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The "Engineer" publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

The journal is published 4 times a year and contains publications in the following main areas:

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- Civil and Structural Engineering;
- Computational Mechanics;
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- Electrical and Electronic Engineering;
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Modeling of organic waste from a gas condensation boiler with anaerobic fermentation in MATLAB

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Abstract: Progress in agricultural production is impossible without the improvement and further development of methods for disinfection and processing of organic waste of plant and animal origin to obtain gaseous fuel. The use of biogas as one of the promising alternative energy sources has been increasing in recent years, as it helps solve many problems in agro chemistry, energy, and environmental protection. The main facilities for anaerobic treatment of organic waste for the production of fertilizers and biogas are biogas plants [1].
The determining factors that influence the quantitative and qualitative composition of emissions from a gas condensing boiler are the composition of the fuel burned and the temperature of the water entering the condensing heat exchanger, coming from the return line of the heating system.
Manufacturers of biogas plants and boiler equipment indicate in their technical data sheets the minimum concentrations of harmful substances emitted by the unit into the atmosphere and certain concentrations of acids disposed of with condensate.
Keywords: biogas, gas holder, reactor, organic substrate, digestion

1. Introduction

With the development of industrial production, agriculture and social services in Azerbaijan, new opportunities are opening up for biomass energy production.The country has the following sources of biomass: combustible industrial waste; forestry and wood processing waste; agricultural products and organic waste; household and municipal waste, as well as waste from regions contaminated with oil and petroleum products.All of these resources can be used for energy production. Azerbaijan produces 2 million tons of solid municipal and industrial waste annually. Recycling solid municipal and industrial waste could be used to heat public buildings in large industrial cities.

Currently, there are over 200 waste landfills operating in Azerbaijan, covering a total area of 900 hectares. The estimated volume of methane emitted from landfills in major cities is 42.8 million m^3 in Baku, 7.2 million m^3 in Ganja, 6.9 million m^3 in Sumgait, and so on. Small combined heat and power plants for electricity generation could be built on these landfills. However, only a small number of biomass-based projects are currently underway in the republic [2].

2. Research methodology

Trends in the Development of the "Green Economy" in Agriculture

The climatic conditions of Azerbaijan (abundance of heat, sunlight, and the duration of the vegetation period) allow for the specialization in the cultivation of many valuable agricultural crops. The main directions of agricultural production include grain farming (wheat), cotton cultivation, viticulture, horticulture, tobacco growing, tea cultivation, vegetable farming (especially early crops), and livestock farming.
In the structure of agriculture in recent years, approximately 56% has been attributed to crop production, and the remainder to livestock production [12].

The volume of agricultural production in Azerbaijan in 2014 amounted to 5.225 billion manats, which represented about 5.7% of GDP. The agro-industrial complex (AIC) of the republic is the largest employer, providing employment to approximately 36% of the working population.

The utilization of industrial and household waste can contribute to heating buildings in industrial cities through the construction of combined heat and power plants based on landfills. For example, in 2012, the Baku Solid Waste Incineration Plant was commissioned, with a processing capacity of 500,000 tons of household waste and 10,000 tons of medical waste per year [13].
The production equipment of the "Balakhani" waste incineration plant includes two incineration lines, each with a capacity of 250,000 tons, as well as a generator with a capacity of 35 MW for electricity production.

In addition, projects related to the use of biomass have begun to be implemented in Azerbaijan. In the village of Khanbalik in the Guba district, a project is planned for the production of methane from biomass. According to estimates by the Ministry of Energy of Azerbaijan, the country has a high potential for methane production from livestock waste, amounting to 24–27 million cubic meters per year [3].

The government of Azerbaijan attaches great importance to climate change issues. The main direction of development within the framework of "Azerbaijan 2030: National Priorities for Socio-Economic Development" is to achieve the same level of energy intensity and carbon dioxide emissions per unit of GDP as the countries of the Organization for Economic Co-operation and Development (OECD). It is planned to reduce greenhouse gas emissions by 35% by 2030, whereas in 1990 the amount of carbon dioxide (CO_2) emissions in Azerbaijan was 73.3 million tons [4].

Agriculture in the Republic of Azerbaijan

Compared to 2022, agricultural production increased by 3.0 percent, including a 3.2 percent increase in livestock

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production and a 2.7 percent increase in crop production. In 2023, a total of 3,248.6 thousand tons of cereals and legumes, including corn, were harvested from an area of 948.3 thousand hectares (in initial weight), with an average yield of 33.0 centners per hectare. Compared to 2022, the harvest increased by 2.8 percent.

Of the cereals and legumes produced in 2023, wheat accounted for 1,833.8 thousand tons, or 56.4 percent. The average yield of wheat was 33.8 centners per hectare.

Livestock

In 2023, 647.7 thousand tons of meat (in live weight), including poultry, were produced. Compared to 2022, meat production increased by 3.1 percent. In 2023, the average milk yield per cow and buffalo was 1,746 kilograms (1,731 kg in 2022). According to preliminary data as of January 1, 2024, there were 7,081.6 thousand head of sheep and goats, and 2,502.4 thousand head of cattle in the country, including 1,235.5 thousand head of cows and buffaloes. Cows and buffaloes accounted for 49.4 percent of the total cattle population [5].

Table 1

The number of livestock and poultry across all categories of farms, thousand head

	Conditions as January 1		**Compared to the same period last year**	
	2024 year	2023 year	%	+, -
Bighorn cattle	2 502,4	2 618,1	95,6	-115,7
Including: cows and bulls	1 235,5	1 288,8	95,9	-53,3
Sheep and goats	7 081,6	7 751,7	91,4	-670,1
Number of pigs	4 469	5 130	87,1	-661
Birds (by farms)	11 647,5	11 635,5	100,1	12,0
For poultry enterprises	11 265,0	10 886,6	103,5	378,4

Target

To identify the design and engineering features of biogas plants. Identify the main factors influencing biogas yield. Predicting the scale of environmental damage or identifying ways to mitigate it requires a tool. A mathematical model for predicting toxic emissions could serve as such a tool.

Biogas Technology

Biogas technology represents complex natural processes of biological decomposition of manure, poultry litter, and other organic substances under anaerobic conditions (without air access). Under the influence of anaerobic bacteria, a mineralization process occurs in nitrogen-, phosphorus-, and potassium-containing organic compounds, resulting in nitrogen, phosphorus, and potassium in mineralized forms that are most accessible to plants, while completely destroying pathogenic microflora, helminth eggs, weed seeds, nitrates, and nitrites.

The fermentation process takes place in a vessel called a methanogenic tank or reactor. In the methanogenic tank, bacteria decompose part of the organic matter, producing methane (60–70%), carbon dioxide (30–40%), a small amount of hydrogen sulfide (0–30%), as well as traces of ammonia, hydrogen, and nitrogen oxides.

This technology helps prevent pollution of the air and water basins, soil, and crops by utilizing and deodorizing manure waste from large livestock farms and poultry complexes.

This has necessitated research to develop advanced methods that ensure higher-quality substrate decomposition, accelerated bacterial growth, and a high degree of fermentation of biologically decomposable organic substances [14].

However, recently, the method of applying high-voltage electric discharges to the organic substrate has attracted the most interest. This method shortens the decomposition time by activating the substrate and increases the yield of high-quality target products (biogas and mineralized organic fertilizers).

Existing methods of anaerobic processing do not ensure complete fermentation and deeper decomposition of agricultural production waste. Given the current situation, the development of biogas plants for fermenting food and agricultural waste using microorganisms is relevant.

Typically, the main components of a biogas plant are:

- Fermentation chamber (reactor, methanogenic tank)
- Devices for maintaining a constant temperature in the reactor
- Equipment for mixing the substrate in the reactor
- Devices for accumulating and storing biogas (gas holder)

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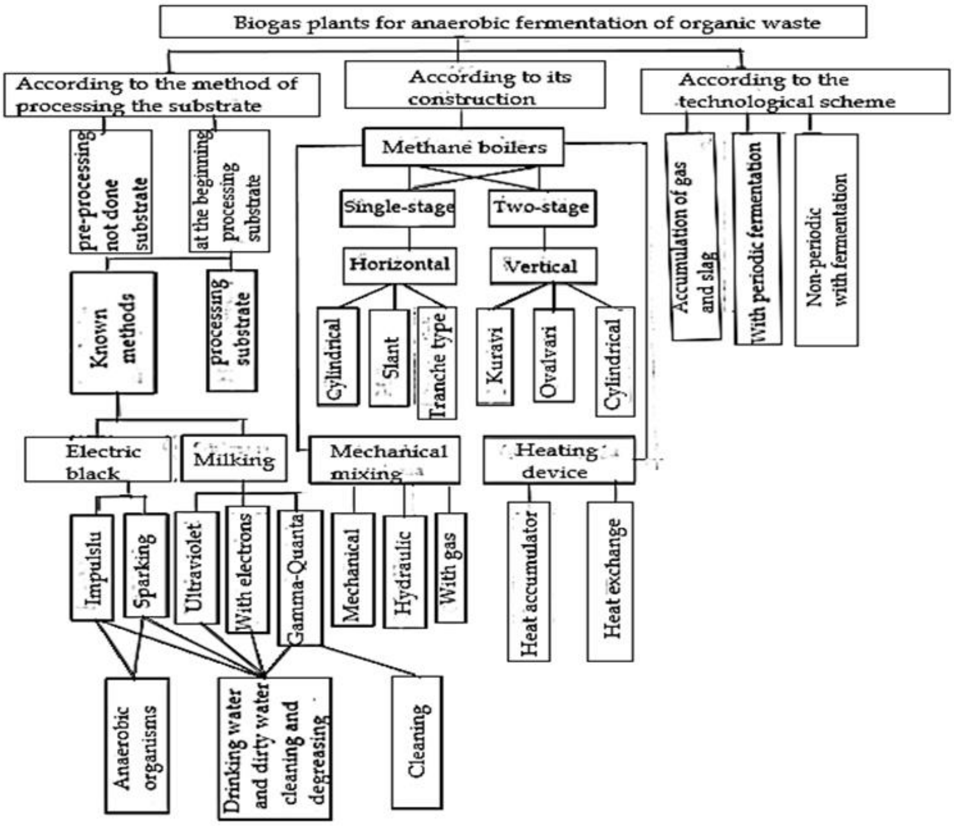

Fig. 1. Scheme of Biogas Plant Classification

According to the new concept of developing anaerobic fermentation technology of organic substances, there is an opportunity to expand the structural scheme of biogas plant classification.

The classification presented in Figure 1 allows identifying the features of design and technical solutions of biogas plants.

Based on the provided scheme, the main factors influencing biogas yield can be distinguished. These include temperature, pH, pressure, mixing intensity, humidity, climatic conditions, etc., which are interrelated, and a change in one parameter can lead to a decrease or increase in biogas production.

Based on the analysis of literature sources and our own research, I consider it advisable to conduct work in this direction. The relevance of these tasks is confirmed by the results of scientific studies [6-7], including the testing of new research directions [8,9]. According to the new concept of anaerobic fermentation technology development, there is an opportunity to expand the structural scheme of biogas plant classification.

Calculation of heat flow and thermal insulation in problems of thermal conductivity under steady-state conditions in the case of a flat wall [15] is performed based on the solution of the problem of thermal conductivity of a flat uniformly heated layer, the thermal conductivity of the material of which is known (reference value [16, 17]). This solution has the form

$$q = \frac{\Delta T_w}{R_{w}};\ R_w = \sum \delta/\lambda_w \qquad (1)$$

where q is the heat flux density, W/m^2 ; $\Delta T_w = t_{w1} \ldots . t_{w2}$ is the temperature difference across a flat layer (in particular, a wall) as the temperature difference across its surfaces; Rw is the thermal resistance of a flat multilayer wall, $(W/(m^2 \cdot K))^{-1}$, determined by the sum of the resistances of its layers of thickness δ with the thermal conductivity of the material as a function of temperature $\lambda_w(t),\ W/(m \cdot K)$, averaged over a given temperature range $t_{w1} \ldots . t_{w2}$ across the wall surfaces.

Generally, the dependence of the thermal conductivity of various materials on temperature is expressed by linear functions

$$\lambda(T) = a(1 + b_1 \cdot t)\ yaxud\ \lambda(T) = a + b_2 \cdot t \qquad (2a)$$

in which the constants a and b are determined by the type of material; temperature t is substituted in degrees Celsius. Formulas of the type (2a) are collected in reference books on the thermophysical properties of substances (e.g., [16, 17]).

The average value of thermal conductivity in the temperature range $t_{w1} \ldots . t_{w2}$, taking into account (2a), is calculated using formula [16]

$$\lambda_w = a(1 + b\frac{t_{w1} + t_{w2}}{2}) \qquad (2b)$$

Example - A flat wall with a thickness of $\delta = 50mm$ (Fig. 2) is made of a homogeneous material and uniformly heated across its surface. The temperatures on the wall surfaces are maintained constant at $t_{w1} = 100°C$ $və$ $t_{w2} = 60°C$.

Investigate the dependence of the heat flux density through the wall on the thermal conductivity of the following materials: steel, concrete, and diatomaceous earth brick. The thermal conductivity of these materials is taken from reference book [16].

Solution: Since the wall is heated uniformly, we will assume that its temperature field is one-dimensional [15], and we will use (1) to calculate the heat flux density through the wall.

1.To solve this problem, it is necessary to determine the thermal conductivity of the materials and average its value over a given temperature range. The following information is found in the reference book [16]:

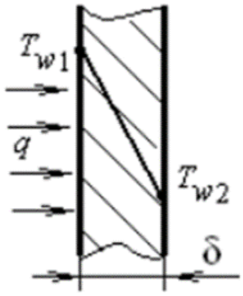

Fig.2. Steady-state heat conduction through a wall of thickness

The thermal conductivity of steel $\lambda_w(t)$ increases with increasing temperature and at $t_{w2} = 60°C$ -də 38 $W/(m \cdot K)$, it is already 42 W/(m K) $t_{w1} = 100°C$. Consequently, the average value of the thermal conductivity of steel in a given temperature range (with the arithmetic mean value $t_{w1} = 80°C$ $\lambda_{w1}(= 40\ W/(m \cdot K)$;

- We find the average values of thermal conductivity of concrete and diatomite brick in a similar way; these values are respectively equal to $\lambda_{w2} = 1{,}1$ və $\lambda_{w3} = 0{,}11\ W/(m \cdot K)$

The above assumptions for solving the problem allow us to obtain an analytical solution for the thermal conductivity of a uniformly heated flat wall [15] in the form of formula (1).

2. From the problem conditions, we determine the temperature difference on the wall:

$$\Delta T_w = t_{w1} - t_{w2} = 100 - 60 = 40°C$$

3. Let us determine the values of the thermal resistances of the wall (1):

$R_{w1} = 50 \cdot 10^{-3}/40 = 1.25 \cdot 10^{-3}$; for steel; $R_{w2} = 50 \cdot 10^{-3}/1{,}1 = 45.45 \cdot 10^{-3}$

for concrete and $R_{w3} = 50 \cdot 10^{-3}/0{,}11 = 45{,}45 \cdot 10^{-2}$ $(W/(m^2 \cdot K))^{-1}$ for diatomite brick.

4. Using (1), we calculate the heat flux density through the wall: $q_1 = 40/(1{,}25 \cdot 10^{-3}) = 32 \cdot 10^3$ for steel; $q_2 = 40/(45{,}45 \cdot 10^{-3}) = 0.88 \cdot 10^3$ for concrete; and $q_3 = 40/(45{,}45 \cdot 10^{-2}) = 88{,}01\ W/m^2$ for diatomite brick.

Conclusions. 1. The thermal resistance of a flat wall under the given conditions varies by two orders of magnitude depending on the thermal conductivity of the material.

2. The thermal resistance of a steel wall of incredible thickness ($\delta = 50mm$, which is quite rare in modern power plant designs) will still be an order of magnitude lower than the resistance of thermal insulation materials and decreases linearly with decreasing thickness.

3. Diamite brick, the material used in the problem, has minimal thermal conductivity and is preferred for wall insulation. Its use, while maintaining a constant temperature difference, significantly reduces heat loss through the concrete wall.

Example 2. The flat wall of a steam boiler furnace [18] is made of fireclay brick with a thickness of

δ = 250 mm. Its surface temperatures are t_{w1} = 1350 ºC və t_{w2} = 50 ºC. The thermal conductivity of fireclay brick depends significantly on its temperature, the value of which must be averaged over a given temperature range.

Formula (2, a, b) for the thermal conductivity of fireclay brick are as follows [16]:

$$\lambda(T) = 0{,}838(1 + 7 \cdot 10^{-4} t), W/(m \cdot K)$$

Calculate the heat flux density through the wall.

Solution: To solve the problem using (1), it is necessary to determine the average thermal conductivity of the brick in a given temperature range. If it is linearly dependent on temperature (2a), the average value is calculated for fireclay brick [16] using the formula

$$\lambda_w = a\left(1 + b\frac{t_{w1} + t_{w2}}{2}\right) = 0{,}838(1 + 7 \cdot 10^{-4}\frac{1350 + 50}{2} = 1{,}249 W/(m \cdot K)$$

Therefore, the heat flux density through the wall (1)

$$q = \frac{1{,}249}{0{,}25}(1350 - 50) = 6{,}495 \cdot 10^3 W/m^2$$

With the widespread use of boiler units, observed in many European countries, the removal or deactivation of condensate is strictly regulated by a number of normative legal acts.

A mathematical model for predicting toxic emissions of a gas condensing boiler can serve as such a tool.

According to this model, a gas condensing boiler can be represented as a complex thermodynamic system with a series of input and output signals.

Inputs:

- Temperature of the combustion air and its volume required for burning a unit volume of fuel, as well as its excess coefficient;
- Temperature of water entering the condensing heat exchanger;
- Fuel consumption and composition;
- Operating time of the boiler unit.

Outputs:

- Temperature of the supply water;
- Temperature of the exhaust gases;
- Heat losses with exhaust gases, due to chemical incomplete combustion, and external cooling;
- Volume and composition of flue gases;
- Volume and composition of the condensate formed, as well as its pH value and temperature.

However, there are two more factors that must be considered in calculations [10].

The first is the amount of heat energy recovered in the condensing heat exchanger, which is transferred from the condensing water vapor to the water supplied to the boiler.

This value depends on the material from which the heat exchanger itself is made, the shape of its surface, the thickness, and the area of its walls.

The heat flow (Joules) can be determined by the following expression [11, p. 60].

$$Q_{bər1} = \frac{t_{is1} - t_{is2}}{\frac{1}{\alpha_1 F_1} + \frac{\delta}{\lambda_1 F_1} + \frac{1}{\alpha_2 F_2}} \quad (1)$$

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The second factor is the amount of heat energy recovered in the coaxial flue gas duct, which is transferred from the hot combustion products to the air supplied to the combustion chamber.

The heat flow (Joules) in this case can be determined using the formula for a single-layer cylindrical wall [11, p.7].

$$Q_{bər2} = \frac{\pi l(t_{y1} - t_{y2})}{\frac{1}{\alpha_1 d_1} + \frac{1}{2\lambda} ln\frac{d_2}{d_1} + \frac{1}{\alpha_2 d_2}} \qquad (2)$$

Combustion and airflow temperature, °C; α_1 and α_2 – heat transfer coefficients on the inner and outer pipe walls, W/(m²·K); λ – thermal conductivity coefficient of the wall material, W/(m·K); d_1 and d_2 – inner and outer diameters of the wall, m; λ – thermal conductivity coefficient of the gas duct material, W/(m·K); l – pipe length, m.

3. Conclusion

Based on the given scheme, the main factors influencing the biogas yield can be identified. These include: temperature, pH, pressure, mixing intensity, humidity, climatic conditions, etc., which are interconnected and a change in one of the parameters can lead to a decrease or increase in the biogas yield. However, recently, the greatest interest has been in the method of influencing the organic substrate with a high-voltage electric discharge, which provides a reduction in the decomposition time due to substrate activation, and an increase in the yield of high-quality target products (biogas and organic fertilizers in mineralized form).

The above values are key to determining the relationships between input and output signals, and subsequently for developing a unified methodology for predicting harmful emissions during the operation of gas condensing boilers.

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