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THERMAL OPERATING CONDITIONS OF THE HYBRID PHOTOMODULE WITH ANY EXPENSE OF THE HEAT CARRIER

В.В. Височин, В.Р. Нікульшин, А.Е .Денисова. **Термічні умови роботи гібридного фотомодуля з довільною витратою теплоносія.** Термічні умови роботи фотомодуля значною мірою визначають ефективність виробництва електроенергії. Введення у фотомодуль пристрою примусового охолодження дозволяє управляти термічним режимом. Вибір способу керування процесом охолодження й режиму його реалізації дає можливість досягнення раціонального сполучення електричної й теплової продуктивності фотомодуля. У даній роботі проведені аналітичні дослідження формування температурного поля абсорбера гібридного сонячного колектора (PVT) при охолодженні зі змінною витратою теплоносія. Метод дослідження дозволяє проаналізувати характеристики PVT-колектора – температуру нагрівання абсорбера й охолоджуючої рідини залежно від зовнішніх і режимних умов роботи пристрою. Ціль роботи – розробка методу розрахунку теплотехнічних експлуатаційних характеристик роботи гібридного сонячного колектора в різних умовах, обумовлених витратою охолоджуючого теплоносія. Використано комплексну математичну модель локального аналізу процесів теплообміну гібридного сонячного колектора для реальних умов динамічної сонячної й кліматичної ситуації. Аналіз теплообміну у варіантних умовах показав, що ефективність передачі тепла в системі охолодження колектора η_T, інакше – співвідношення температури абсорбера й кінцевої температури теплоносія, не є постійною величиною й значно змінюється під впливом зовнішніх і внутрішніх факторів. На неї впливає інтенсивність інсоляції, температура навколишнього середовища й витрата теплоносія. З ростом цих параметрів η_T знижується. Отримані узагальнюючі залежності для визначення температури рідини на виході із пристрою й середньої температури абсорбера при зміні витрати теплоносія, які можуть бути використані для оцінки ефективності перетворення сонячної енергії в електричну й теплову в завданнях конструктивної й режимної оптимізації.
Ключові слова: гібридний сонячний колектор, PVT-колектор, температурний режим, змінна витрата теплоносія

V. Wysochin, V. Nikulshin, A. Denysova. **Thermal operating conditions of the hybrid photomodule with any expense of the heat carrier.** Thermal operating conditions of the photomodule considerably define production efficiency of the electric power. Introduction to the photomodule of the device of forced cooling allows to operate the thermal mode. The choice of a way of management of process of cooling and the mode of its realization gives the chance of achievement of a rational combination of electric and thermal performance of the photomodule. In this work analytical researches formation of the temperature field of an absorber of a hybrid solar collector (PVT) when cooling with a variable expense of the heat carrier are conducted. The method of a research allows to analyze characteristics of the PVT collector – temperature of heating of an absorber and cooling liquid depending on external and regime operating conditions of the device. The work purpose – development of a method of calculation of heattechnical operational characteristics of work of a hybrid solar collector in various conditions determined by an expense of the cooling heat carrier. The complex mathematical model of the local analysis of processes of heat exchange of a hybrid solar collector for real conditions of a dynamic solar and climatic situation is used. The analysis of heat exchange in alternative conditions showed that efficiency of transfer of heat in the cooling system of the collector η_T, otherwise - the ratio of temperature of an absorber and final temperature of the heat carrier, is not a constant and considerably changes under the influence of external and internal factors. It is influenced by intensity of insolation, ambient temperature and an expense of the heat carrier.With growth of these parameters η_T decreases. The generalizing dependences for determination of temperature of liquid at the exit from the device and the average temperature of an absorber are received at change of an expense of the heat carrier which can be used for assessment of efficiency of transformation of solar energy in electric and thermal in problems of constructive and regime optimization.
Keywords: hybrid solar collector, PVT collector, temperature condition, variable expense of the heat carrier

Introduction

It is known that the efficiency of electricity production by a photocell depends on its temperature [1, 2, 3, 4, 5, 6, 7]. As the temperature increases, the efficiency of the module decreases. Various cooling methods, both natural and forced, are used to reduce the heating intensity of the device. The latter method allows to utilize the heat of cooling, which increases the overall energy efficiency of the device [1, 5]. In such a hybrid solar collector (PVT), photovoltaic cells are usually cooled by an active liquid heat dissipation system through channels in the rear of the module.

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The introduction of a heat exchanger into the photocell leads to the appearance of uneven temperature field along the flow of the coolant. This affects local and, therefore, general electricity production. For PVT collector, where the heating temperature of the coolant determines the direction of use of energy resources, as well as the efficiency of electricity generation, it is important to justify the thermal mode of operation of the device.

Analysis of recent research and publications

The temperature of the absorber in the PVT collector is often determined as the average on the surface for typical operating conditions of the cooler [6]. The final temperature of the coolant and the efficiency of electricity generation is associated with the found temperature of the absorber, involving, for example, a poorly substantiated coefficient of process efficiency [6]. In [5, 7] it is shown that the selected cooling temperatures are significantly reflected in the characteristic cooling temperatures, which is not taken into account by the process efficiency coefficient. Taking into account the influence of cooling operating conditions, generalized methods [7] for determining the average temperature of the absorber and the final heating temperature of the coolant in modes characterized by independent of the size of the absorber, fixed, coolant flow rate $g = \text{idem}$, and – at the flow rate taken depending on the absorber area $g = f(A_{ab})$. However, in practice, use the mode of control of PVT with arbitrary coolant flow, which is set depending on the process control algorithm ($g = \text{var}$). However, for these conditions, the method of determining the temperature is absent.

Analytical models are usually used to study the modes of operation of the PVT collector [5, 6, 7, 8, 9]. Such models differ in the way and detail of the mathematical description of the work of objects, which is carried out in combined and significantly changing conditions. Obtaining the necessary information directly depends on the completeness and adequacy of the description. An important factor in the research of different models is the generalization of the results in the format required for engineering implementation, which in most cases is not performed.

Purpose

Development of a method for calculating the thermal performance characteristics of a hybrid solar collector in different conditions due to the consumption of coolant and approximation of analytical data in the form of generalized functions.

Presentation of the main material

The model structure of the device consists of a solar absorber, on one side fenced off from the outside space by a transparent wall. On the other hand, as an element of a flat duct for cooling coolant, surrounded on three sides by external walls.

The external conditions of heat transfer in the PVT collector are the intensity of the absorber irradiation and heat exchange with the environment. Internal conditions are formed during heat exchange between the absorber and the coolant, as well as between the coolant and the rear wall adjacent to the external environment. These processes are described by a system of equations of energy conservation in the absorber, coolant and in the rear wall of the channel [7].

The efficiency of the photovoltaic cell η_{ep} depends on the temperature, and in the region of positive temperatures can be represented by a linear relationship [5]:

$$\eta_{ep} = \eta_{\max SC}[1 + \alpha_P(t_{ab} - t_{SC})],$$

where $\eta_{\max SC}$ – photovoltaic efficiency at the point of maximum power under standard conditions (SC);

t_{SC} – the temperature of the photovoltaic battery at SC;

α_P – temperature coefficient of photovoltaic capacity.

The system of equations, supplemented by boundary conditions characteristic of the operation of solar devices [5], was solved by numerical method. Because the change in temperature in the system occurs along the flow of the coolant, the normalization of the considered indicators relative to the width of the channel.

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When considering heat transfer processes, the main parameters of the analysis are the final coolant temperature and the absorber temperature. These parameters vary significantly along the surface of the absorber [7], and for practical purposes it is necessary to develop an easy-to-use method for determining such temperatures. Based on the fact that the dependence of temperature on the length of the channel in the general case differs from the linear [7], as the calculated temperature is taken as its average integral value for the entire surface of the channel ($\overline{t}_{ab}$).

The law of change of the expense of the heat carrier can be chosen in various ways. In this case, it is assumed that the cost does not depend on the size of the module, and is set arbitrarily. This, for example, occurs when regulating the temperature. When analyzing the processes in the collector, you can choose the external conditions as determinants – the temperature of the outside air and the intensity of irradiation, as well as the consumption of the coolant. It is convenient to express the consuption of the coolant in the form of the relative value $k_g = g / g^*$, which is given to the base flow rate (g^* = 0.015 l/s), generally accepted for solar collectors.

Fig. 1 shows the dependence of the absorber temperature on the determining factors at a fixed size of the absorbing surface, equal to A = 2 m^2. This value is typical for the surface of solar panels: of course, based on the conditions of transportability, the width is about 1.0 m, length – 2 m.

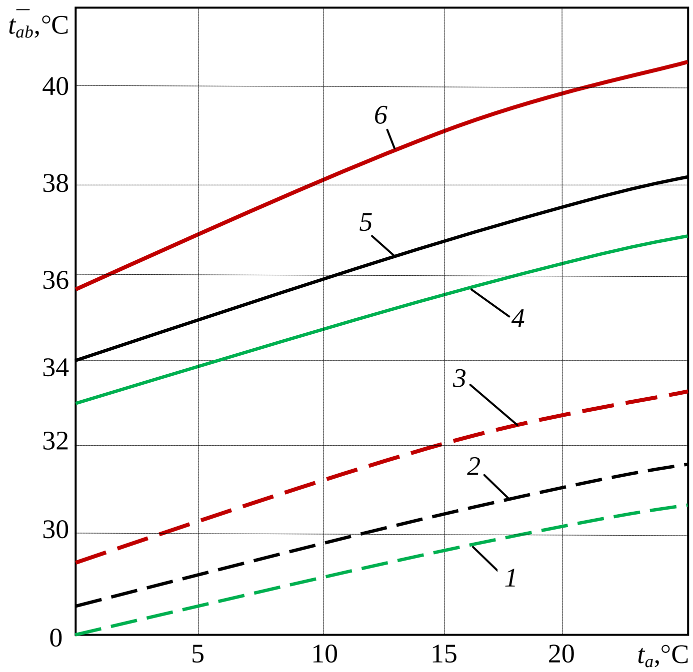

Fig. 1. The influence of the relative flow rate of the coolant on the temperature of the absorber with variant external factors, H, W.m^2/k$_g$: 1 – 500/2; 2 – 500/1.5; 3 – 500/1; 4 – 800/2; 5 – 800/1.5; 6 – 800/1

An increase in the temperature of the outside air and the intensity of irradiation leads to an increase in the average temperature of the absorber $\overline{t}_{ab}$, but with increasing rate k_g of change $\overline{t}_{ab}$ from the temperature of the outside air decreases (Fig. 1). The intensity of solar radiation affects this dependence to a lesser extent. The considered mode with variable flow rate at a fixed area of the module is characterized by a wide field of temperature distribution in the available range of changing conditions. At the same time higher temperatures of the absorber are available, than in other modes. However, under equal conditions in the mode carried out at variable module sizes ($g=g^* \cdot A$), similar dependences also correspond to curves 1 and 4 in Fig. 1. It should be noted that a distinctive feature of the heat transfer process with area-related consumption is the independence of the average temperature of the absorber from its size.

Functional dependence for determining the average temperature of the absorber, which summarizes the influence of the determining parameters, obtained in the form:

$$\overline{t}_{ab} = 1.32(k_g + 11.51) + 0.0094H(1.58 + 1/k_g) + 0.135t_a(0.34 + 1/k_g),$$

where H – radiation flux density; t_a – ambient temperature.

Taking into account that the temperatures of the absorber and the coolant are interdependent, to solve the system of equations we use a complex that determines the ratio of changes in temperature of the coolant and the average temperature of the absorber [7]:

$$\eta_{he} = \frac{t''_f - t'_f}{\overline{t}_{ab}}.$$

This complex is called the coefficient of heat transfer efficiency from the absorber to the coolant.

For PVT collector of a specific design, the coefficient of heat transfer efficiency depends on external conditions - ambient temperature and intensity of insolation. With increasing these parameters η_{he} increases (Fig. 2). The internal factor of dependence is the relative consumption k_g. Growth of k_g reduces the effect of temperature and insolation on function. At the same time there is a decrease in the efficiency of heat transfer, as well as the rate of its dependence on t_a.

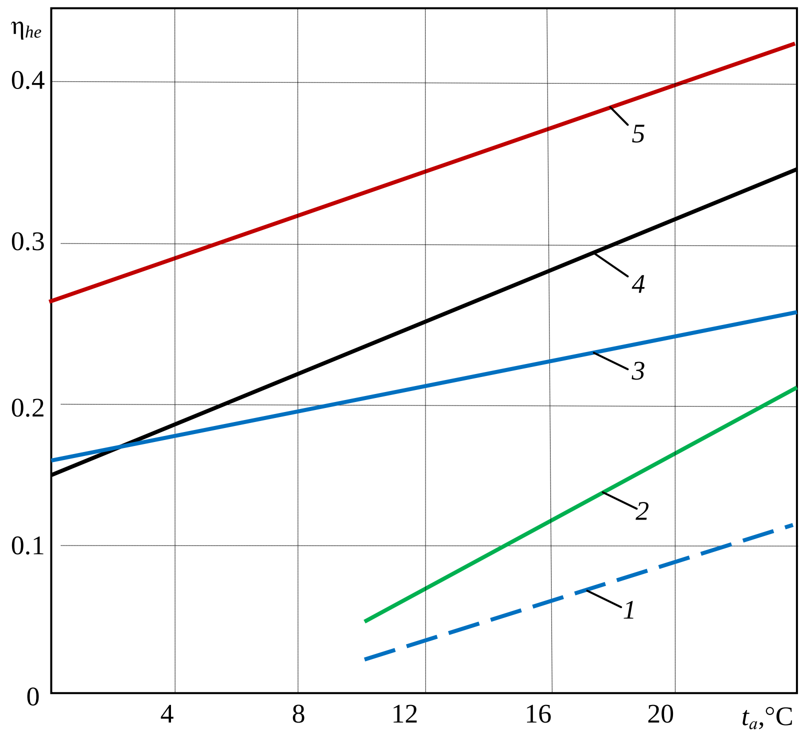

Fig. 2. The influence of external conditions on the efficiency of heat transfer at a channel length of 2 m; coefficient k_g /intensity of irradiation, W/m^2: 1 – 2/200; 2 – 1/200; 3 – 2/800; 4 – 1/500; 5 – 1/800

Based on the obtained data, the intensity of irradiation, ambient temperature and coolant consumption have a decisive influence on the coefficient of heat transfer efficiency under constant heat exchange conditions. With this in mind, a generalized dependence in the form is obtained:

$$\eta_{he} = \left(0.039 + \frac{0.205}{k_g}\right)\ln\frac{H}{k_g} - \left(0.03 + \frac{1.322}{k_g}\right) + t_a \exp\left[\frac{1}{k_g}\left(1.18 + \frac{0.00275H}{k_g - 3.66}\right) - 5.53\right].$$

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Because the optimization of the modes of operation of thermal devices involves the task of the basic level of comparison, in this method as such a base adopted the initial temperature of the coolant t'_f, the value of which in obtaining formulas was chosen equal to 20 °C. The choice is due to the ability to control this parameter in real conditions.

Conclusions

Analytical researches of operational heat engineering work characteristics influence of a hybrid solar collector in the conditions caused by a expense of the cooling heat carrier are carried out.
The results of the study show:

1. An increase in the temperature of the outside air and the intensity of irradiation leads to an increase in the average temperature of the absorber $\overline{t}_{ab}$, but with increasing relative flow rate k_g of change $\overline{t}_{ab}$ from the temperature of the outside air decreases. The intensity of solar radiation to a lesser extent affects this dependence.

2. The mode with variable flow rate at a fixed area of the module is characterized by a wide field of temperature distribution in the available range of changing conditions. In general, higher absorber temperatures are available than in other modes.

3. With increasing ambient temperature and insolation intensity, the coefficient of heat transfer efficiency in the η_{he} module, which determines the ratio of changes in coolant temperature and average absorber temperature, increases. Growth of k_g reduces the effect of temperature and insolation on function. At the same time there is a decrease in the efficiency of heat transfer and reduce the rate of its dependence on temperature.

Generalized dependences for determination of the average temperature of the PVT collector absorber and the coefficient of heat transfer efficiency to the cooling coolant are obtained. The offered model generalizations can be used for an estimation of efficiency of conversion of solar energy into electric and definition of final temperature of the heat carrier of the combined solar device in problems of mode optimization.

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