

# Heliopyrolysis of Sunflower Waste Using a Parabolic Solar Concentrator

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**Abstract**—The article proposes a technological scheme of a heliopyrolysis plant with a parabolic solar energy concentrator and presents the results of a study of the thermal technological regime of the process of pyrolysis of sunflower waste. To study the process, an experimental heliopyrolysis installation with a parabolic solar concentrator was created. The purpose of this work is to evaluate the practical possibility of solar technology for the thermal processing of sunflower waste using a parabolic solar concentrator and to determine the main parameters of the thermal technological regime of heliopyrolysis. The results of experimental studies of the process of heliopyrolysis of sunflower waste at a temperature of 400–500°C are presented. The values of the heat of combustion of liquid and gaseous biofuels obtained by solar pyrolysis were determined. It has been established that the value of the lower calorific value of liquid pyrolysis fuel is 35–40 MJ/kg, and the calorific value of gaseous fuel is 25–28 MJ/m<sup>3</sup>. During the experiments, the temperature dependence and material balance of the resulting products during the thermal processing of sunflower waste using concentrated solar thermal energy were studied. In experiments carried out at the installation, as a result of the pyrolysis of 1 kg of sunflower waste loaded into the reactor of a heliopyrolysis installation, 63% of biochar, 10% of liquid, and 27% of gaseous biofuels were obtained. The results of the studies showed that the yield of liquid pyrolysis products is affected by the humidity of the initial biomass; and the maximum yield of the liquid pyrolysis, and product of sunflower waste corresponds to a temperature of about 430°C and a humidity of the loaded initial biomass of 25%. Based on the conducted research, the effectiveness and possibility of using a heliopyrolysis installation with a solar parabolic concentrator to maintain the required temperature regime for the pyrolysis of sunflower waste in the daytime operating mode of the installation was substantiated.

**Keywords:** solar energy, parabolic concentrator, material balance, biomass pyrolysis, alternative fuel, solar pyrolysis plant, biomass energy, pyrolysis reactor, thermal energy

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## INTRODUCTION

In connection with the decrease in reserves of traditional fuel and energy resources (natural gas, coal, fuel oil) and the aggravation of environmental problems, the development of effective methods for using renewable energy sources, in particular, solar energy and biomass energy, has become particularly urgent. However, to implement technologies for producing alternative fuels from biomass and implementing the operating cycle in power plants, large amounts of thermal and electrical energy are required. That is why the use of parabolic solar concentrators is important for the efficient use of solar energy in biomass processing and in high-temperature processes. Over the past several years, scientific research has been carried out around the world and in Uzbekistan and practical results have been achieved on the use of solar energy in various technological processes [1–11].

One of the promising areas for the energy use of plant biomass is their processing using high-tempera-

ture pyrolysis technology. The main products of pyrolysis of plant biomass are pyrolysis liquid, charcoal, and pyrolysis gas [12, 13]. In order to obtain alternative fuels from various biomass (wood waste, sawdust, sunflower seed husks, pumpkin, etc.), research has been carried out by scientists and specialists from around the world [13–15]. To reduce the energy intensity of the pyrolysis process of biomass and organic waste, pyrolysis systems using solar energy have been proposed [16, 17]. However, the proposed biomass processing technologies have not yet found real practical application in industry.

One of the promising areas in the climate of Uzbekistan is also the use of solar energy in the technology of high-temperature pyrolysis of biomass. The production of alternative types of fuel and energy (heat and electricity) from biomass and organic waste by pyrolysis using solar energy is primarily important for energy consumers located far from centralized energy supply systems, such as residents of rural residential

areas and individual houses, as well as farms. For this reason, the processing of plant biomass for the production of fuel, heat, and electricity is essential mainly for the energy supply of the rural population, especially in those areas where there is a shortage of energy.

An analysis of research and existing technologies for biomass processing shows that sunflower waste is an accessible raw material for producing alternative biofuel. Research also shows that one sunflower bush produces an average of 0.8–1.5 kg of biomass waste, and as a result of complete processing by pyrolysis, it becomes possible to obtain alternative fuels [18, 19].

Based on the above, the purpose of this work is to evaluate the practicality of solar technology for the thermal processing of sunflower waste using a parabolic solar concentrator and to determine the main parameters of the thermal technological regime of heliopyrolysis.

## METHODS AND MATERIALS

One of the main problems is ensuring the temperature regime in the reactor of the pyrolysis unit, since in order to achieve the optimal temperature regime (350–500°C), the reactor initially requires a supply of energy (heat). In a traditional pyrolysis plant, this is typically accomplished by consuming coal, natural gas, or electricity as energy sources. As a result, a large amount of energy is required for the installation's own needs [18].

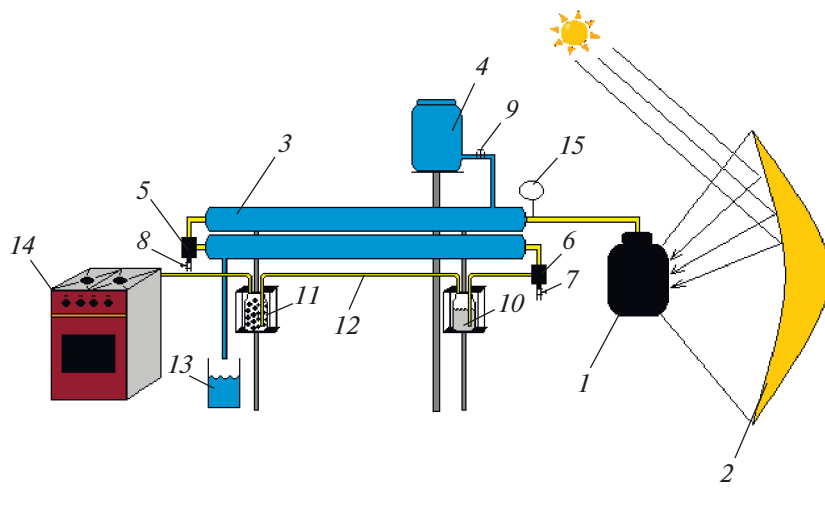
In the course of this study, the temperature regime of the heliopyrolysis plant, the material balance, and the influence of temperature in the reactor during the heliopyrolysis of biomass (sunflower waste) on the product yield were studied [19–22]. To study the

pyrolysis process, a technological scheme of a heliopyrolysis plant with a parabolic solar concentrator was developed (Fig. 1) and its thermal testing was carried out [18–22].

The material balance of various types of biofuels obtained in the process of pyrolysis of sunflower biomass waste loaded into the reactor of a heliopyrolysis plant with a parabolic solar concentrator was compiled in laboratory conditions using the following method. Before the start of the experiment, samples of raw materials with an initial moisture content of 5–20% and a size of 4–6 mm were prepared (Fig. 2). The mass of the loaded product was measured using electronic scales (Electronic Sf-400), humidity, using an AR971 universal digital moisture meter with an accuracy of  $\pm 2\%$ , and the temperature in the reactor was controlled using a Mobile-CASSY 2 thermometer (measurement accuracy:  $\pm 3^\circ\text{C}$ ,  $\pm 2\%$ ; measurement range:  $-200$  to  $+200^\circ\text{C}/-200$  to  $+1200^\circ\text{C}$ ), bimetallic Pakkens thermometer (measurement accuracy: SL 2.0; measurement range:  $0-500^\circ\text{C}$ ) and Snegir-700MT thermal imager (measurement accuracy:  $\pm 2^\circ\text{C}$ ; measurement range:  $-20$  to  $+700^\circ\text{C}$ ). Solar radiation intensity was measured using a Photovoltaic Data Logger MacSolar actinometer (irradiance measurement range:  $0-1500\text{ W/m}^2$ ; temperature range from  $-40$  to  $85^\circ\text{C}$ ; temperature measurement accuracy:  $\pm 0.1^\circ\text{C}$ ).

For biomass pyrolysis, sunflower waste was selected, which was crushed into particles 6–8 mm in size. The process of preparing sunflower waste for pyrolysis is shown in Fig. 2.

The heat of combustion of liquid fuel obtained during the pyrolysis of sunflower waste was determined using an XRY-1A calorimetric bomb (Fig. 3).



**Fig. 1.** Technological diagram of the experimental installation for heliopyrolysis of biomass.

(1) heliopyrolysis reactor; (2) parabolic solar concentrator; (3) condenser (cooler); (4) water tank; (5) first condensing unit; (6) second condensation unit; (7–9) valves; (10) water filter; (11) activated carbon filter; (12) gas pipe; (13) tank for collecting water; (14) consumer (gas stove); (15) pressure gauge.



Fig. 2. The process of preparing sunflower waste for pyrolysis.

The processes of thermal processing of sunflower waste in an experimental installation using highly concentrated solar thermal energy depend on the thermo-physical properties of the raw material. The conducted studies show that from one sunflower bush an average of 0.8–1.5 kg of biomass waste is formed, the thermo-physical properties of which are given in Table 1, and as a result of their complete processing by pyrolysis, it becomes possible to obtain alternative types of fuel.

Research on the pyrolysis of sunflower waste was carried out in laboratory conditions. The experiments were carried out in a parabolic concentrator with a diameter of 1.8 m and an aperture of 2.54 m<sup>2</sup>, focal length 0.7 m, and concentration factor of 126. At the same time, a reactor sample with a volume of 0.003 m<sup>3</sup> and heat exchange surface area of 0.02 m<sup>2</sup> was manufactured. The experiments were carried out in the conditions of Karshi (Uzbekistan) on August 26, 2023 in the period from 12<sup>00</sup> to 14<sup>00</sup> hours at an average ambient temperature of 36.4°C and average solar radiation values of 910–960 W/m<sup>2</sup>. Using the developed experimental setup, it is possible to carry out pyrolysis of 1 kg of biomass.

Table 2 presents the main characteristics of the parabolic concentrator and receiver (reactor).

One of the most important characteristics of the quality of a concentrator is the degree of compaction of solar energy in the radiation receiver. This degree of compaction is estimated by average concentration coefficient  $C$ , which is equal to the ratio of the total power of solar radiation falling on the surface of the concentrator to the power entering the focal band of the receiver, or ultimately the ratio of the entrance area to concentrator  $S_0$  to focal fringe area  $S_1$  taking into account reflection coefficient  $\eta_r$ , hence  $C = \eta_r S_0 / S_1$  [23–28].

With normal incidence of sunlight on the entrance surface of a parabolic concentrator with opening angle (aperture)  $\Theta_0$  and the focal parameter the average concentration coefficient will be equal for a flat receiver:

$$C_n = \eta_r \frac{S_0}{S_1} = \eta_r \frac{\sin \Theta_0 \cos \Theta_0}{\frac{\alpha_0}{2} + 2\delta} = \eta_r \frac{\sin 2\Theta_0}{\alpha_0 + 4\delta}. \quad (1)$$

In this case, the concentration coefficient increases to:

$$C_{nw} = \eta_r \frac{\sin 2\Theta_0}{\alpha_0 + \frac{1}{16}\Theta_0^3}. \quad (2)$$

As you can see, the maximum values of coefficient  $C_{nw} \approx 1.2C_{ne}$ , however, they do not reach the values of the concentration coefficients of parabolic reflectors. This level can be achieved by installing v-shaped counter-reflectors with a reflectance coefficient on receiver  $\eta_r$ .

Then, the concentration coefficient will be equal to:

$$C_k = \eta_r \frac{4 \left[ \sin \varphi_k + \eta_r' (\sin \varphi_m - \sin \varphi_k) \right]}{\alpha_0}, \quad (3)$$

where  $\varphi_k \leq 6$  is the the angle of arc at which the shape of a parabola is practically indistinguishable from a circle.

The surface material of the concentrator is mirrors with an external coating. The mirror reflection coefficient is determined by formula [29]:

$$R = \frac{E_{ref}}{E_{di}}, \quad (4)$$

where,  $E_{ref}$  is the solar radiation flux reflected from the mirror;  $E_{di}$  is the direct flux of incident solar radiation. In our case  $R = 0.9$ .



Fig. 3. XRY-1A calometric bomb.

**Table 1.** Thermophysical properties of sunflower waste

Indicators	Values
Density, kg/m <sup>3</sup>	130–140
Humidity, %	20–25
Dimensions, mm	6–10
Thermal conductivity coefficient, W/m °C	0.046–0.093
Heat capacity, J/kg °C	1600–2300
Heat of combustion, MJ/kg	15–17

## RESULTS

In the course of this study, the material balance of flammable substances that are released from sunflower waste loaded into the reactor of a heliopyrolysis plant with a parabolic solar concentrator was analyzed. During the experiments, it was experimentally established that under the conditions of Karshi, it is possible to create an average temperature in the reactor of the installation of 350–500°C (Figs. 4 and 5).

The duration of the pyrolysis process averaged 110–120 min. Studies have shown that on sunny days in the city of Karshi, the proposed installation can perform 3–4 cycles. As a result, it is possible to compensate for the thermal energy spent on the installation's own needs using solar energy.

The experimental results of studying the temperature regime during the thermal processing of sunflower waste in a heliopyrolysis reactor are given in Table 3.

A graph of changes in the temperature field of the reactor of a heliopyrolysis plant with a parabolic solar concentrator is shown in Fig. 6.

During the experiment, the influence of the humidity of sunflower waste loaded into a heliopyro-

lysis reactor on the amount of liquid products obtained during the pyrolysis process was investigated. Analysis of the data shown in Fig. 7 shows that the amount of liquid products released as a result of heliopyrolysis of biomass depends on their moisture content and varies linearly with the temperature of the process.

The results of compiling the material balance of alternative fuels obtained from sunflower waste loaded into the reactor of a heliopyrolysis plant are given in Table 4.

The composition of gaseous fuel obtained from sunflower waste during pyrolysis was obtained using a KM9206 Quintox gas analyzer (O<sub>2</sub>–CO–NO–CO<sub>2</sub>) (Table 5).

The value of the minimum required heat of combustion of the pyrolysis liquid, taking into account its composition, was also determined by the following formula [30]:

$$Q_q^i = 338C + 1025H - 108(O - S) - 25W^i, \text{ kJ/kg.} \quad (5)$$

Where values 338; 1025; and 108 are the values of the lower calorific value of 1% dry sample of carbon, hydrogen, and oxygen, respectively.

The minimum heat of combustion of gaseous fuel obtained as a result of the experiment was determined analytically, according to the formula of D.I. Mendeleev based on the data given in Table 4:

$$Q_{in}^c = 127CO + 108H_2 + 358CH_4 + 591C_2H_6 + 911C_3H_8 + 234H_2S, \text{ kJ/kg.} \quad (6)$$

As a result, it was determined that the minimum heat of combustion of liquid pyrolysis obtained by thermal processing of sunflower waste using solar energy is  $Q_{in}^p = 35\text{--}40$  MJ/kg, and for the combustion of gaseous fuel— $Q_{in}^p = 25\text{--}28$  MJ/m<sup>3</sup>.

**Table 2.** Parameters of a heliopyrolysis plant with a parabolic solar concentrator

Options	Unit change	Values
Concentrator aperture	m <sup>2</sup>	2.54
Hub diameter	m	1.8
Focal length	m	0.7
Concentrator surface reflectance	–	0.9
Geometric concentration coefficient	–	126.56
Solar radiation intensity	W/m <sup>2</sup>	1000
parabolic dish reflectance (3 mm thickness, face reflection, no protection)	%	90
Light absorption coefficient of the reactor material	–	0.95
Reactor volume (solar energy receiver)	m <sup>3</sup>	0.003
Heat transfer surface of the reactor	m <sup>2</sup>	0.02
Focal spot diameter	m	0.16



Fig. 4. Temperature created inside the solar reactor (08/26/2023).



Fig. 5. Temperature at the bottom of the reactor.

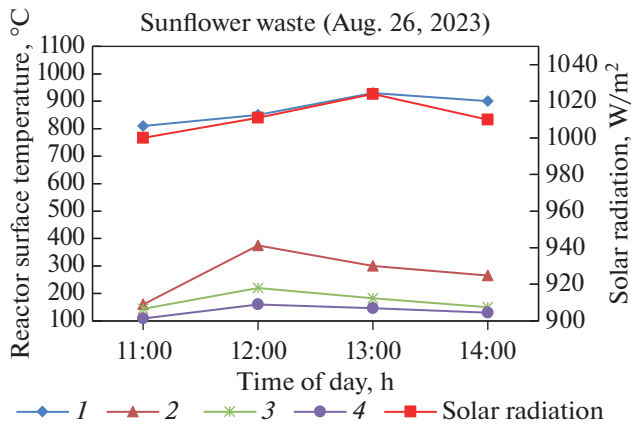


Fig. 6. Graph of temperature on the surface of a heliopyrolysis reactor depending on time and solar radiation.

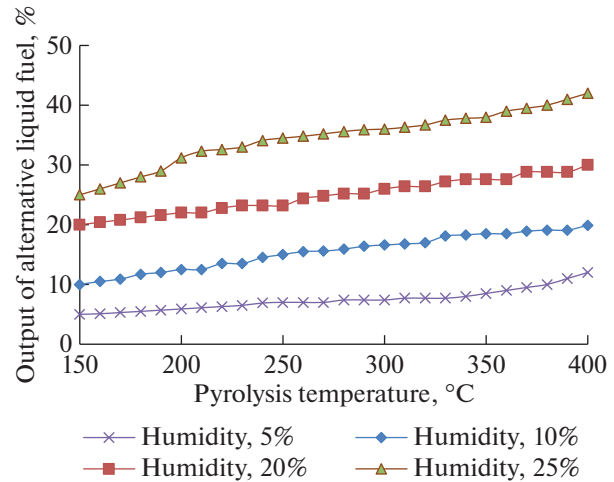


Fig. 7. Graph of the dependence of the yield of liquid bio-fuel on the humidity and temperature of the process.

The percentage of the yield of gaseous, liquid, and solid fuels obtained from sunflower waste loaded into the heliopyrolysis reactor, depending on the process temperature, is shown in Fig. 8.

DISCUSSION

According to the results of experiments, pyrolysis of sunflower waste reaches high intensity in the temperature range of 150–400°C, and the amount of liq-

uid and gaseous fuel released during pyrolysis increases as the temperature rises. At the same time, an analysis of the experimental results showed that the total yield of pyrolysis products depends little on temperature changes in the range of 350–400°C. Thus, as a result of pyrolysis of 1 kg of sunflower waste loaded into the reactor during the experiment, 63% of bio-char, 10% of liquid, and 27% of gaseous fuel were obtained.

Table 3. Results of a study of the temperature regime of a heliopyrolysis reactor

P/n	Time	Incident solar radiation, $q_r, W/m^2$	Outside temperature air, $t_{t,x}, °C$	Temperature at various points of the reactor, $t_r, °C$				Average temperature in the reactor, $t_{o,rt}, °C$
				1	2	3	4	
1	12 <sup>00</sup>	910	35.4	656	237	151	115	289
2	12 <sup>30</sup>	925	35.9	801	258	165	131	338
3	13 <sup>00</sup>	950	36.1	817	285	178	145	356
4	13 <sup>30</sup>	960	36.6	820	301	227	152	375
5	14 <sup>00</sup>	950	36.9	807	290	217	140	363

**Table 4.** Results of an experiment on heliopyrolysis of sunflower waste

No.	Type of loaded raw materials	Weight of loaded raw materials, $m$ , kg	Initial humidity of loaded raw materials, %	Initial temperature of the loaded raw material, $t$ , °C	Average value of incident solar radiation, $q_r$ , $W/m^2$	Average temperature in the reactor, $t_r$ , °C	Process duration $\tau$ , min	Pyrolysis products		
								liquid, kg	gas, kg	hard, kg
1	Sunflower waste	1.0	20	27	940	430.25	120	0.10 (10%)	0.27 (27%)	0.63 (63%)

**Table 5.** Composition of pyrolysis gas

Components	Quantitative composition, %
Carbon monoxide (CO)	27.6
Hydrogen (H <sub>2</sub> )	4.2
Methane (CH <sub>4</sub> )	50–60
Ethane (C <sub>2</sub> H <sub>6</sub> )	4.85
Propane (C <sub>3</sub> H <sub>8</sub> )	1.15
Hydrogen sulfide (H <sub>2</sub> S)	2.2

300 m<sup>3</sup> gaseous, 100–150 kg of liquid, and 550–600 kg of solid alternative fuel were produced. This heliopyrolysis plant with a parabolic solar concentrator is intended for farm clusters and enterprises growing and processing sunflower.

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#### FUNDING

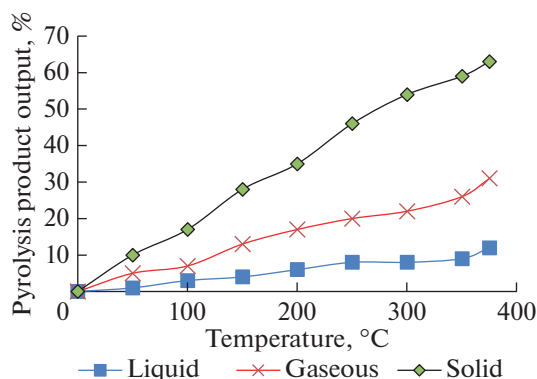
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#### CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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**Fig. 8.** Graph of the dependence of the yield of alternative fuels in a solar pyrolysis plant on the process temperature.

#### CONCLUSIONS

The experimental studies carried out show that the developed heliopyrolysis installation with a parabolic solar concentrator makes it possible to compensate for the energy spent on the installation's own needs to carry out the cycle in daytime mode using solar energy. As a result of experimental studies carried out at this site, samples of solid, liquid, and gaseous fuel were obtained from sunflower waste by pyrolysis. During the year, using the proposed heliopyrolysis plant up to 1 ton of sunflower waste was processed and 270–

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