PARABOLOCYLINDRICAL SOLAR DEVICE FOR THERMAL ENERGY PRODUCTION

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Annotatsiya: Mazkur tadqiqotda parabolosilindrik quyosh kollektorlarining geometrik parametrlarini hisoblash, ishlash samaradorligini baholash va ularning sanoat hamda xususiy sektorda qo‘llanish imkoniyatlari o‘rganilgan. Farg‘ona viloyati sharoitida o‘tkazilgan tajribaviy sinovlar asosida suv oqimi tezli gi va harorat o‘zgarishlarining ta’siri tahlil qilindi. Natijalar shuni ko‘rsatdiki, bunday quyosh kollektorlari suvni yuqori haroratgacha isitish va uni samarali saqlash imkoniyatiga ega bo‘lib, sanoatda texnologik jarayonlar uchun samarali issiqlik manbai vazifasini o‘taydi. Tadqiqot natijalari quyosh issiqlik tizimlarini rivojlantirish va ularni keng qo‘llash istiqbollariga hissa qo‘shadi.

Kalit so‘zlar: quyosh energiyasi, parabolosilindrik kollektor, issiqlik samaradorligi, optik parametrlar, suv oqimi tezligi, harorat tahlili, sanoat qo‘llanishi, qayta tiklanadigan energiya, termal energiya saqlash.

Аннотация: В данной работе исследованы расчет геометрических параметров параболоцилиндрических солнечных коллекторов, оценка их эффективности и возможности их применения в промышленности и частном секторе. На основе экспериментальных испытаний, проведенных в Ферганской области, проанализировано влияние быстрых перепадов расхода и температуры воды. Результаты показали, что такие солнечные коллекторы способны нагревать воду до высоких температур и эффективно ее аккумулировать, служа эффективным источником тепла для технологических процессов в промышленности. Результаты исследования способствуют перспективам развития солнечных тепловых систем и их широкому применению.

Ключевые слова: солнечная энергия, параболоцилиндрический коллектор, тепловая эффективность, оптические параметры, расход воды, анализ температуры, промышленное применение, возобновляемая энергия, хранение тепловой энергии.

Annotation: This paper examines the calculation of the geometric parameters of parabolic trough solar collectors, assessing their efficiency and potential for use in both industry and the private sector. Based on experimental tests conducted in the

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Fergana region, the impact of rapid fluctuations in water flow and temperature was analyzed. The results demonstrated that these solar collectors are capable of heating water to high temperatures and efficiently accumulating heat, as well as serving as effective heaters for industrial and process applications. The results of the study contribute to the development of solar thermal systems and their widespread use.

Keywords: Solar energy, parabolic trough collector, thermal efficiency, optical parameters, water flow, temperature analysis, industrial application, renewable energy, thermal energy storage.

Introduction

Energy is one of the most important means of human life and economic development. Energy can be obtained from both fossil and renewable sources. Today, the world's need for energy is growing rapidly. At the same time, oil has gained political and strategic importance and has taken its place in social life. In recent years, natural gas has become one of the most important factors determining the economy, politics and development of a country [1].

The world's energy consumption is mainly derived from oil (39%), coal (27%), natural gas (21%), and hydroelectricity and other renewable energy sources (13%) [2]. It is also expected that 87% of the world's energy consumption will come from fossil fuels. According to energy experts, fossil fuels are expected to last for 40 years, while natural gas is expected to last for 62 years [3].

The use of fossil fuels has a negative impact on global warming, environmental pollution and human health. The reasons for this are carbon, hydrogen, sulfur and other elements contained in fossil fuels. An analysis of the current political and economic map of the world shows that energy, resource and environmental problems are going beyond the boundaries of local character and are becoming global in nature. Maintaining the current level of development of human society and its further development requires the intellectual consciousness of the advanced masses of society to develop new approaches to solving this problem [4]. Therefore, it is necessary to create modern technologies that are so integrated that, through their implementation, the above-mentioned problems will find their solutions to some extent.

In recent years, a number of works have been carried out in our Republic to improve the energy sector, including increasing production based on renewable energy sources (which can reduce dependence on fossil fuels and improve the environmental situation), increasing the efficiency of energy systems, reducing energy consumption, and forming a culture of energy saving among the population [5-6].

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Currently, solar energy is one of the most promising renewable energy sources. Flat-plate and focusing solar collectors are used to convert solar energy into other types of energy [7-8].

Today, parabolic trough solar collectors are widely used to obtain thermal energy. This is a type of solar heat collector, which heats the heat carrier to a high temperature by concentrated solar radiation passing through focused light-receiving tubes. In addition, thermal energy can be used to obtain process water in industrial enterprises and private sectors. Also, this type of device can be described by the classifier in Figure 1 according to its application areas [9-10].

Materials and methods.

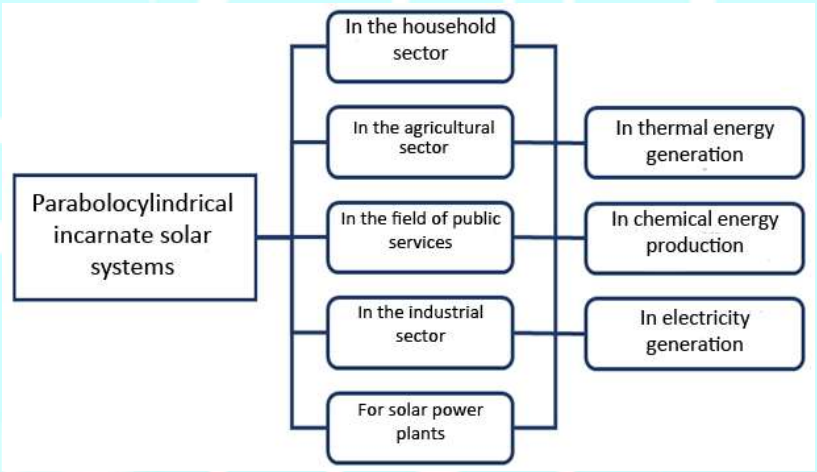


Figure-1. Description of parabolic trough solar systems by application.

Parabolic trough systems for solar radiation are equipped with a single light-collecting optical surface and separate flat collector elements, as well as a tubular heat sink arranged and installed in the focal zone. Such a module can be used to obtain thermal, mechanical or electrical energy from autonomous solar installations of a specific purpose. On the basis of such modules, it is possible to create energy systems with a capacity of hundreds of MW. The module under consideration is a modification of previously developed experimental solar parabolic trough installations [11]. A general view of the developed parabolic trough module is shown in Figure 2.1.

The calculation of the geometric parameters of a parabolic cylindrical solar collector is carried out as follows. The main working surface of the collector is calculated as follows:

$$S_{mid}=B\times L=1{,}4m\times 3{,}0m = 4{,}2m^2$$

A typical parabolic trough solar collector has a focal-line receiver (a tubular receiver). If its effective diameter is d, then its effective area A_{receiv} is given by the length L:

$$A_{receiv}=d\times L=0{,}44\times 3{,}0m=0{,}12m^2$$

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Based on the above, the average solar radiation flux integration level of the device is the ratio of the total light area falling on the parabolic cylindrical collector to the light-receiving surface:

$$C=\frac{A_{mid}}{A_{receiv}}=\frac{4{,}2m^2}{0{,}12m^2}\approx 35.$$

Under standard conditions, the energy falling on a parabolic cylindrical solar collector is:

$$Q_{in}=1000\ W/m^2 \times 4{,}2\ m^2 = 4200\ W.$$

The collector system has the following main optical parameters:

-reflectance coefficient R_z - this is the ability of mirrors or flat elements used in a solar collector to reflect sunlight. This coefficient is usually from 0.85 to 0.95. For example, if the reflection coefficient $R_z = 0.9$, this means that 90% of the light falling on the surface of a parabolic-cylindrical solar collector is reflected.

- the light absorption capacity of the light receiver (A_s) - this indicator indicates how effectively the sunlight directed to the focal line is captured by the receiver. This value is usually around 0.95, which means that 95% of the incident light is absorbed by the receiver.

-cosine loss (cos θ) – expresses the angle at which the sun's rays fall on the parabolic-cylindrical solar collector. If the sun's rays fall on the collector directly, that is, at an angle of 90°, cos θ = 1 and losses are minimal. If the rays fall obliquely, this indicator decreases, and as a result, the efficiency of using solar energy decreases.

The product of the above three parameters determines the overall optical efficiency of the collector:

$$\eta_{opt} = R_z \cdot A_s \cdot \cos\theta$$

For example, if $R_z = 0.9$, $A_s = 0.95$ and $\cos\theta = 1$:

$$\eta_{opt} = 0{,}9 \times 0{,}95 \times 1 \approx 0{,}855$$

Therefore, the optical efficiency of the system is 85.5%.

Assuming the collector input power Q_{in} = 4200 W, the useful energy reaching the light receiver is determined as follows:

$$Q_s = Q_{in} \cdot \eta_{opt} = 4200 \times 0{,}855 \approx 3591\ W$$

This result shows that the collector provides high efficiency even when taking into account optical losses under real operating conditions.

A heat accumulator is used to temporarily store the heat generated after optical losses and use it later. In this system, a tank with dimensions of 40 × 40 × 60 cm is used. Its total volume is determined as follows:

$$V = 0{,}4 \cdot 0{,}4 \cdot 0{,}6 = 0{,}096\ m^3$$

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This volume is selected according to the power ratings of the collector module, taking into account the heat exchange rate, insulation qualities, and external heat losses.

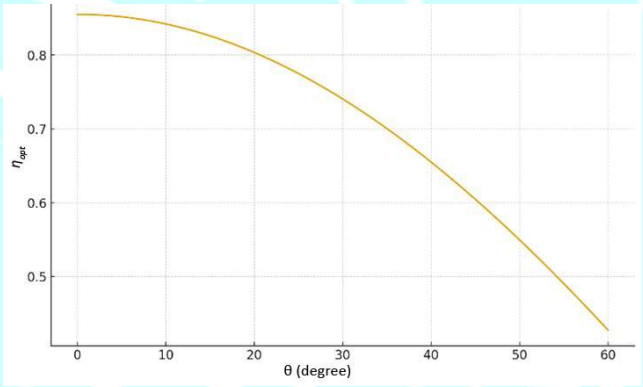


Figure 2. Optical efficiency η_{opt} divided by the angle of incidence cosθ.

Figure 2 shows that the optical efficiency η_{opt} decreases with increasing angle of incidence of sunlight on the collector surface. At θ = 0° (perpendicular incidence), η_{opt}≈0.855 is the maximum value. When θ = 60° is reached, the efficiency decreases by about 40% and reaches η_{opt}≈0.43. Thus, the installation angle and tracking systems play an important role in maintaining the collector efficiency at a high level.

A hydraulic system based on a parabolic-cylindrical solar collector was assembled as an experimental object in the study. The experimental complex consists of the following main elements:

– parabolic trough solar collector;
– heat storage tank;
– water pump;
– connecting hoses and control fittings.

The geometric dimensions of the parabolic trough solar collector are 1.4 × 3.0 m, which generates thermal energy by focusing sunlight onto the focal line. A water tank measuring 40 × 40 × 60 cm was used as a heat accumulator, which temporarily stores the thermal energy transferred through the collector. A centrifugal water pump with a power of 0.375 kW was selected as a pumping unit. Its nominal flow rate was 10 l/min, and the flow rate of the transferred liquid was adjusted using a special valve. The pump continuously supplied water to the collector from the storage tank.

During the experimental studies, water was heated in a solar collector and returned to the heat storage chambers. The system was configured to operate in a continuous flow mode, which allowed for stable monitoring and measurement of heat exchange processes.

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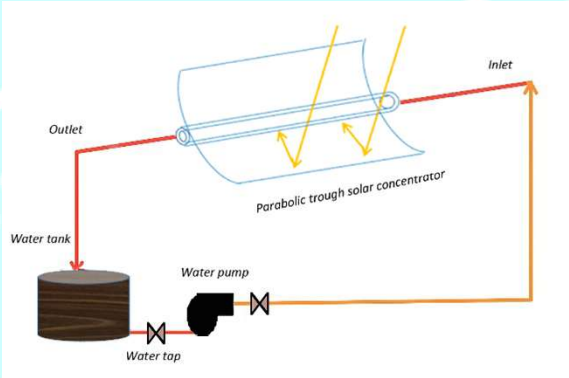


Figure 2.1. Schematic diagram of a parabolic trough solar collector system.



Figure 2.2. General view of the experimental parabolic trough solar collector.

Results and discussion

The sunlight falling on the reflecting surface of the parabolic trough solar collectors is directed to the heat transfer fluid passing through the light receiving tube. For the experimental data, the tube inlet ($T_{h,i}$) and tube outlet ($T_{h,o}$) temperatures are measured simultaneously to estimate the energy transferred to the water. In addition, the water temperature in the storage tank (T_{bak}) is also measured to model the heat transfer.

Table-1.

Experimental data obtained in Fergana on June 10

Time	T_{inlet}(°C)	T_{outlet}(°C)	T_{bak}(°C)	Flow(l/min)	ΔT(°C)
11:00	35,5	42,5	25,6	0,4	7
11:10	37,4	51,2	27	0,4	13,8
11:20	37,5	54	30	0,4	16,5
11:30	38,7	57	32	0,4	18,3
11:40	38,7	57	32	0,4	18,3
11:50	40	58	35	0,4	18
12:10	45,7	63,5	35	0,4	17,8
12:20	46,7	65	37	0,4	18,3
12:30	47,5	68	38	0,4	20,5
12:45	48,3	71,2	39	0,4	22,9
13:15	50	70,6	40	0,4	20,6
13:30	54,2	74,6	42	0,4	20,4
13:40	56,5	75	43	0,4	18,5
13:50	58	75,2	44	0,4	17,2

As can be seen from Table 1, the outlet temperature ($T_{h,o}$) was around 42.5 °C at 11:00 at the beginning of the experiment, and gradually increased over time, approaching 75 °C at 13:50. This indicates that the parabolo-cylindrical concentrator is highly optically and thermally efficient. The inlet temperature ($T_{h,i}$)

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was initially 35.5 °C, and had a slight tendency to increase over time (up to 58 °C). This is a result of the water entering the collector after being additionally heated in the heat storage tank during circulation. The tank temperature (T_{bak}) increased steadily during the study and increased from 25.6 °C to 44 °C. This indicator confirms that the thermal energy transferred through the system is successfully accumulated in the water.

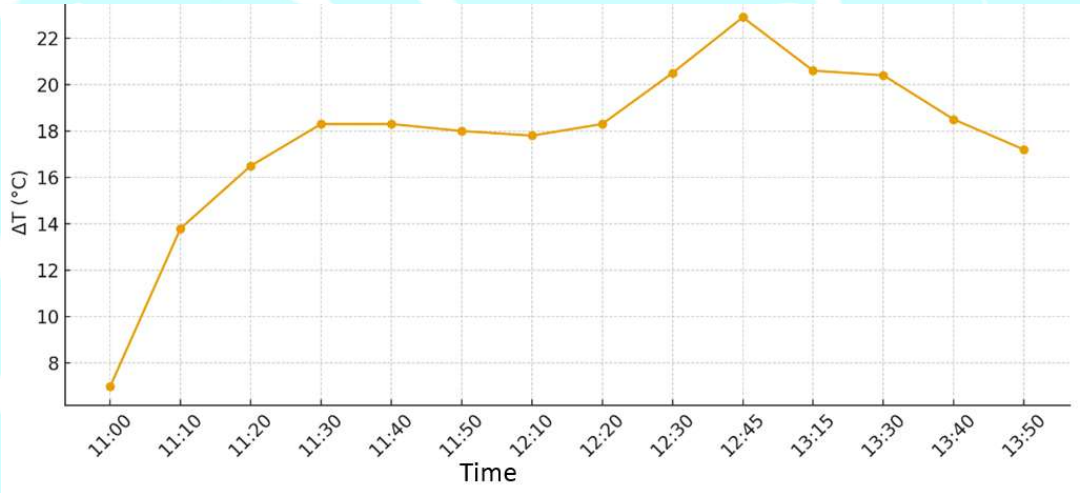


Figure 3. Variation of ΔT (difference between outlet and inlet temperatures) over time.

The graph shows the change in ΔT (the difference between the outlet and inlet temperatures) over time. Initially, ΔT at 11:00 was only 7 °C, but it rose sharply with the increase in solar radiation for a short time and stabilized at around 18 °C at 11:30. Between 11:40 and 12:10, ΔT was maintained at around 18 °C, indicating that the collector had reached a balance between heat output and heat loss. Starting from 12:20, ΔT increased again as the solar intensity increased, reaching its highest value of approximately 23 °C at 12:45. In the next stage, ΔT gradually decreased and stabilized at around 17 °C by 13:50.

These changes show that the efficiency of the collector is directly dependent on the intensity of solar radiation over time: during the maximum solar period, ΔT is also the highest, while when radiation decreases, ΔT decreases. At the same time, as the heat accumulation in the system increases, the temperature difference decreases, which is a natural consequence of the heat balance.

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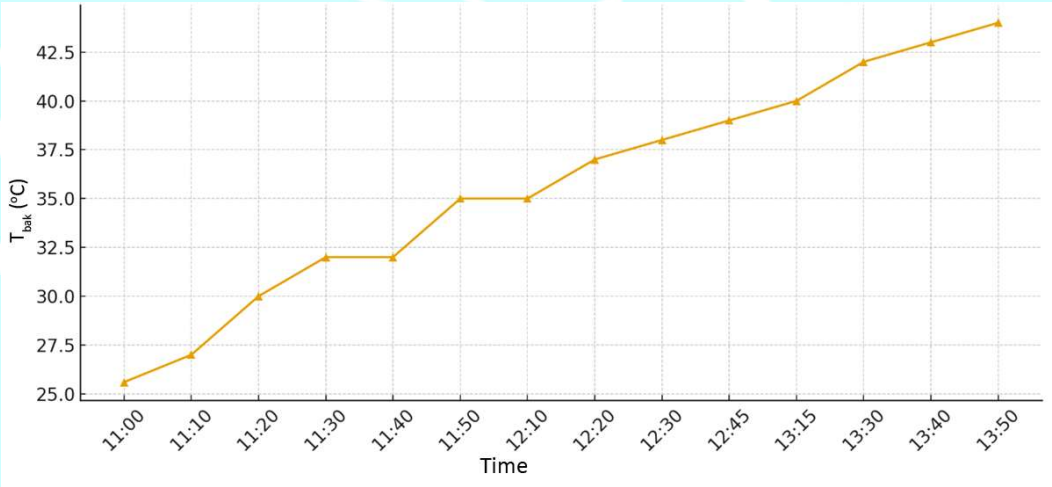


Figure 4. Temperature variation of the storage compartment (T_{bak}) over time.

Figure 4 clearly shows the time-dependent change in the temperature of the storage compartment in the experiment. Initially, at 11:00, the initial water temperature was 25.6 °C, and the temperature in the tank increased steadily due to the increase in solar radiation and the increase in collector outlet temperature. By 11:20, it reached 30 °C, and the heating was rapid due to the high heat input during this period. In the following period, between 11:30 and 12:10, the temperature was around 32–35 °C, and the heat input and loss in the system were balanced, and the growth rate slowed down slightly. From 12:20, coinciding with the maximum period of solar radiation, the temperature rose again rapidly and reached 38–40 °C. In the final stage, between 1:15 PM and 1:50 PM, the temperature of the water in the tank continued to increase steadily, reaching a peak of 44 °C. The results show that the temperature of the water in the tank increased by about 18 °C during the experiment, indicating the efficient operation of the collector and the high energy storage capacity of the heat accumulator.

Table-2

Solar radiation values obtained in Fergana on June 1 [12].

Time	Total hours	Direct radiation (W/m^2)	Total hourly global radiation	Total global radiation average (W/m^2)	Direct rad/total rad.
7	21912,4	365,21	12740,2	212,34	1,73
8	38103,5	635,06	22930,9	382,18	1,66
9	42862,1	714,37	34290,5	571,51	1,25
10	47643,2	794,05	44917,5	748,62	1,06
11	47876,5	797,94	51923	865,38	0,92
12	45194,9	753,25	53000,5	883,34	0,85
13	47150,1	785,84	59046,4	984,11	0,80

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14	38666,1	644,44	54621,9	910,36	0,72
15	44314,3	738,57	43199,2	719,99	1,025
16	33630,7	560,51	33788,8	563,15	0,99
17	31220,3	520,34	29778,8	496,31	1,05
18	8234,8	137,25	19108,2	318,47	0,

As shown in Figure 4, the ratio of direct solar radiation to total radiation varies from 0.7 to 1. In June, the ratio of direct radiation to total radiation in Fergana region is 0.6.

Conclusion

The results of the study showed that the use of parabolic trough solar collectors is one of the effective methods for heating water. According to the results of the experiments, the difference between the inlet and outlet water temperatures reached a maximum of 22.9°C, which confirms the high efficiency of the system. Also, the study found that the change in sunlight during the day is an important factor affecting the efficiency of the collector.

The advantages of parabolic trough solar collectors include their high focusing ability, low optical losses, and the ability to obtain high-temperature heat carriers. At the same time, measures should be taken to reduce optical and thermal losses to increase the efficiency of the system. The results of the study show that the production and implementation of parabolic trough solar collectors can be economically viable for industrial enterprises and private households. Such systems can be widely used in agriculture, the food industry, and other industries that require thermal energy.

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