Study on Heat and Material Balance of Heliopyrolysis Device

Xayrulla Davlonov[1], Xamidulla Almardanov[1, a)], Inomjon Khatamov[1], Sadriddin Urunboev[2], Palvan Kalandarov[2], and Orif Olimov[3]

[1]*Department of Renewable Energy Sources, Karshi Engineering Economics Institute, 180100 Karshi, Uzbekistan*
[2]*Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, 100000 Tashkent, Uzbekistan*
[3]*Jizzakh Polytechnical Institute, Jizzakh, Uzbekistan*

[a)] *Corresponding author: hamid_8191@mail.ru*

Abstract. The article proposes a technological scheme of the process of obtaining alternative fuels from local biomass by the method of heliopyrolysis. A schematic diagram of a solar concentrator experimental pyrolysis device has been developed, and samples of alternative fuels (pyrogas, liquid, solid fuels) have been obtained as a result of thermal processing of biomass. The article also examines the heat and material balance of a heliopyrolysis device. The use of a solar concentrator has made it possible to reduce the specific energy consumption for the pyrolysis process by up to 30%.

INTRODUCTION

Demand for energy is growing in Uzbekistan as a result of industrial development and population growth. According to estimates approved by the State Statistics Committee of the Republic of Uzbekistan, in 2019 Uzbekistan's oil reserves reached 100 million tons and natural gas reserves - 1.1 trillion cubic meters, total reserves of petroleum products (diesel, kerosene, gasoline, natural gas) in the country, 4 bln. tons of conventional fuel. At present, 86% of the electricity generated in the country is thermal power plants (TPPs). 90% of these thermal power plants run on natural gas. In recent years, special attention has been paid to reducing energy consumption in production costs and product costs, as well as the introduction of mechanisms for the use of renewable energy sources [1]. In particular, the Resolution of the President of the Republic of Uzbekistan No. PD-3012 "On the program of measures for further development of renewable energy, energy efficiency in the economy and social spheres in 2017-2021" and Resolution of the Cabinet of Ministers of the Republic of Uzbekistan dated November 25, 2015 No 343 "On measures to encourage the construction of biogas plants in livestock and poultry farms" provides comprehensive measures to ensure energy efficiency in the economy and social spheres of the country [2]. The potential for the use of solar energy in the country is high, and in about 270-300 sunny days of the year (2700-3000 hours) radiant energy can be used effectively for various purposes [3]. In world practice, the use of solar energy for lighting, heating, cooling, ventilation, heating and electricity generation of buildings is established [4, 5]. Nowadays, it is important to use solar concentrators for use in technological processes that require high temperatures from solar energy. In recent years, Uzbekistan has conducted research on the use of solar energy in various technological processes and achieved practical results [6, 7, 8, 9].

In recent years, research on the use of pyrolysis devices in the production of alternative fuels from biomass shows that significant theoretical and practical results have been achieved in this area. Currently, foreign scientists are conducting research on the use of solar concentrators in the pyrolysis process. In particular, the Mexican scientist Morales studied the pyrolysis process using parabolic concentrators, but the studies did not fully explore the practical possibilities associated with the daily location of the sun and seasonal radiation levels [10]. A rapid pyrolysis system using a parabolic reflector was studied by Bangladesh scientist Joardder [11]. In China, Zeng proposed a two-stage heliostatic parabolic concentrator with a display system to control the heating rate and temperature of the pyrolysis reactor. Their research examined the effect of temperature (600–2000℃) and heating rate (5–450 ℃/s) on the productivity and properties of the hard coal obtained as a result of the process, rather than on the performance of the system during this period [12]. A solar pyrolysis device with a two-axis tracking system was developed and tested by Lebanese scientist Zeitter using a Fresnel lens. In the process, a temperature of 550 ℃ was generated and pyrolysis of fuel from household waste was studied [13]. Also, a number of scholars from the commonwealth independent state (CIS) countries have conducted a comprehensive research on the thermal conversion of various sources of biomass into value-added energy products [14, 15, 16, 17, 18, 19, 20, 21, 22].

MATERIALS AND METHODS

The aim of the study is to develop a solar concentrator heliopyrolysis device for biomass pyrolysis and to analyze heat and material balance. Taking into account the solar energy potential of the region, a technological scheme of the gelipyrolysis process for thermal processing of biomass has been created (Figure 1).

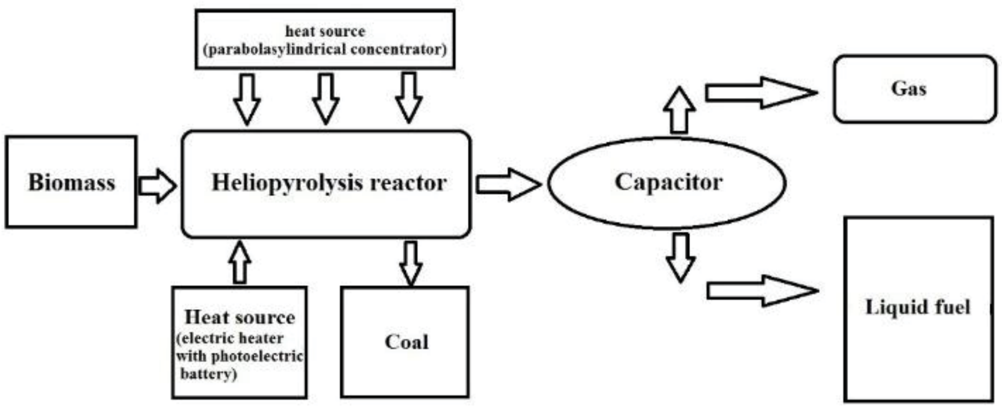

FIGURE 1. Technological scheme of heliopyrolysis process

The average temperature regime during biomass pyrolysis is 350 ÷ 500 ℃. Biomass raw material reserves are a very common alternative energy source, from which 1 m^3 - biogas - 5000 - 6000 - kcal / m^3 of combustion heat, 0.6 liters of gasoline, 1.7 kg of wood equivalent to heat energy gives [23]. Reducing energy consumption in pyrolysis technology is a major challenge. This is because energy (heat) must first be supplied to maintain the temperature regime of the reactor. Typically, the processes carried out in a pyrolysis unit are carried out at the expense of coal, natural gas or electricity consumption. This is because very large thermal energy is required to decompose biomass waste, and additional heating of biomass requires excessive energy consumption.

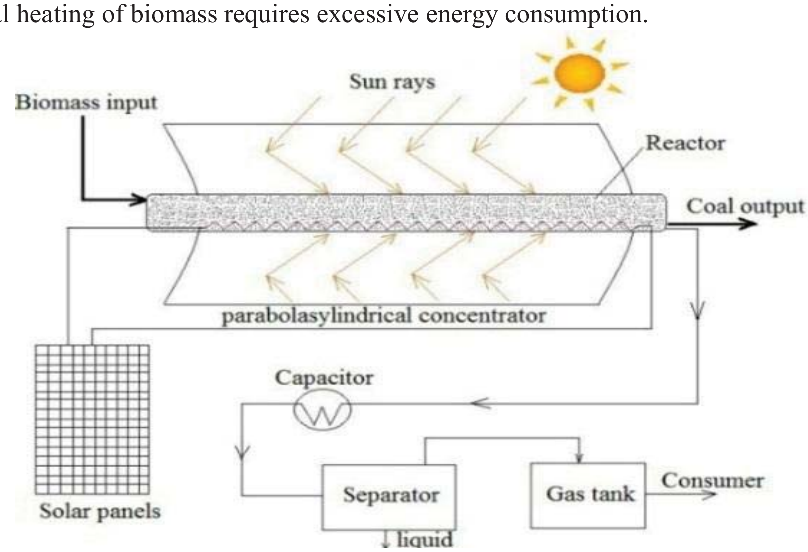

FIGURE 2. Schematic diagram of a heliopyrolysis device

These technical and economic problems can be overcome by using a heliothermal heating system. As a result of research in this area, a method of using solar concentrators in the process of biomass pyrolysis, i.e. the method of heliopyrolysis, has been proposed (Figure 2).

The solar concentrator-based heliopyrolysis device does not harm the environment and reduces the energy consumption for the process. The temperature required for the process is generated by parabolacylindrical solar concentrators. The advantage of the proposed method is that the pyrolysis reactor can be continuously heated by solar energy using solar concentrators. Initially, the pyrolysis reactor is heated to a certain temperature by a solar heating system, while the pyrolysis reactor is heated continuously, ie during the pyrolysis cycle by a solar heating system at the same time as a conventional or electric heating system [24].

FIGURE 3. Heliopyrolysis unit with rotary reactor and solar concentrator: 1-parabolacylindrical concentrator; 2-reactor; 3-base foundations; 4-gas outlet

It is important to study the heat balance of a pyrolysis reactor to obtain fuel from biomass by the heliopyrolysis method. This is because it is important to heat the reactor surface with the help of the sun and to provide heat continuously. An experimental version of a heliopyrolysis device with a rotating reactor and a solar concentrator in the proposed device is shown in Figure 3.

The pyrolysis reaction takes place inside a stainless steel reactor (2). The main components of a solar pyrolysis system are the reactor (2), the parabolacylindrical solar concentrator (3), and the condenser. The reactor is heated from the outside by means of parabolacylindrical solar concentrators together with a continuous heating system. In this case, parabolacylindrical solar concentrators are used as a heat source for additional heating of the reactor. As a result, using this combined device allows obtaining heat at a temperature of 350 - 500°C. Pyrolysis vapors move to the condenser through the formation of a pressure above atmospheric pressure inside the reactor. Condensate (biofuel) from pyrolysis vapor accumulates in liquid collectors. The separated gas is collected in a gas holder.

In this research work, the theory of heat-mass transfer of thermal engineering and solar devices and methods of calculating heat balance equations were used.

RESULTS AND DISCUSSION

To calculate the results of experimental research on a computer, a "Program for modeling the device of heliopyrolysis and calculation of exergetic balance for the production of alternative fuels from biomass" was developed [25].

We create the heat balance as follows:

$$Q_{reak} = Q_{proc} + Q_{en.th} - Q_{pc} - Q_{elec}\ , W \quad (1)$$

The amount of heat required to heat the loaded biomass to the temperature of the pyrolysis process, Q_{proc}:

$$Q_{proc} = m_b \cdot c_b \cdot (t_{proc} - t_b) \cdot 3{,}6 \cdot 10^{-3},\ W \quad (2)$$

The amount of heat released into the environment through the reactor in the process Q_{proc}, *W,* [26, 27, 28]:

$$Q_{en.th} = \frac{2\pi l \lambda (t_{proc} - t_{biom})}{ln \frac{d_2}{d_1}},\ W \quad (3)$$

Here,
λ– thermal conductivity, *W/(m·^{0}C)*;
l – reactor length, *m*;
t_{proc} – the temperature required for pyrolysis, ^0C.
t_{biom} – biomass temperature, ^0C.
d_2 – the inside diameter of the reactor, *m.*
d_1 – the outside diameter of the reactor, *m.*
Calculation of solar energy density Q_{pc} in the focal zone of a parabolacylindrical concentrator [29, 30]:

$$Q_{pc} = 2 \cdot P \cdot tg(\frac{U_м}{2}) \cdot L \cdot R \cdot E_o,\ W \quad (4)$$

Here, P – focal parameter; $U_м$ – the angle of incidence of sunlight; L – concentrator length, m; E_o– the amount of the falling solar radiation, W/m^2; R – return coefficient.
The amount of heat released from a solar-powered electric heater Q_{elec}[31, 32, 33]:

$$Q_{elec} = I \cdot U \cdot \tau \cdot 3{,}6 \cdot 10^{-3}, W \quad (5)$$

Here, I – current strength, A; U – electrical voltage, V; τ – time, hour.
If we accept that $Q_p + Q_{lost}$ in $Q_{release}$:

$$Q_p + Q_{lost} = Q_{release}\ , \quad (6)$$

If we accept that $Q_{pc} + Q_{elek}$ in $Q_{enter.}$:

$$Q_{pc} + Q_{elec} = Q_{enter.} \quad (7)$$

The amount of heat required for a solar device Q_{demand}:

$$Q_d = Q_{release} - Q_{enter.} \quad (8)$$

TABLE 1. Reactor heat balance parameters

№	Raw materials (biomass)	m, кг	V, l	λ, W/m· K	$t_{w2}, ^0C$	$t_{w1}, ^0C$	*Qproc*, kW	*Qen,th*, kW	*Qpc, kW*	*ΔQ, kW*
1	Woodwool	2,7	9	45,4	40	350	6,7	3,4	2,7	7,3
2	button	4,71	9	45,4	40	350	11,68	3,4	2,7	12,12
3	wood	3,76	9	45,4	40	350	9,33	3,4	2,7	10,03

TABLE 2. Material balance of heliopyrolysis process

Raw materials (biomass)	Loaded biomass, kg	The products of heliopyrolysis		
		Pyrogas, m^3	Liquid, l	Solid fuel, kg
Woodwool	2,7	0,6 (22)	1 (38)	1,1 (40)
button	4,71	0,8 (18)	2,4 (52)	1,41 (30)
wood	3,76	0,75 (20)	2,2 (60)	0,75 (18)

The results of a comparative study on the extraction of alternative fuels from conventional and heliopyrolysis methods from wood shavings are given in Table 3.

TABLE 3. Thermal and technical characteristics of the heliopyrolysis process

Raw materials	Loaded biomass, kg	Biomass moisture, %	Loaded biomass temperature, ^{0}C	Working pressure, Mpa	In the traditional way				Application of solar concentrator to system	
					Process temperature, ^{0}C	Process time, min	Consumed heat, kW	Consumed fuel (natural gas), m^3	Heat received from the sun, kW	Fuel (natural gas) saved, m^3
Wood chips	2.7	20	40	0.1	350-500	180	10.1	0.9-1.0	2.7	0.3

The energy consumption diagram of the heliopyrolysis process is shown in Figure 4.

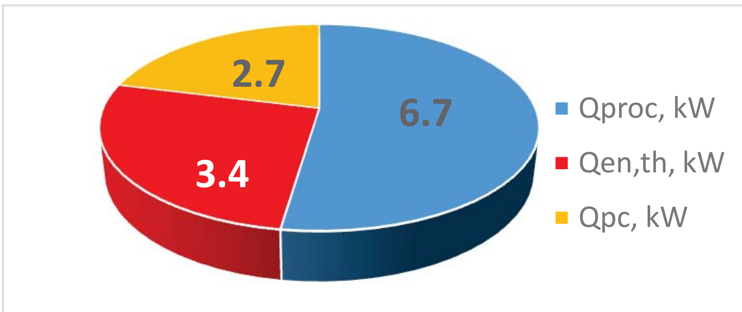

FIGURE 4. Energy diagram of the process of heliopyrolysis

CONCLUSIONS

The efficiency of biofuel production varies mainly depending on the operating temperature of the pyrolysis reactor, the size of the biomass particles and the duration of operation. Experiments showed that 1,0 m^3 of natural gas was burned when the moisture content of 2,7 kg of biomass was 20% and to raise the internal temperature of the reactor to 350 ℃ for the pyrolysis process to take place. At the same time, 10,1 kW of energy was used to form the pyrolysis process. The process saved 0.3 m^3 of natural gas or 2,7 kW of energy through the use of solar concentrators. The use of solar concentrators has made it possible to reduce the amount of fuel consumed for the process by 30%. The experimental results can be used in the design and calculation of the heliopyrolysis device.

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