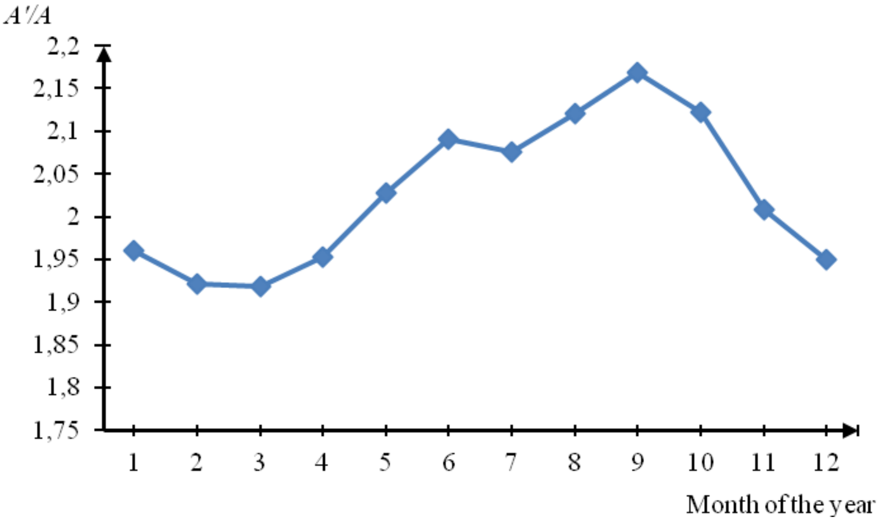

Fig. 3. Dependence of the area of additional cooling surface A' on time of the year

Fig. 1 shows the change of the ambient temperature T_a and the photocell's surface temperature T_p over the year obtained by simulation.

Fig. 2 shows that the presence of an additional cooling surface reduces the heating of photocell's surface especially in the summer months. At this time of the year, the temperature difference between environment and the photocell increases (Fig. 1). That is why there is more intensive heat transfer between the photocell and the environment, both through the protective coating and additional cooling surface. During this heat transfer, photocell is cooled actively giving heat to the atmosphere. In constructing of these dependencies was considered that the areas of additional cooling surface and the photocell are equal and are 1 m^2.

Fig. 3 shows that the area of additional cooling surface A' during the year changes insignificantly, and 2 – 2.2 times bigger than the area of the photocell A. The simulation data was obtained for the relationship of additional cooling surface area to the area of the photocell A'/A. This information, according to the authors, is representative, universal and suitable for further analysis.

5. Conclusions

1. On the basis of mathematical models, the change in temperature of photocell's surface during the year was calculated. Coefficients of heat transfer between photocell's surface and the environment by convection, radiation and conduction were obtained for the Simferopol city.

2. The calculation of the area of additional cooling surface is made. It was determined that for full compensation of the photocell heating by incident solar radiation the surface area must be 2 – 2.2 times bigger than the area of photocell.

3. The performed calculations will enhance in the future the solar energy conversion efficiency by photocells throughout the year, even at high temperatures of environment and the photocell's surface.

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Received 10 June 2015.

М.М. Асанов[1], Е.А. Бекіров[2], О.В. Соломенцев[3], М.Ю. Заліський[4]. Зниження впливу нагріву поверхні фотоелемента на продуктивність його роботи

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Як відомо, сонячне випромінювання, потрапляючи на фотоелемент, перетворюється не тільки в електричну, але й у теплову енергію, нагріваючи його поверхню. Тільки 6–20 % сонячного випромінювання використовується для отримання електроенергії. Інша частина енергії в основному витрачається на нагрівання фотоелемента, що значно знижує ефективність його роботи. Коефіцієнт корисної дії перетворення сонячної енергії зменшується у разі збільшення температури. Цю статтю присвячено зменшенню впливу нагріву фотоелемента на ефективність перетворення ним сонячної енергії шляхом встановлення його на додаткову охолоджуючу поверхню, яка грає роль радіатора. Дані щодо величини сонячного випромінювання, яке падає на одиницю площі фотоелемента, температури навколишнього середовища та швидкості вітру взяті для м. Сімферополя. У роботі виконаний розрахунок площі додаткової охолоджуючої поверхні. Встановлено, що для повної компенсації нагріву фотоелемента площа цієї поверхні повинна бути в 2 – 2,2 рази більша за площу фотоелемента. У результаті моделювання були отримані дані не щодо площі додаткової поверхні A', а щодо відношення цієї площі до площі фотоелемента A'/A. Ці відомості, на думку авторів, є більш наочними, універсальними та зручними для подальшого аналізу.

Ключові слова: ефективність фотоелемента; нагрів фотоелемента; оптимізація розмірів фотоелемента

М.М. Асанов[1], Э.А. Бекиров[2], А.В. Соломенцев[3], М.Ю. Залисский[4]. Снижение влияния нагрева поверхности фотоэлемента на продуктивность его работы

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Как известно, солнечное излучение, попадая на фотоэлемент, преобразуется не только в электрическую, но и в тепловую энергию, нагревая его поверхность. Только 6–20 % падающего на фотоэлемент солнечного излучения используется для получения электричества. Остальная энергия, в большей степени, идет на нагрев фотоэлемента, что значительно снижает эффективность работы фотоэлемента. Коэффициент полезного действия преобразования солнечной энергии уменьшается при повышении температуры. Данная работа посвящена уменьшению влияния нагрева фотоэлемента на эффективность преобразования им солнечной энергии путем установки его на дополнительную охлаждающую поверхность, которая играет роль радиатора. Данные о величине солнечного излучения, падающего на единицу площади фотоэлемента, температуре окружающей среды и скорости ветра взяты для города Симферополя. Произведен расчет площади дополнительной охлаждающей поверхности. Определено, что для полной компенсации нагрева фотоэлемента падающим солнечным излучением площадь этой поверхности в 2 – 2,2 раза должна быть больше площади самого фотоэлемента. В результате моделирования были получены данные не о площади дополнительной охлаждающей поверхности A', а об отношении этой площади к площади самого фотоэлемента A'/A. Эти сведения, по мнению авторов, являются более репрезентативными, универсальными и удобными для последующего анализа.

Ключевые слова: эффективность фотоелемента, нагрев фотоэлемента, оптимизация размеров фотоэлемента

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