The European Journal of Technical and Natural Sciences 2024, No 1
ISSN 2414-2352

PREMIER Publishing
ppublishing.org

Section 1. Electrical engineering

DOI:10.29013/EJTNS-24-1-3-10

THERMAL AND ENERGY CHARACTERISTICS OF A COGENERATIVE FRACTAL SOLAR COLLECTOR

Rustamov Nasim Tulegenovich [1], ***Kibishov Adylkhan Talgatovich*** [1], ***Mukhamejanov Nuridin Baktiyaruly*** [1]

[1] International Kazakh-Turkish University named after Khoja Ahmed Yasawi,

Cite: *Rustamov, N.T., Kibishov, A.T., Mukhamejanov, N.B. (2023). Thermal and Energy Characteristics of a Cogenerative Fractal Solar Collector. European Journal of Technical and Natural Sciences 2024, No 1.* https://doi.org/10.29013/EJTNS-24-1-3-10

Abstract

The paper considers the design and thermal energy characteristics of a new type of fractal solar collector operating in cogeneration mode. The principle of operation of the proposed solar installation is given. The efficiency of using solar insolation in comparison with flat solar collectors is shown.

Keywords: *Fractal, solar collector, cogeneration mode, solar insolation, electric energy*

Introduction

A solar collector is a device for collecting thermal energy from the Sun (solar installation), carried by visible light and near infrared radiation. Unlike solar panels, which produce electricity directly, the solar collector heats the coolant material.

As is known, thermal energy analysis is especially important for solar installations, since this natural source is characterized by stochasticity and strong energy dissipation in space, which requires a design change to increase the use of solar energy. The problem of the need to conduct an energy analysis of such installations was formulated in the works of P. L. Kapitsa.

The more incident energy is transferred to the coolant flowing in the collector, the higher its efficiency. It can be increased by using special optical coatings that do not emit heat in the infrared spectrum. All existing solar collectors in the world differ mainly in their design, material and manufacturing technology of their absorbers (Avezova, N. R. Avezov, R. R., Rustamov, N.T., Vakhidov, A., Suleymanov, Sh.I., 2013; Ermuratsky, V.V., Postolatiy, V.M., Koptyuk, E.P., 2009). At the same time, the option of increasing the efficiency of the collector by changing the location of the absorbers on the aperture area of the collector is not considered.

The development of efficient designs of solar collectors and installations for heat supply to the population, as well as the search for ways and new technologies that are economically advantageous for the use of solar heat supply systems today, is one of the urgent problems of large-scale use of solar energy in the field of municipal thermal power engineering.

The purpose of the work is to increase the efficiency of using solar rays by solar collectors, due to their operation in a cogenerative mode.

The solution method

The Department of Electrical Engineering of the A. Yassavi International Kazakh Turkish University has developed and patented several fundamentally new designs for the location of absorbers on the aperture area and their shape of solar collectors. In order to reduce heat loss and increase the energy efficiency of solar collectors, an optimal design has been developed, where absorbers in the form of fractals are located on the aperture area of a parabolic concentrate according to the principle of the Fibonacci number. Such a solar installation was called fractal solar collectors ФСК (Rustamov, N. T., Meirbekov, A. T., Korganbaev, B. N., Patent No. 2639; Rustamov, N. T., Meirbekov, A. T., Kibishev, A. T., invention No. 36213).

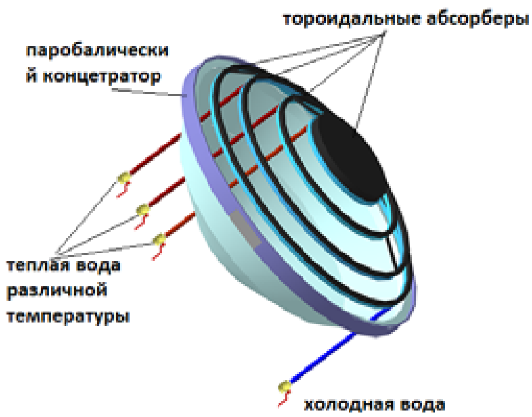
The aperture area of such a collector serves as a reflector of the sunlight passing through and past the absorbers. The reflected rays additionally heat the collector pipes arranged in the form of fractals. Thus, the sun's rays are used multiple times. As a result, the efficiency of the ФСК increases compared to a flat solar collector (Rustamov, N. T., Kibirov, A. T., Israilov, F. M., Ernazar, K. E., 2023; Rustamov, Nassim, Kibishov, Adylkhan, Naci Genc, Shokhrukh Babakhan, Ernazar Kamal, 2023).

This type of solar installation is a battery of a parabolic concentrator (similar in shape to a satellite dish), which focuses reflected sunlight from the aperture area onto receivers located at the focal point (the first fractal). In the presented case, the solar installation allows the consumer to receive m of thermal water of various temperatures.

Figure 1. Toroidal absorber: a), the general design of fractal solar collectors b) If the ФСК operates in cogeneration mode, the efficiency of the solar installation will increase even more. Based on this concept, the department has developed a cogenerative fractal solar collector

a) b)

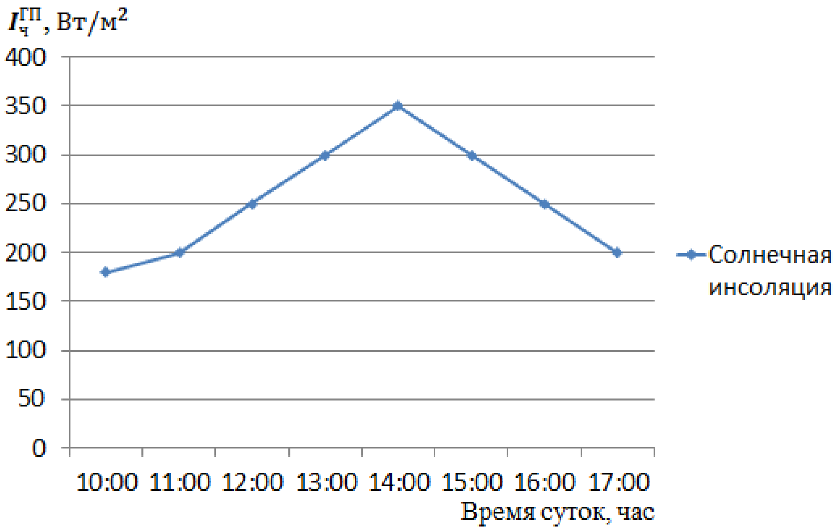
Figure 2. General view of a cogenerative fractal solar collector



As is known, when a solar installation generates both electrical and thermal energy, then it is said that the solar installation operates in the mode of cognition. In order for the ФСК to work in cogeneration mode, the reverse side of the toroid absorber is sheathed with a polymer photo panel. Then the reflected rays from the aperture area of the collector colliding with the photo panel will generate an electric current. As a result, the ФСК starts working in cogeneration mode.

During the operation of the КФСК, the consumer will receive heat and electricity at the same time, this is the cogeneration of the solar installation. To assess the thermal and energy characteristics, the КФСК was manufactured according to the method described in (Rustamov, Nassim, Kibishov, Adylkhan, Naci Genc, Shokhrukh Babakhan, Ernazar Kamal, 2023). Based on the experimental data obtained, the ability of the КФСК to absorb solar radiation, the useful power of solar radiation for a solar collector, heat losses, and the electrical power that the solar installation generates were evaluated. All calculations were carried out for solar insolation for the city of Turkestan for the month of March 2023. (Fig. 3).

Figure 3. Daily solar insolation for Turkestan (1.03.2023)



The electrical characteristics of the КФСК were measured every hour. The electric current generated by миthe solar panels was measured for each fractal of the КФСК. The estimates obtained are shown in Table 1.

Table 1. Energy characteristics in КФСК

КФСК Energy description 	**Daily hours**							
	10^{00}	**11^{00}**	**12^{00}**	**13^{00}**	**14^{00}**	**15^{00}**	**16^{00}**	**17^{00}**
$I_ч^{ГП}, W/m^2$	180	200	250	300	350	300	250	200
R	2.56	2.18	2.09	2	2	2.09	2.18	2.56
$t_{окр}, °C$	8	9	10	11	12	13	14	13
$I_ч^{НП}, W/m^2$	460.8	436	522.5	600	700	627	549.4	512
$I_ч^{погл}, W/m^2$	354.8	335.7	402.3	462	539	482.8	423	394.2
$\gamma_ч^{mn}, W/m^2$	312	306	300	294	288	282	276	282
$Q_{l_{a1}}^{ч}, W/m^2$	5	8.5	21.9	39.6	60.4	49.5	34.2	24.1

КФСК Energy description 	**Daily hours**							
	10^{00}	**11^{00}**	**12^{00}**	**13^{00}**	**14^{00}**	**15^{00}**	**16^{00}**	**17^{00}**
$Q^{ч}_{l_{a2}}, W/m^2$	6.2	10.3	24.7	46.2	78.1	56.9	34.2	26.2
$Q^{ч}_{l_{a3}}, W/m^2$	7.3	12	37.5	50.7	86	66.3	36.1	34.2
$Q^{ч}_{l\,отр} W/m^2$	14.7	15.9	17.2	18.4	19.6	21	19.6	17.2
$Q^{ч}_{общ}, W/m^2$	16.8	18.2	19.6	21	22.4	23.8	22.4	19.6
$\eta^{a_1}_{ч}, \%$	21	22.8	24.5	26.3	35	29.8	28	24.5
$\eta^{a_2}_{ч}, \%$	52.5	56.9	61.3	65.7	77	74.6	70	61.3
$\eta^{a_3}_{ч}, \%$	71	84	145.4	202.2	301.5	247.3	174.5	145.8
$\eta^{отр}_{ч}, \%$	60	70	74	75.4	76	75.3	75	74.6

First of all, we measure the radius of each fractal located in the solar collector, R_1, R_2, R_3, and the inner radius of the fractal tube r.

R_1 = 0.15 m, R_2 = 0.30 m, R_3 = 0.40 m, r = 0.016 m.

Using the measured radii, we calculate the surface area of each fractal pipeline $A_{a_1}, A_{a_2}, A_{a_3}$.

$A_{a_1} = 0.13\,\text{m}^2; A_{a_2} = 0.19\,\text{m}^2; A_{a_3} = 0.25\,\text{m}^2;$

The hourly values of the useful part of the solar radiation power are found by the formula, $F_R = 0.9$

$$Q^{ч}_{l_{a1}} = AF_R\left(I^{погл}_{ч} - \gamma^{mn}_{ч}\right)$$

Where

A –absorber

F_R – is the heat transfer coefficient from the solar collector

$I^{погл}_{ч}$ – the corresponding hourly values of absorbed solar radiation

$\gamma^{mn}_{ч}$ – hourly value of heat losses

For the first absorber

$$Q^{12^{00}}_{l_{a1}} = A_{a_1}F_R\left(I^{погл}_{12^{00}} - \gamma^{mn}_{12^{00}}\right) =$$

$$= 0.13 * 0.9(704{,}8 - 300) = 47.4\,\text{W/m}^2$$

For the second absorber

$$Q^{12^{00}}_{l_{a2}} = A_{a_2}F_R\left(I^{погл}_{12^{00}} - \gamma^{mn}_{12^{00}}\right) =$$

$$= 0.19 * 0.9(704{,}8 - 300) = 69.2\,\text{W/m}^2$$

For the second absorber

$$Q^{12^{00}}_{l_{a3}} = A_{a_3}F_R\left(I^{погл}_{12^{00}} - \gamma^{mn}_{12^{00}}\right) =$$

$$= 0.25 * 0.9(704{,}8 - 300) = 91.1\,\text{W/m}^2$$

We determine the area of the solar panel under each absorber A_1, A_2, A_3

We determine the area of the solar panel under the first absorber A_1

R_1 – is the first radius of the fractal (0.15 m)

$$A_1 = \pi R_1^2 = 3.14 * 0.15^2 = 0.07\,\text{m}^2$$

The area of the solar panel under the second absorber is determined by the formula A_2

$$A_2 = l_2 * a$$

First of all, we measure the length of the second fractal $l_2 = 2\pi R_2$ $R_2 = 0{,}3$ m

$$l_2 = 2\pi R_2 = 2 * 3.14 * 0{,}3 = 1.9\,\text{m}$$

Now let's determine the area of the solar panel under the second absorber A_2

$$A_2 = l_2 * a$$

a – the width of the solar panel, a = 0.04 m

$$A_2 = l_2 * a = 1.9 * 0.04 = 0.08\ \text{m}^2$$

We determine the area of the solar panel under the third absorber A_3

We measure the length of the third fractal $l_3 = 2\pi R_3$ where $R_3 = 0{,}4$ m

$$l_3 = 2\pi R_3 = 2 * 3.14 * 0{,}4 = 2.6\,\text{m}$$

The area of the solar panel under the third absorber is determined by the formula

$$A_3 = l_3 * a$$

$$A_3 = l_3 * a = 2.6 * 0.04 = 0.1\ \text{m}^2$$

The power of the solar panel is determined by the formula P

$$P = A * \eta * I_{луч} \tag{9}$$

where

A – solar panel area m²

η – the percentage of solar panel efficiency of 15% is 0.15

$I_{луч}$ – radiance is the radiant power of reflected solar radiation w/m^2

We find the area of the area of reflection of sunlight

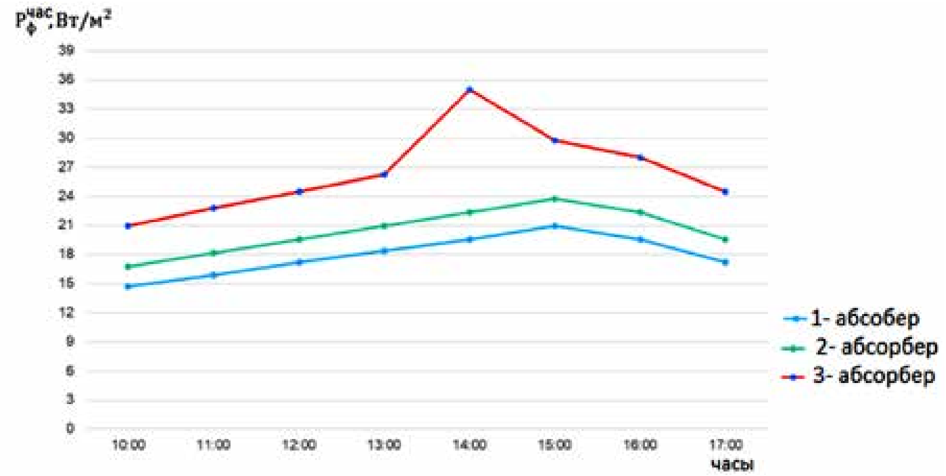
$$A_{пар} = \pi\left(h^2 + 2a^2\right) =$$
$$= 3.14 * \left(0.25^2 + 2 * (0.40)^2\right) = 1.2\,m^2$$
$$A_{абсор} = A_1 + A_2 + A_3 = 0.13 + 0.19 +$$
$$+0.25 = 0.57\,m^2$$

$$A_{кв.площ} = A_{пар} - A_{абсор} = 1.2 - 0.57 = 0.63\,m^2$$

Calculate the value of reflected solar radiation from a parabolic concentrator, $F_R = 0.9$; $A_{кв.площ} = 0.63\,m^2$.

$$I_{луч}^{12^{00}} = A_{ш.ау} F_R \left(I_{12^{00}}^{жут} - \gamma_{12^{00}}^{ТП}\right) =$$
$$= 0.63 * 0.9(704.8 - 300) = 229.5\,W/m^2$$

Figure 4. Graph of the electric power on the solar panel in each fractal of the КФСК by the hour



Doubles the value of solar radiation reflected from a parabolic concentrator

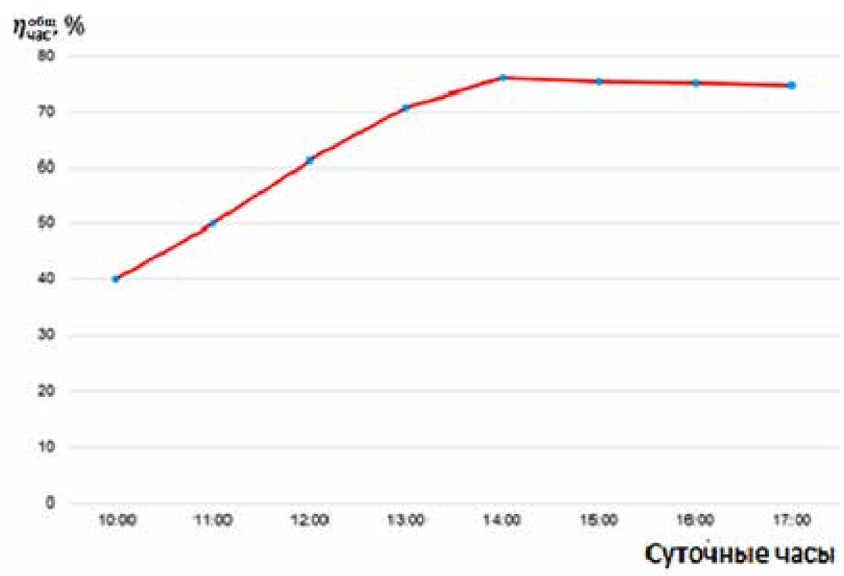
Using formula (9), we find the power of the solar panel on each fractal of the КФСК P P_1, P_2, P_3

$$P_1 = A_1 * \eta * I_{луч}^{12^{00}} =$$
$$= 0.07 * 0.35 * 700 = 17.2\,W$$

$$P_2 = A_2 * \eta * I_{луч}^{12^{00}} =$$
$$= 0.08 * 0.35 * 700 = 19.6\,W$$

$$P_3 = A_3 * \eta * I_{луч}^{12^{00}} =$$
$$= 0.1 * 0.35 * 700 = 24.5\,W$$

Figure 5. Dynamics of efficiency by daily hours to КФСК



We calculate the total power received from the solar panel from КФСК at 12:00 $P_{общ}$

$$P_{общ} = P_1 + P_2 + P_3 = 17.2 + 19.6 + 24.5 = 61.3W$$

Analyzing this graph, we can add that the generation of electric energy using a water-heating solar installation has a number of advantages. Our experiments have shown that the generated electric energy by a water-heating solar installation can meet the needs of the solar installation itself. Thus, we can verify the effectiveness of the КФСК. Below we present the dynamics of efficiency changes.

An assessment of such dynamics of a water heating solar installation makes it possible for the consumer to optimize the operating time of this solar installation.

As an example, we will show the dynamics of the efficiency of a cogenerative fractal solar collector in eight hours. To do this, we selected the following initial values from Table 1.

$$I_{12^{00}}^{НП} = 555.5\frac{Вт}{м^2};\ Q_{общ}^{12^{00}} = 196.5\frac{Вт}{м^2};$$

$$P_{общ}^{12^{00}} = 17.25W;$$

The efficiency for the CFSC as a whole, where we determined the total area of the solar panel $A_{кв.площ} = 0.63м^2$

$$\eta_{12^{00}}^{общ} = \frac{Q_{общ}^{12^{00}} + P_{общ}^{12^{00}}}{A_{общ} I_{12^{00}}^{НП}} * 100 =$$

$$= \frac{196.5 + 61.3}{0.63 * 555.5} * 100 = 74\%$$

Taking into account the corresponding hourly electrical values of the КФСК $Q_{общ}^{ч}$ and $I_{ч}^{НП}$, their daily (total) values are determined by the formulas Q $\Sigma Q_{общ}^{ч}$ и $\Sigma I_{ч}^{НП}$, using formula (9), we found the daily efficiency of CFSC:

$$\eta_{ФСК_{сут}} = \frac{\sum Q_{общ}^{ч}}{A_{абсор} \sum I_{ч}^{НП}} * 100 =$$

$$= \frac{71 + 84 + 145.4 + 202.2 + 301.5 + 247.3 + 174.5 + 145.8}{0.63 * (460.8 + 436 + 522.5 + 600 + 700 + 627 + 549.4 + 512)} *$$

$$* 100 = \frac{1371.7}{4407.7 * 0.48} * 100 = 71.3\%$$

Using the following empirical formula in the КФСК, we determined the average daily value of efficiency:

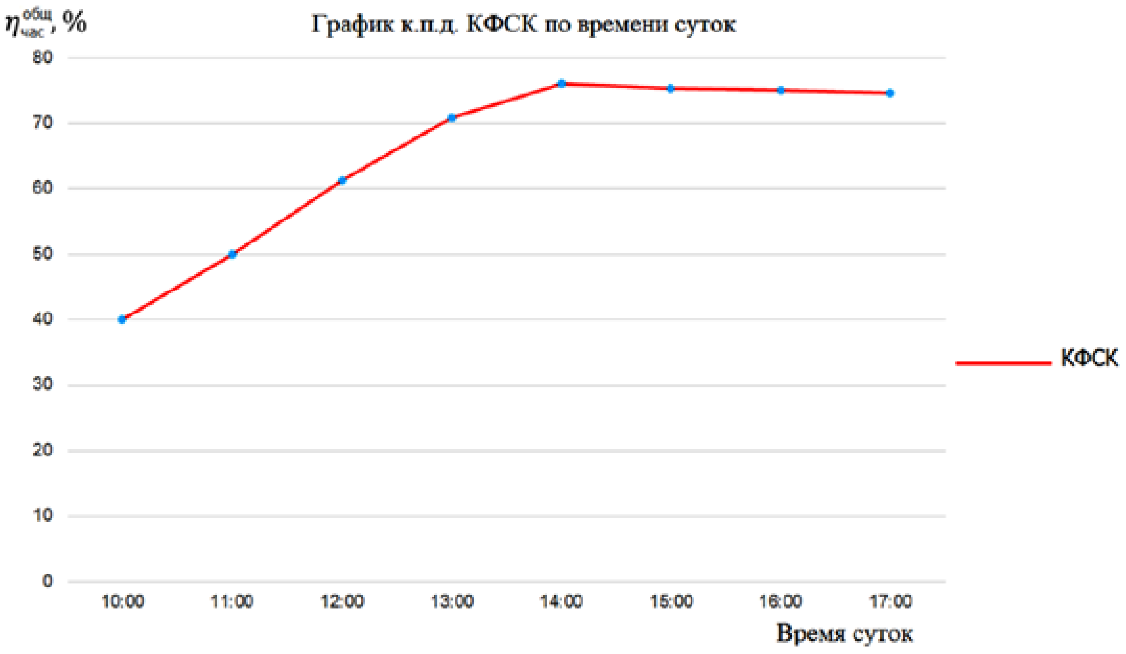
$$\eta_{КФСК_{сут}}^{сред} = \frac{\sum \eta_{общ}}{n} =$$

$$= \frac{71 + 84 + 145.4 + 202.2 + 301.5 + 247.3 + 174.5 + 145.8}{24} =$$

$$= 58.3\%$$

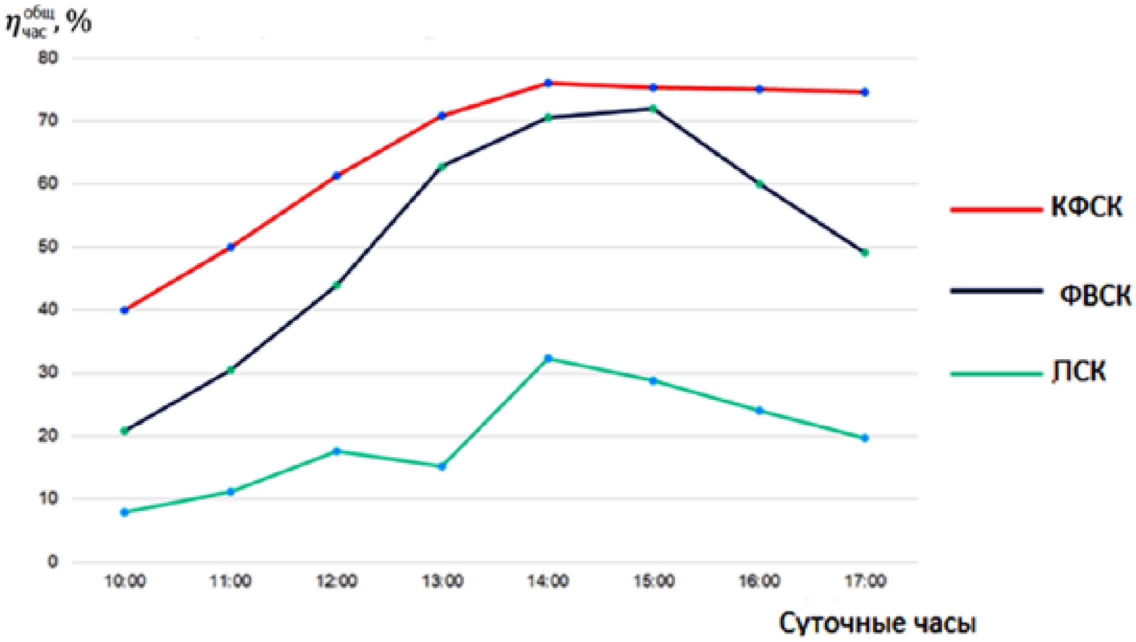
where $\eta_{общ} = \sum \eta_{час}$ – the hourly efficiency values in the КФСК are taken from Formula (7).

Figure 6. Dynamics of changes in the efficiency of a cogenerative fractal solar collector



Now let's consider a retrospective analysis of the efficiency of three solar collectors ПСК, ВФСК and КФСК. The efficiency data for a fractal evacuated collector (ФВСК) and a flat solar collector (ПСК) are taken from (Rustamov, Nassim, Kibishov, Adylkhan, Naci Genc, Shokhrukh Babakhan, Ernazar Kamal, 2023).

Figure 7. Retrospective analysis of the efficiency of three solar installations



This graph confirms the concept that was given at the beginning of the article. The positive and negative results obtained during the experiments stimulate the further development of research in this direction.

Conclusions

The use of solar collectors due to solar energy can reduce the cost of heating and hot water. Recent studies have shown that by changing the design of the absorbers in the aperture area, the use of solar insolation in a solar installation can increase its efficiency. The efficiency of installations performed with such a design can reach 80–85%. The new type of solar collector described in this paper is called a cogenerative fractal solar collector (КФСК). On the other hand, the creation of a КФСК producing both heat and electricity will stimulate the further development of solar collectors.

According to the results of the experiment, it can be said that the КФСК has shown itself to be on the good side in terms of the simplicity of its design and the low cost of consumable material, small footprint, and the efficiency of using solar insolation.

References

Avezova, N. R. Avezov, R. R., Rustamov, N. T., Vakhidov, A., Suleymanov, Sh. I. Resource indexes of flat solar water-heating collectors in hot-water supply systems: 4. Specific collector thermal yield and efficiency. Journal Applied Solar Energy, 2013.— Vol. 49.— Issue 4.— P. 202–210.

Ermuratsky, V. V., Postolatiy, V. M., Koptyuk, E. P. Prospects of application of solar water heaters for sanitary purposes in the Republic of Moldova. Problems of regional energy. 2009.— № 2. URL: http://ieasm.webart.md/data/m71_2_107.doc

Rustamov, N. T., Meirbekov, A. T., Korganbaev, B. N. Fractal solar collector. RK, Patent. – No. 2639 for a utility model.

Rustamov, N. T., Meirbekov, A. T., Kibishev, A. T. Vacuum fractal solar collector. Patent of the Republic of Kazakhstan for invention No. 36213.

Rustamov, N. T., Kibirov, A. T., Israilov, F. M., Ernazar, K. E. Efficiency coefficient of a vacuum fractal solar collector. European Journal of Technical and Natural Sciences – 2. 2023.– P. 46–53.
Rustamov, Nassim, Kibishov, Adylkhan, Naci Genc, Shokhrukh Babakhan, Ernazar Kamal. Thermal Conductivity of a Vacuum Fractal Solar Collector. International Journal of Renewable Energy Research N,– Vol. 13.– No. 2.– June, 2023.– P. 613–618.

submitted 22.08.2023;
accepted for publication 20.09.2023;
published 8.10.2023

Contact: babakhan.shokhrukh@ayu.edu.kz