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The study of the heat power effectiveness
of a parabolic solar concentrator

Abstract. In this paper, the results of research work on the development of an experimental device based on a parabolic solar concentrator. The concentrator dish was radiated by line parabolic solar imitator. The concentrator, have designed on the basic of satellite dish with different reflecting covers. Two tips of layers: aluminium plates and silver paint were used. In this work the focus of the parabolic concentrator was determined: is equal 0,56 m. The concentrator dish was radiated by line parabolic solar imitator. The temperature in the focus zone was actually obtained in full-scale tests concentrator and was 400 ^{0}C. The temperature is directly proportional to the illumination. The illumination parameter was measured by industrial luxmeter and at distance 2 m brightness of source is reduced to approximately 500 Lux. The brightness more the 500 lux concentrated on the focus area with square about 9 cm^2. The distribution of brightness on cross section area was determined.

Key words: parabolic solar concentrator, heat power effectiveness, aluminium plate, silver paint, full-scale tests, distribution of brightness.

Introduction

The acute environmental problems in the world and depletion of fossil resources set the task of developing reliable and efficient solar energy converters. In this regard, in the world there is a certain demand for power plants with a concentration of solar energy. Using a solar concentrator to focusing of the sun's rays is an effective method for obtaining an alternative energy source. Thermal radioactive transport continues to emerge as an important energy transfermechanism in a wide variety of practical systems such as high-temperature heatexchangers, boiler, rocket propulsion system and material sciences.

Many researches related to parabolic concentrators are found. J. Kleih [1] has been setting up a test facility for parabolic dish systems with power conversion unit in their focus. R.Y. Nuwayhid*et al.* [2] was realized a simple solar tracking concentrator for university research applications. C.A. Pérez-Rabago*et al.* [3] treated heat transfer in a conical cavity calorimeter formeasuring thermal power of a point focus concentrator. In work [4] A.R. El Ouederni1 *et al.*designed and experimentally studied of parabolic solar concentrator.

In general solar concentrating systems comprise a reflective surface in the shape ofparaboloid of revolution intended to concentrate solar energy on an absorbing surface,which makes it possible to reach a high temperature.This process gives the possibility to use solar energy in many high temperatureapplications. But the manufacture of the most of these systems is very expensive due tomaterials quality, dimensions and precision. So that, many authors worked to reduce thecost of this kind of systems [5, 6]. For more information, we refer to [8, 9, 10]

For Kazakhstan, which has significant resources of solar energy, the development of solar concentrator is justified. However, for the development of solar concentration power plants, it is necessary to study of their work and engineering features.In this work the task was set to develop a technique for determining the energy parameters of a laboratory installation based on a solar concentrator. It was also necessary to make an experimental station for approbation of the lighting and positioning system.

Experimental devices

The reflector of our experimental device consists of a parabolic concentrator of 0.6 m opening diameter. Its interior surface is covered with a reflecting layer. We used two tips of layers: aluminum plates and silver paint. The reflection coefficients of this material used in the creation of the concentrators 0.78 and 0.25 respectively.

Which reflect solar rays on the face of a receiver placed at the focal position of the concentrator. The geometric parameters of the concentrator and the copper receiving disk is:

Diameter of the parabolic concentrator is equal $D = 0.6$ m.

Area of the parabolic concentrator was calculated is equal S= 0.28 m^2.

Depth of the parabolic concentrator $h = 0,04$m.

The focus of the parabolic concentrator determined by:

$$f = \frac{d^2}{16 \times h}$$

is equal 0,56 m. Diameter of the receiving disk: $d = 5$cm, thickness of the receiving disk: $H = 0.08$ cm and mass of the receiving disk: $m = 14$g. Gain factor: $k = 2,33$.

The concentrator dish was radiated by line parabolic solar imitator. The light source made with halogen lamp at 1500 W AT power. In this device we used nickel hard cover reflector. The light source was positioned on the centum of dish and at several distances from focus point of concentrator.

The concentrator, have designed on the basic of satellite dish with different reflecting covers, the light source and the receiving disk showed on the picture 1. The tracer system for this device was described on work [7].

a

b

c

d
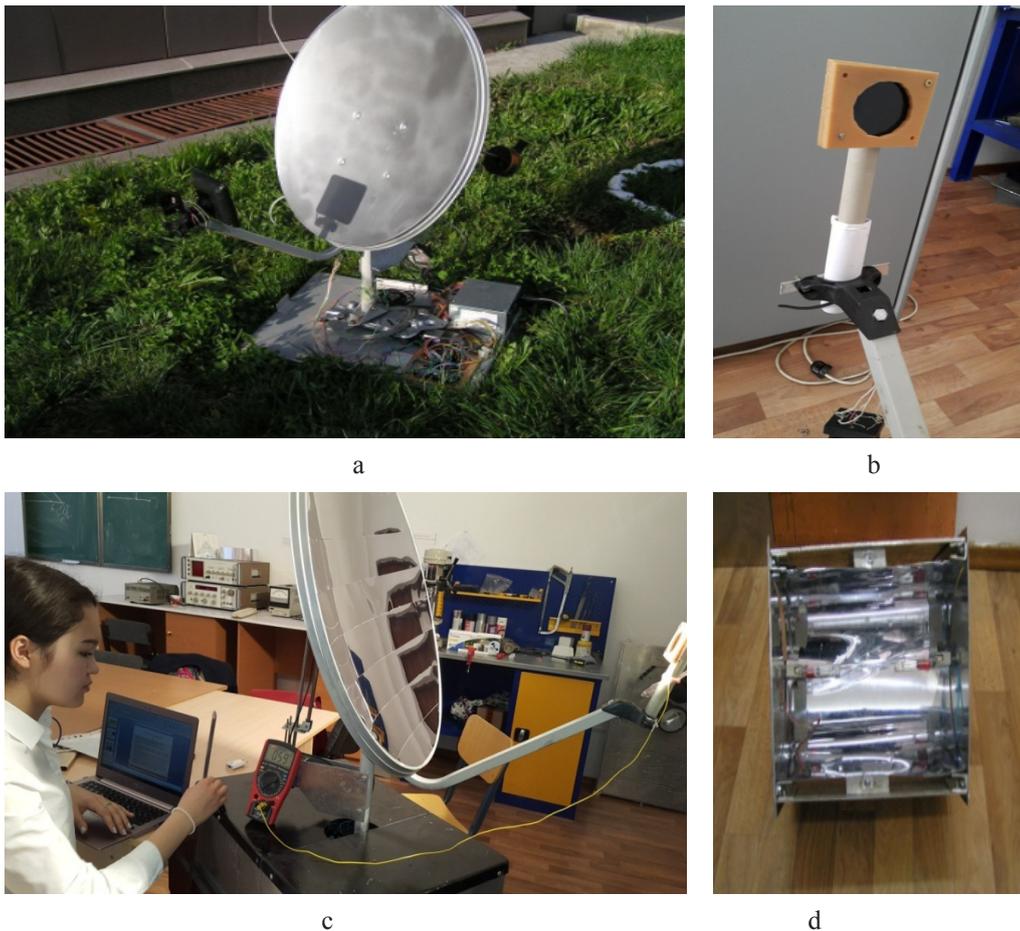
a, c – the satellite dish with different reflecting covers; b, d – the light source and the receiving disk

Figure 1 – The experimental devices

Results

At first we determined the light source parameters. The illumination parameter was measured by industrial luxmeter. The illumination dependence from distance of light face is shown on the Figure 2. So, at distance 2 m brightness of source is reduced to approximately 500 Lux. The distribution of brightness on cross section area with square 10x10 dm^2 on this distance shown on the table 1.
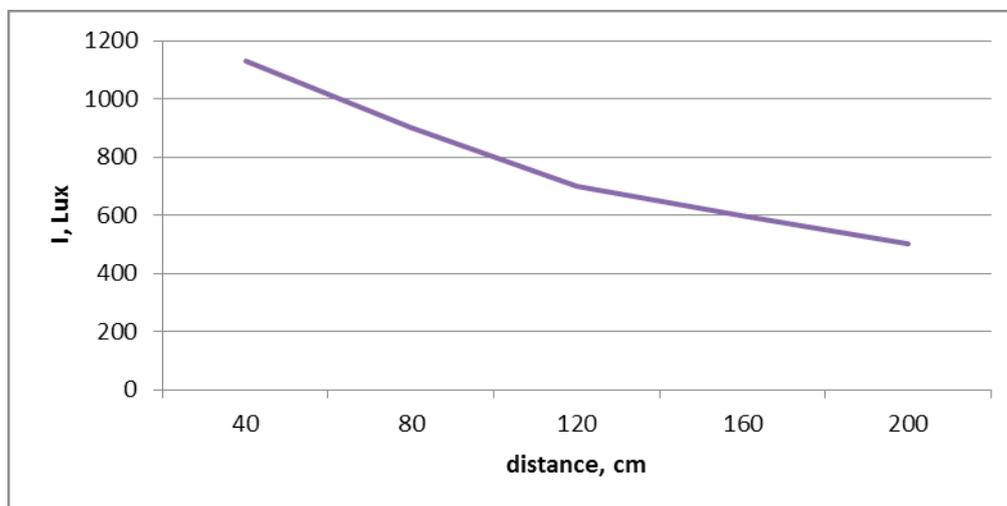

Figure 2 – The Illuminance from distance of source

Table 1 – The brightness on the wall on 2 m distance from light source

2	3	3	5	6	7	8	9	10
366	373	378	384	382	375	369	365	355
387	397	405	415	413	402	395	386	373
420	430	445	453	448	441	434	426	410
430	441	448	453	455	448	442	436	420
445	454	461	468	463	455	448	440	430
442	452	457	465	462	454	447	439	432
422	432	440	449	446	442	433	424	417
418	425	433	440	438	433	425	412	399
384	395	404	413	415	407	400	393	380
361	366	373	386	378	371	366	362	354

Then we stand light source at 2 m distance and illuminate the concentrator dish and measured the radiation parameters on their focus area. The results of experiments shown on the figure 3.

On this experiment, we determined the exact location of the focus where the receiving disk was placed, to further study the effectiveness of the focusing properties of the solar concentrator. The Illumination at the concentrator focus in lux shown on the table 2.
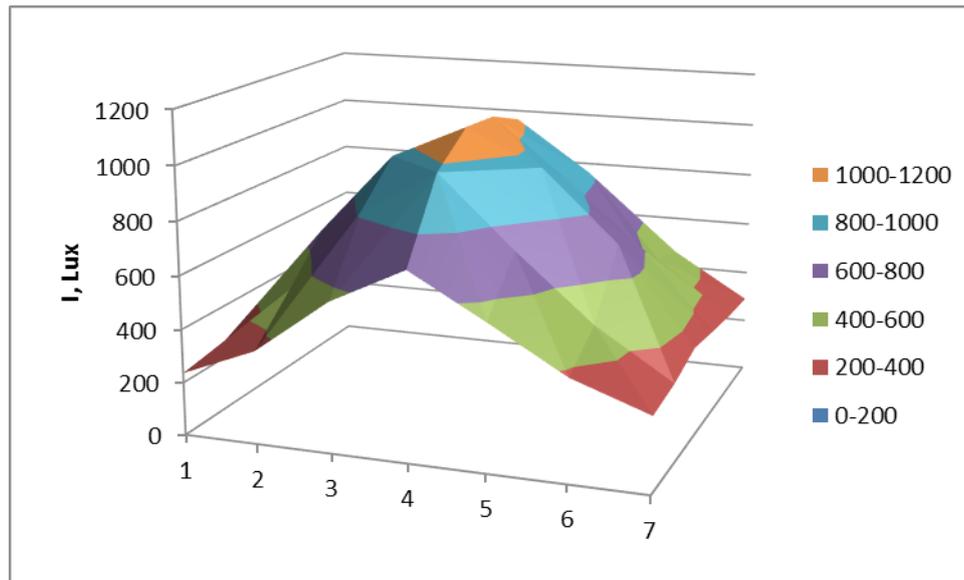
Figure 3 –The Illuminance of focus area

Table 2 – The brightness on the focus area with square 7x6 cm^2

см	1	2	3	4	5	6	7
1	236	350	560	700	543	380	280
2	257	500	820	980	720	480	300
3	260	660	964	1090	960	700	342
4	243	565	946	1080	860	623	320
5	220	470	720	1020	830	500	301
6	210	309	604	740	656	460	290

Thus, the brightness more the 500 lux concentrated on the focus area with square about 9 cm^2.

Temperature measurements. Power density

The energy of light on the focus area can determined by equation

$$Q = cm\,(T_2 - T_1)$$

where c is heat capacity of receiver material, m- mass of receiver and T2 is finish temperature.

In the steady state, the energy flux density transmitted by thermal conductivity is proportional to the temperature gradient:

$$\vec{q} = -\varkappa\,\mathrm{grad}(T),$$

where q is the heat flux density vector is the amount of energy passing per unit time per unit area perpendicular to each axis, κ is the coefficient of thermal conductivity (specific heat conductivity), and T is the temperature. The minus sign on the right shows that the heat flux is directed opposite to the grad T vector (i.e., in the direction of the soonest temperature decrease). This expression is known as the Fourier thermal conductivity law.In integral form, the same expression will be written this way (if it is a stationary flow of heat from one face of the parallelepiped to another):

$$P = -\varkappa\frac{S\Delta T}{l},$$

where P is the total heat loss power, S is the sectional area of the parallelepiped, ΔT is the temperature difference of the faces, l is the length of the parallelepiped, that is, the distance between the faces.

At first we used cylindrical copper receiver for determination of heat energy, realized on focus area, measured by calorimetrical method. On the figure 4 showed the temperature dependence on receiving disk from radiating time in the focus of concentrator by light source positioned at 2 m from dish.

The dependence of the heating temperature of the receiving disk on time in the focus of the concentrator with aluminum plates is shown in Figure 5.
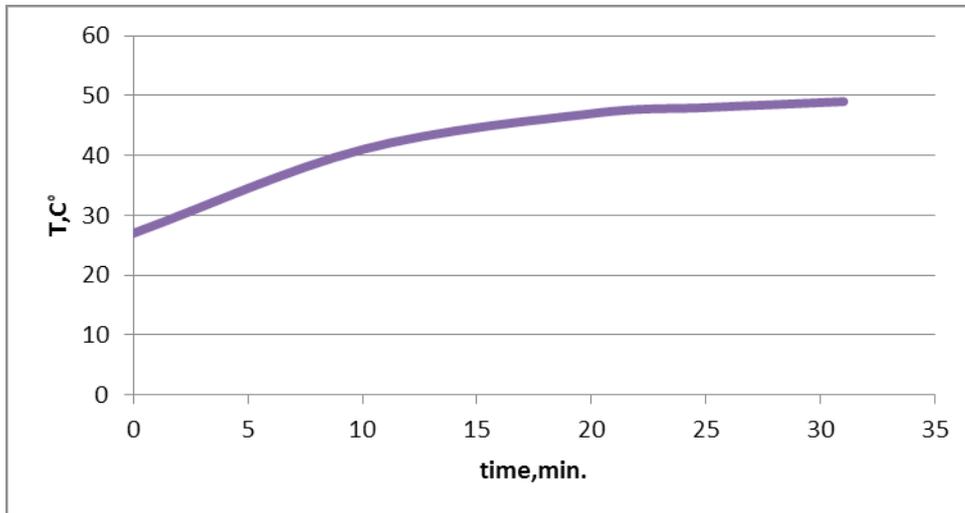

Figure 4 – Dependence of the heating temperature
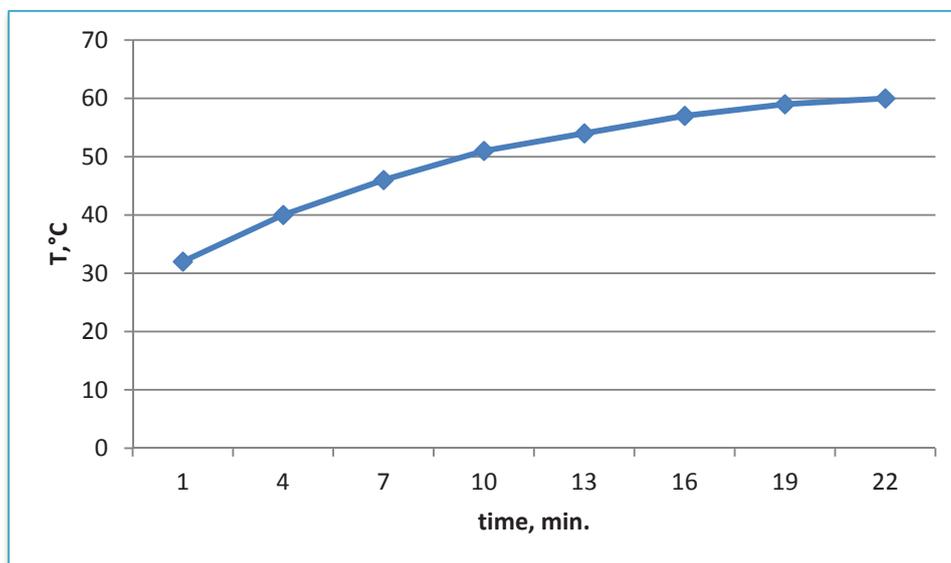of the receiving disk on time with the paint coating

Figure 5 – Dependence of the heating temperature
of the receiving disk on time with aluminum plates

Calculation of energy by this method was given 128 and 156 J for dish with paint cover and aluminum plate, respectively. As shown, with aluminum cover the maximal temperature reached fast, but this method is not enough exactly. Calculation of power density. This parameter calculated by using of Fourier method, described over. As receiver we used aluminum disks with thickness 1,1 cm.

$$P = \frac{\lambda S(T1 - T2)}{h}$$

$$P = \frac{203,5 \times 15,09 \times 1,8 \times 10^{-4}}{1,1 \times 10^{-2}} = 50,25W$$

$$\rho = \frac{50,25 Bm}{15,09 \times 10^{-4} \, m^2} = 33,3 \frac{\kappa W}{m^2} = 3,3 \frac{W}{cm^2}$$

Conclusion

A parabolic concentrator with different types of coatings, as well as devices for lighting and measuring energy parameters have been developed. With an average illumination, the 500 lux light source in the focus zone received a temperature of 50 ^{0}C. If it is assumed that the temperature is directly proportional to the illumination, then in direct sunlight with a brightness of 5000 lux, the temperature in the focus zone should be 500 ^{0}C. This temperature was actually obtained in full-scale tests concentrator and was 400 ^{0}C. Two well-known methods for determining the energy and power parameters were used in the work. The obtained experience allows using these methods for calculating parameters and creating other, more powerful concentrators.

References

1. J. Kleih, 'Dish-Stifling Test Facility', Solar Energy Materials. – 1991. – Vol. 24. – P. 231-237.

2. R.Y. Nuwayhid, F. Mrad and R. Abu-Said, 'The Realization of a Simple Solar Tracking Concentrator for University Research Applications', Renewable Energy. – 2001. – Vol. 24, No. 2. – P. 207-222.

3. C.A. Perez-Rabago, M.J. Marcos, M. Romero and C.A. Estrada, 'Heat Transfer in a Conical Cavity Calorimeter for Measuring Thermal Power of a Point Focus Concentrator', Solar Energy. –2006. – Vol. 80, No. 11, – P. 1434-1442.

4. A.R. El Ouederni, A.W. Dahmani, F. Askri, M. Ben Salah and S. Ben Nasrallah. Experimental study of a parabolic solar concentrator. Revue des Energies Renouvelables CICME'08 Sousse (2008). –Vol. 193 – P. 199-193

5. S.Kalogirou, P. Eleflheriou, S. Lloyd and J. Ward, 'Low Cost High Accuracy Parabolic Troughs Construction and Evaluation', Renewable Energy. – 1994. – Vol. 5, No. 1-4. – P. 384-386.

6. I. Palavras and G.C. Bakos, 'Development of a Low-Cost Dish Solar Concentrator and its Application in Zeolite Desorption', Renewable Energ., – 2006. – Vol. 31, No. 15, – P. 2422-2431.

7. Zhukeshov A.M., Sundetov T. Calculation of the wind load of a solar concentrator with a two-axis tracker. KazNU bulletin, Physics series. – 2015. – No. 4. – P. 23-29.

8. Harmim, A., Merzouk, M., Boukar, M., Amar, M.: Design and experimental testing of an innovative building-integrated box type solar cooker. Solar Energy. – 2013. – Vol. 98. – P.422-433.

9. Hafez, A. Z., Soliman, Ahmed, El-Metwally, K. A., Ismail, I. M.: Solar parabolic dish Stirling engine system design, simulation, and thermal analysis. Energy conversion and management. – 2016. – Vol. 126. – P.60-75.

10. Tan, Woei-Chong, Chong, Kok-Keong, Tan, Ming-Hui: Performance study of water-cooled multiple-channel heat sinks in the application of ultra-high concentrator photovoltaic system. Solar Energy. – 2017. – Vol. 147. – P.314-327.