

DEVELOPMENT OF SOFTWARE FOR MODELING AND CALCULATION OF THE HEAT BALANCE OF THE PYROLYSIS PLANT

Sayyora Gulyamovna Mamatkulova

Senior Teachers at Karshi Branch of the Tashkent University of Information

Alisher Islomovich Ganiyev

Technologies Named after Muhammad Al-Khwarizmi,
Beshkent road 3 km Street, Karshi, 180100, Uzbekistan.
e-mail: urisheva80@mail.ru

ABSTRACT

In this article, in order to determine the consumption of thermal energy for biomass processing, modeling and calculation of the thermal balance of a pyrolysis plant are performed. Based on these equations, the calculation of parameters such as the thermal balance for a tubular (cylindrical shape) bioreactor, the heat used, the efficiency of the tubular bioreactor, the exergy of the source fuel, the exergetic efficiency of the bioreactor, the loss of exergy to the environment, the heat transfer coefficient, etc. The heat balance calculation software is developed using the Java programming language. In addition, the article provides a comparative analysis of the technical and energy characteristics of bioenergy plants, which shows that the energy intensity of biomass processing in existing plants reaches up to 50-60% in the total heat balance.

INTRODUCTION.

During the period of economic globalization, two main threats at the global level that are directly related to bioenergy have been clearly highlighted: the growing shortage of energy resources, climate change and global warming. The increase in anthropogenic impact on the environment makes an undoubted contribution to the speed of planetary processes associated with climate change and global warming currently observed. [1]. The most striking manifestation of this process is the problem of waste, which is attracting more and more attention. The total global volume of municipal solid waste (MSW) alone is projected to grow to 2.59 billion tons by 2030, and to 3.4 billion tons by 2050. Environmentally friendly recycling and energy utilization of production and consumption waste finds a solution, first of all, in the range of bioenergy technologies [2].

The development of a new industry, which is modern bioenergy, requires maximum concentration of efforts of scientists working in the field of fundamental and applied research to form a scientific basis and modern methodological and technological approaches to solve numerous problems in this area.

METHODOLOGY AND MATERIALS

One of the classic renewable energy sources is biomass. The use of biomass in natural solid form is associated with a number of problems, the main of which are ecology and insufficient efficiency of conversion and energy use of raw materials. Preliminary thermal processing of biomass into liquid gaseous forms seems to be the most promising. Liquid and gaseous fuels

produced from biomass are more versatile, environmentally acceptable and have a high energy content compared to raw materials (plant waste, manure and other types of biomass). Thermochemical technologies for producing solid, liquid and gaseous fuels from various types of biomass include the following processes: direct combustion, pyrolysis, gasification, synthesis [3].

Among modern thermochemical technologies for the energy use of biomass, pyrolysis is the most versatile, which makes it possible to obtain high-quality, environmentally safe solid, liquid and gaseous alternative fuels from almost any raw material. At the same time, the energy costs of providing a thermochemical process usually do not exceed 5-10 % of the energy products obtained [3].

In the process of designing pyrolysis plants, the calculation of the thermal balance of the bioreactor is of key importance in order to determine the consumption of thermal energy for processing biomass. For thermal processing of biomass in the reactor, a certain consumption of thermal energy is required. The thermal energy supplied supports the temperature regime of biomass processing. To assess the energy intensity of biomass processing, it is necessary to study the thermal balance of the reactor. On the basis of mathematical modeling of the thermal balance of the reactor, important tasks of energy saving and optimization of bioenergy reactors are solved.

During the operation of the bioreactor, part of the heat released during the combustion of fuel is irretrievably lost in the environment. The relationship between the total heat input into the bioreactor, the useful heat used in it and the thermal losses are expressed by the thermal balance of the reactor [4].

DESCRIPTIONS OF EXPERIMENTAL OBJECTS

The heat balance equation for a tubular (cylindrical) bioreactor has the following form:

$$Q_{arriv} = Q_{consum}, \text{ kJ/kg} \quad (1)$$

where: Q_{arriv} — the arrival of heat, kJ/kg; Q_{consum} — heat consumption.

The thermal balance of the bioreactor is calculated for 1 kg of fuel:

$$Q_{arriv} = q_{used} + q_{lost.out} + q_{lost.env} + q_{lost.ch} + q_{lost.m} + q_{lost.s} \quad (2)$$

where: q_{used} , $q_{lost.out}$, $q_{lost.env}$ — accordingly, the heat used in the reactor by raw materials, lost with outgoing flue gases, lost in the environment.

$q_{lost.ch}$ — heat loss from chemical incompleteness of fuel combustion потеря тепла от химической неполноты сгорания топлива; $q_{lost.m}$ — heat loss from mechanical incompleteness of fuel combustion; $q_{lost.s}$ — heat loss with physical heat slags, kJ/kg.

When burning gaseous fuel (or liquid), in which there is no ash, you can take

$$q_{lost.m} = 0; \quad f q_{lost.s} = 0 \quad [4]$$

The arrival of heat can be determined by the expression [5]:

$$Q_{arriv} = Q_c^l + C_m \cdot t_m + \alpha \cdot \alpha_0 \cdot C_v \cdot t_v + C_b \cdot m_b \cdot t_b \quad (3)$$

or

$$Q_{arriv} = Q_c^l + Q_{fuel} + Q_{air} + Q_b \quad (4)$$

where Q_c^l - lower heat of combustion of fuel, kJ/kg; Q_{fuel} , Q_{air} , Q_b - heat introduced into the reactor by fuel, air and biomass, kJ/kg.

The apparent heat of fuel, air and biomass is usually small and they are often neglected in technical calculations. Then $Q_{fuel} = C_m \cdot t_m = 0$; $Q_{air} = 0$; $Q_b = 0$

Then the heat balance equation of the bioreactor has the following form:

$$Q_{arriv} = Q_{consum} \approx Q_c^l$$

From equation (2) the useful heat used is equal to

$$q_{usef} = Q_c^l - q_{outg} - q_{lost} = \eta \cdot Q_c^l \tag{5}$$

Efficiency of a tubular bioreactor:

$$\eta = \frac{q_{usef}}{Q_c^l} \tag{6}$$

or

$$\eta = 1 - \frac{q_{outg}}{Q_c^l} - \frac{q_{lost}}{Q_c^l} \tag{7}$$

where, $\frac{q_{outg}}{Q_c^l}$, $\frac{q_{lost}}{Q_c^l}$ - accordingly, heat losses with outgoing flue gases and heat losses to the environment are fractions of the lowest heat of combustion of biofuels.

Heat loss to the environment according to preliminary calculated and experimental data, fuel combustion can take 6% (0.06 in fractions) of the lowest heat.

The temperature of the outgoing flue gases is determined by the formula [4,5]:

$$T_{outg} = T_1 + \Delta T = T_1 + (100 \div 150) \text{ K}; \tag{8}$$

where T_1 - temperature of the heated product at the reactor inlet, K; ΔT - temperature difference of heat carriers at the input of raw materials into the coil of the convection chamber, $\Delta T=150$ K.

Now let's make up the exergetic balance of the bioreactor according to the equation:

$$E_{fuel} + E_{air} = E_{usef} + \Delta E_{exlos} + \Delta E_{gor} \tag{9}$$

where, E_{fuel} - exergy of the source fuel, kJ/kg. In our case, to maintain the temperature regime of the reactor, a part of the biogas obtained in its own pyrolysis plant is used, kJ/kg.

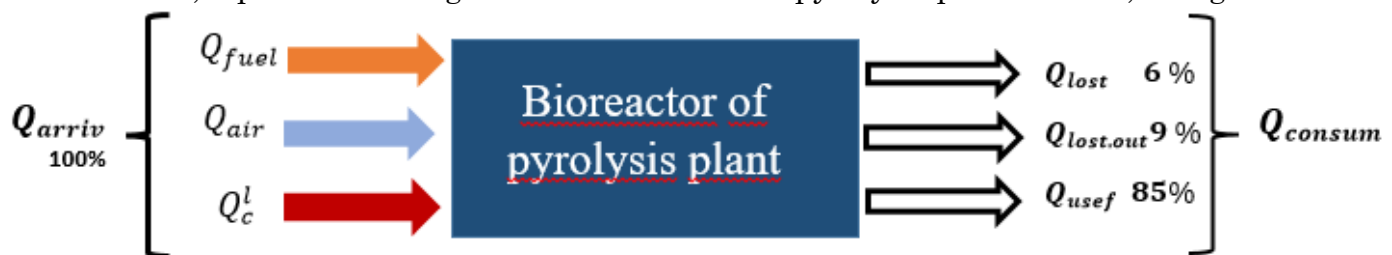


Figure 1. Diagram of heat flows in a PP bioreactor [6].

E_{air} - exergy of atmospheric air, kJ/kg.

$$T_{air} = T_{env} \text{ и } P_{air} = P_{env} = 0,1 \text{ MPa}; E_{air} = 0 .$$

E_{ecp} - exergy of biofuel (biogas) combustion products, kJ/kg.

$$E_{ecp} = Q_c^l \left(1 - \frac{T_a}{T_e}\right) \tag{11}$$

where, T_a - ambient temperature (atmospheric air), K; T_e « temperature - enthalpy » ($t-i$), K.

By $T_a = t_a + 273,15 K$.

Exergy of the heat of the resulting steam:

$$E_{st} = Q_c^l \left(1 - \frac{T_a}{T_{usef}}\right)$$

Exergy losses per 1 kg of spent fuel:

$$\Delta E_{exlos} = E_{exlos} - E_{st}, \text{ kJ/kg.}$$

ΔE_{env} — loss of exergy to the environment, kJ/kg.

$$\Delta E_{env} = Q_{env} \left(1 - \frac{T_a}{T_{gor}}\right)$$

ΔE_{gor} - loss of exergy due to the irreversibility of the gorenje process, kJ/kg; calculated from the energy balance.

Exergetic Efficiency of the bioreactor:

$$\eta = \frac{E_{outp}}{E_{inp}} = \frac{E_{st}}{E_T}$$

The exergetic diagram is shown in figure 3.

The exergetic balance of the bioreactor of the Pyrolysis Plant is shown in Table 1.

The need for heat to create the required temperature regime consists of the amount of heat needed to heat up the biomass (manure) from the temperature characteristic of the dry manure supplied to the reactor to the pyrolysis temperature, and the heat used to compensate for losses caused by heat transfer.

The amount of heat, kJ, required to heat the loaded mass to the temperature of the pyrolysis process,

$$Q_{amount} = M_c \cdot C_c (t_b - t_d) \tag{12}$$

where M_c — mass of biomass,; C_c — average specific heat capacity of biomass, kJ/(kg·oS); t_b — biomass temperature, °C; t_d — also, downloadable, °C.



Figure 2. Exergetic diagram

Table 1. Exergetic balance of the bioreactor of the pyrolysis plant [7]

Energy supply			Exergy with drawal			
Parameter	kJ/kg	%	Parameter	kJ/kg	%	
Exergy of the source fuel, $E_{inp} = E_T$	20800	100	1. Loss of exergy by combustion products, ΔE_{exlos}	5920	28.5	
			2. Loss of exergy to the environment, ΔE_{env}	504	2.5	
			3. Loss of exergy due to the irreversibility of the gorenje process, ΔE_{gor}	2576	12	
			4. Usefully used exergy, $E_{outp} = E_{usef}$	11800	57	
	20800	100		20800	100	

Heat losses in a bioreactor are determined by the difference between the temperature of the processed biomass and the outside temperature of the reactor surfaces, the area of the contact surfaces of biomass and outside air, the thermal conductivity coefficient of the reactor wall material, the heat transfer coefficient of the contact surface between the media, the thickness of the wall layers.

The amount of heat lost by biomass as a result of heat transfer through the reactor wall to the environment, kJ

$$Q_a = kF(t_b - t_a) \quad (13)$$

where k — heat transfer coefficient, kJ/(m³·h·°C); F — reactor heat exchange surface area, m³; t_b — biomass temperature in the reactor, °C; t_a — ambient temperature, °C.

Коэффициент теплопередачи определяем по формуле [4]:

$$K = \frac{1}{\frac{1}{\alpha_1 d_1} + \frac{1}{2\lambda_w} \ln \frac{d_1}{d_2} + \frac{1}{2\lambda_{is}} \ln \frac{d_{is}}{d_2} + \frac{1}{\alpha_2 d_2}} \quad (14)$$

Using the expression (13), it is possible to calculate the heat loss by heat transfer by any element of the reactor surface. Consequently, the total heat demand for the plant is determined mainly by the cost of heating the biomass to the pyrolysis temperature. The need for heat to compensate for losses caused by heat transfer can be reduced by applying appropriate thermal insulation.

The source of heat for the pyrolysis plant is its own biogas (pyrolysis gas). To save energy and biogas, it is necessary to strive to ensure that animal excrement cools less on the way to the reactor (for this the path should be shorter, and even better if the reactor is located inside a livestock farm), the pipelines are well insulated.

RESULTS OF CALCULATIONS

To produce a simplified calculation of a thermal bioreactor with a different loading mass of biomass (manure), we have developed software that makes it possible to determine the parameters based on the input variables (figure 3).

Parameter	Value
Lower heat of combustion	20000
Temperature of the heated product	450
Ambient temperature	20
Mass of biomass, kg	100
Average specific heat capacity of biomass, kJ	1.8
Biomass temperature	20
Outer diameter of the reactor, mm	820
Reactor inner diameter, mm	800
Thickness of thermal insulation, mm	10
Reactor height, m	1
The conductivity coefficient of the reactor wall	0.0022
Insulation conductivity coefficient	0.12

Figure 3. Dialog box for entering heat process variables

After entering the variables of the thermal process in the dialog box, by clicking the Calculate button, you can get the parameters that relate to the thermal balance (figure 4).

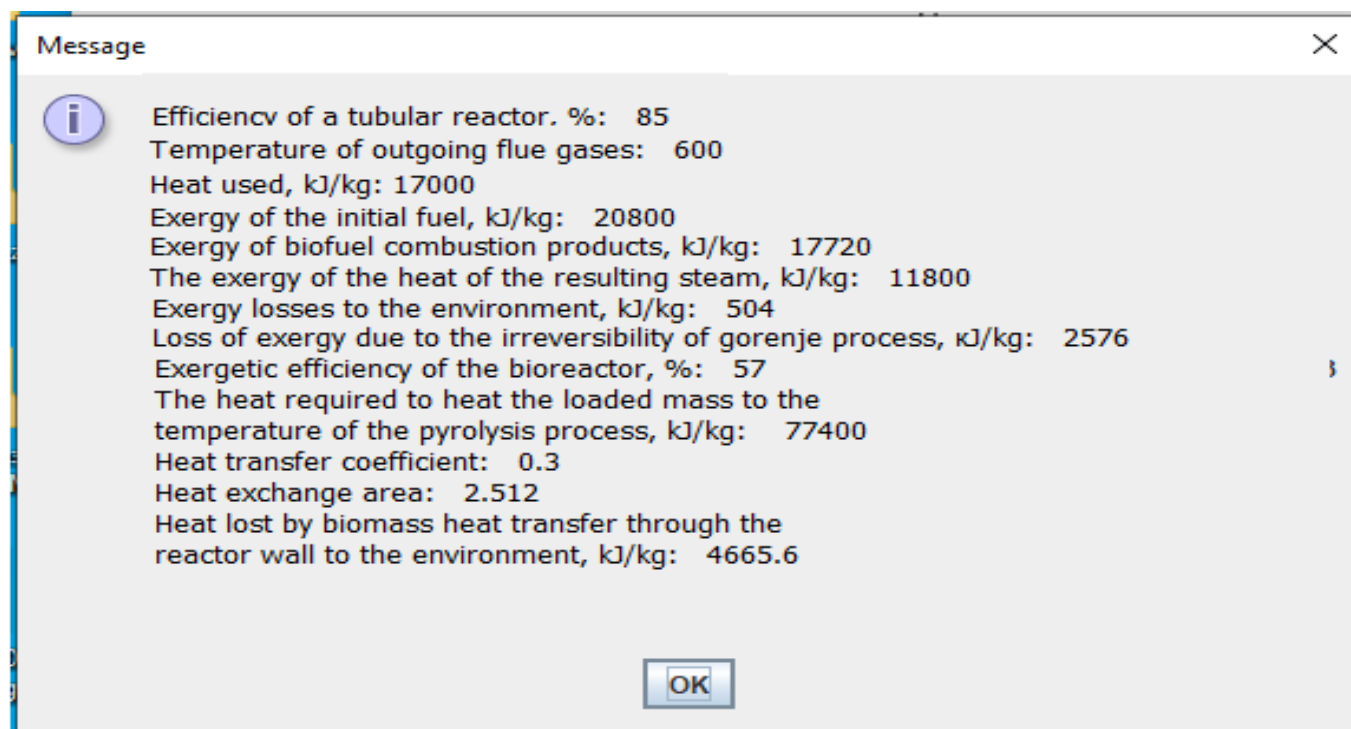


Figure 4. Dialog box for calculating the thermal balance of the reactor

CONCLUSIONS

A comparative analysis of the technical and energy characteristics of bioenergy plants shows that the energy intensity of biomass processing in existing plants reaches up to 50-60% in the total heat balance, which leads to certain difficulties of implementation and reduces their energy efficiency..

Among modern thermochemical technologies for the energy use of plant biomass, pyrolysis is the most versatile, which allows obtaining high-quality, environmentally safe solid, liquid and gaseous alternative fuels from almost any raw material. At the same time, the energy costs of providing a thermochemical process usually do not exceed 5-10 % of the energy products obtained.

The results of the calculation of the thermal balance of the bioreactor of the pyrolysis plant show that the heat loss during full loading of the reactor is 6% of the supplied heat, and when loading 50 kg of biomass (50% load), the reactor heat loss will be 12%. Thus, in order to save energy, thermal processing of biomass must be carried out when the reactor is fully loaded.

Exergetic analysis of the bioreactor operation shows that the greatest losses of exergy occur with the outgoing combustion products of fuel (28.5%), which must be disposed of for pre-drying of biomass.

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