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PRINCIPLE OF OPERATION AND FIELD OF APPLICATION OF SOLAR CONCENTRATORS AND FURNACES

Kozimjonov Nozimjon Azimjon o‘g‘li
Andijan Institute of Mechanical Engineering Assistant of the Department of “Alternative Energy Sources **”.**
Solijonov Asilbek Shuxratjon o‘g‘li
Andijan Institute of Mechanical Engineering, student of “Alternative Energy Sources”.
Olimov Fazliddin Sirojiddin o‘g‘li
Andijan Institute of Mechanical Engineering, student of “Alternative Energy Sources”.
Zoidov Otabek Rustambek o‘g‘li
Andijan Institute of Mechanical Engineering, student of “Alternative Energy Sources”

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Abstract:

This article describes the principle of operation and field of application of solar concentrators and furnaces.

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INTRODUCTION

Today, due to the growth of the world's population and the development of industry, the demand for electricity is increasing. Therefore, obtaining and supplying low-cost, efficient and environmentally friendly electricity remains one of the most pressing issues today. One of the solutions to this problem is the production of electricity from alternative energy sources (sun, water, wind, biogas, geothermal, etc.). The use of solar energy from these energy sources is developing much more than in previous times. That is, solar concentrators are widely used to collect solar energy.

Solar concentrators are devices that collect sunlight almost parallel to the Earth's surface. The main part of concentrators is a concave mirror. The light falling on the concentrator glass surface is collected in the focal plane. Depending on the shape of the glass, there are conical, elliptical, cylindrical, parabolic-cylindrical and paraboloid solar concentrators. In some cases, a secondary reflecting surface is installed to transfer the light collected in the focal plane of the main mirror to the back of the mirror.

6-7 mm thick polished glass, 2-3 mm ordinary mirror glass, pure A 95 aluminum and even polymers can be used as solar reflective material [1-2].

Concave mirrors and lenses can be used to make concentrators. But from a technological and economic point of view, mirrors are much better than lenses. That's why we focus mainly on mirror concentrators. Let's denote the projection of the concentrator surface to the sun's rays on a plane perpendicular to S_k, the absorber surface S_p, and the glass reflection coefficient of the light from the concentrator surface by R_{mirror}. Concentration occurs when $S_k > S_p$. In this case, the average flux density E_{qr} in the absorber is [4-8]:

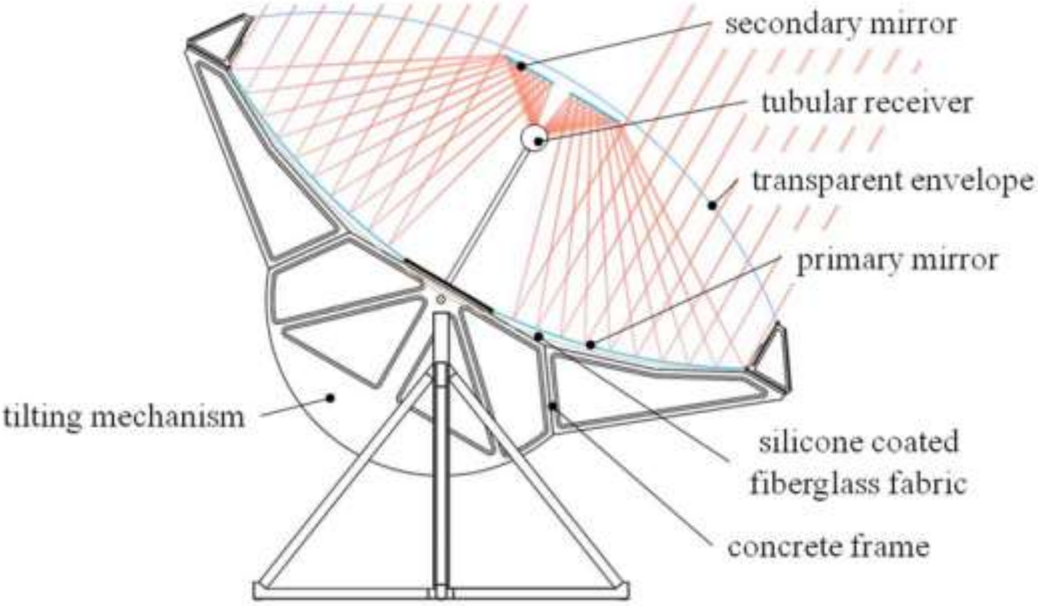
$$E_{qr} = E_q \cdot R_{\text{glass}} \cdot \frac{S_k}{S_p} \tag{1}$$

will be equal to From this, the dimensionless average flux density or concentration K is calculated as:

$$K = \frac{E_{qr}}{E_q \cdot R_{\text{mirror}}} \tag{2}$$

or, considering (1),

$$K = \frac{E_{qr}}{E_q \cdot R_{\text{mirror}}} = \frac{S_k}{S_p} \tag{3}$$



Picture 1. Scheme of operation of solar radiation concentrator

It is agreed that the concept of concentration is denoted by S when used in relation to the entire sunspot in the absorber, and by K when used in relation to its parts. Calculation methods for concentrators are based on concepts of geometrical optics and photometry. One of the methods of calculating the degree of concentration of the concentrator and the temperature generated in the focal plane is the optical-geometric method, in which the balance equation of energy is first applied [3-5]:

$$\Phi_p = \Phi_k \cdot \Phi_{\text{mirror}} \tag{4}$$

here, Φ_p and Φ_k are the light flux falling on the absorber and the concentrator, respectively; We consider that the light absorber has the size to fully receive the light stream directed from the concentrator. Then the basic equation is:

$$C_m = \frac{E_{qr}}{E_q \cdot R_{\text{mirror}}} \tag{5}$$

it will be visible. Based on this method, the average current density E_{qr} is determined and the relationship between the concentrator gauge and the absorber is established. Let's look at the view of connection (4) for the paraboloid concentrator-flat absorber (the absorber is located in the focal plane) system.

It is known that the equation of the parabola according to Cartesian coordinates, whose center is at the apex of the parabola, was as follows.

$$R^2 = 2 \cdot p \cdot z \tag{6}$$

Here, p is the focal parameter of the paraboloid ($p = 2f$). For a paraboloid surface $R = x + y$; x, y, z - coordinates of surface points; in a polar coordinate system with center F at the focus

$\rho = p(1+\cos U)$ (7)

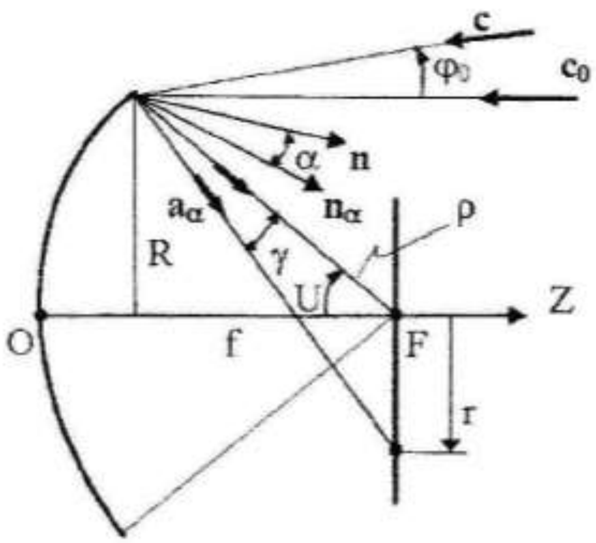


Figure 2. Scheme of a paraboloid concentrator with a flat absorber in the focal plane

Let the sun's rays fall parallel to the optical axis of the parabola. It is known that the Sun is a source of light with an angular radius of $\varphi_o=16'$ for the Earth [8].

The surface of the paraboloid projection $S_k = \pi R$

The surface of the light absorber is $S_p = \pi r^2$

Also from Fig. 2 $R = \rho \sin U$

$$r = \frac{\rho \cdot \gamma}{\cos\,(U+\gamma)}$$

where $\gamma = \varphi_o + 2\alpha$. Substituting this into (5), we get:

$$C_m = \frac{\sin^2 \cdot U_0 \cdot \cos^2(U_0+\varphi_0+2\alpha)}{(\varphi_0+2\alpha)^2} \qquad (8)$$

Correspondingly, for a parabolocylindrical concentrator (PSK)

$$C_m = \sin \cdot U_0 \cdot \frac{U_0+\varphi_0+2\alpha}{\varphi_0+2\alpha} \qquad (9)$$

we get the equation.

To determine the maximum value of concentration C_m

$$\frac{\delta C_m}{\delta U_0} = 0$$

is used from equation.

As an example, let's use it for a parabolocylindrical concentrator.

For clarity, we open the expression $\cos(U_0 + \varphi_o + 2\alpha)$:

$\cos(U_0 + \varphi_o + 2\alpha) = \cos U_0 - \gamma \cdot \sin \varphi_o \cdot U_0 + 2\alpha)$

Differentiating (9) and taking into account that $U_0 > 0$,

$\mathrm{tg} U_0 = (1+\gamma^2)^{0,5} - \gamma$

we will have Considering the smallness of γ, $\mathrm{tg} U_0 = 1$, or the optimal angle $U_0 = 45$. So, for the parabolocylindrical concentrator (PSC).

$C_m = \frac{1}{2\gamma} \approx 107{,}5$

Similarly, for a paraboloid concentrator (PC) $U_0 = 45^0$ and

$C_m = (\frac{1}{2\gamma})^2 \approx 11562$

When the intensity of direct solar radiation directed to the surface of the concentrator is $Q_0 = 800\ W/m^2$, the intensity in the focal plane is as follows [7].

$Q = C_m \cdot Q_0 = 11562 \cdot 800\ W/m^2 = 9{,}25 \cdot 10^6\ W/m^2$

According to the Stefan-Bolsmann law, the radiation energy of an absolute black body is directly proportional to the 4th degree of absolute temperature:

$Q = \varepsilon \cdot \sigma_0 \cdot T^4$

For an absolute black body, $\varepsilon = 1$; Stefan-Bolsman constant $\sigma_0 = 5{,}672 \cdot 10^{-8} W/(m^2 \cdot K^4)$; Considering the above,

$C_m \cdot Q_0 = \varepsilon \cdot \sigma_0 \cdot T^4$

we write that It follows that the absolute temperature in the absorber is the following formula.

$$T = \sqrt[4]{\frac{C_m \cdot Q_0}{\varepsilon \cdot \sigma_0}} = \sqrt[4]{\frac{9{,}25 \cdot 10^6 W/m^2}{5{,}672 \cdot 10^{-8} W/m^2\,K^4}} = 3573\ K$$

It should be noted that even in an ideal case, the temperature of the absorber in the focal plane of the concentrators cannot be reached to the temperature of the Sun's surface, i.e. 5800 K.

In conclusion, the energy problem as a global problem in the world requires bold steps to be taken to improve the current system of using energy sources and to use renewable and ecologically clean energy sources. In particular, the large-scale development of technology for the use of inexhaustible and ecologically clean solar energy acts as a powerful lever in bringing the continuity and quality of energy supply to a higher level, and helps to maintain the cleanliness of the environment.

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