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THE INFLUENCE OF PERMANENT ELECTRICAL FIELD IN THE BROWN DESTINATION PROCESS ON THE QUANTITATIVE COMPOSITION OF BIOGASIC MIXTURE

Abstract: *The article presents the results of an experiment showing the efficiency of stimulating the release of biogas from a cow's substrate under the influence of a constant electric field of a certain intensity at a mesophilic temperature regime, as well as the change in the chemical composition of the obtained biogas and the amount of residual due to this effect. The studies were conducted on the basis of a specially designed laboratory biogas plant. It contains two reactors housed inside a thermostat and connected to a biogas collection and storage system. This allows you to determine its volume and chemical composition. One of the reactors is equipped with a system of exposure to the substrate by a constant electric field. The optimum intensity of the latter was determined by previous experiments. Studies were performed on the cow substrate under mesophilic regimen.*

Studies have shown that biogas output per unit of dry organic matter under the influence of a constant electric field increased by 11.3%, the destruction of the latter increased by 12.2%, and the total volume of biogas (excluding CO_2*) increased by 8.2%. It should also be noted that the lag phase decreased by 12.2%.*

Keywords: *biogas, biomethanogenesis, bioenergy, biogas plant, chemical composition.*

Introduction

Electric fields are widely used in modern biotechnology. But it is not clear how the electric field acts on microbial populations. Electric fields are likely to disrupt microbial cells by changing the charge of cell membranes [1].

In Ukraine and in the world, fundamental studies of constant electric field influence on fermentation process of organic matter have not been performed. Among the proposed solutions for improving the efficiency of biogas production by stimulating the activity of microorganisms involved in biomethanogenesis by the fields of different types and intensities [2-4], research have covered only individual bacteria and fungi, not the substrate as a whole. For example, the use as an object of experiments of E. coli bacteria under influence of pulsed electric fields to increase the permeability of membranes, the intensification of absorption and excretion of cellular substances showed an acceleration of these processes by 140%, as reported in their work by D. Chang and others [5]. A similar effect for Trichodermareesei was noted by G. Cairns et al. [6]. The effect of electric field in static and alternating modes has also been investigated for various yeasts. Thus, the behavior of Saccharomyces Cerevisiae in a environment with a voltage up to 1.5 kV/cm differed from the control culture with a maximum increase of 100% at 0.85 kV/cm [7]. In addition, G. Cairns et al. [8-10] proved that, due to a pulsed electric field with intensity of 1.5 mV/cm for 115 hours, Trichoderma reesei increases the activity of cellulase and its secretion by 60% and 80%, respectively, and for different groups of microorganisms at 1.25-3.25 kV/cm there is more intensive elimination of toxic substances from them, which increases their viability [11].

The effect of low-intensity ultra-high frequency fields is presented in research conducted in the 1970s in Europe. In their works V. Grundler et al. [12] used frequencies close to 42 GHz. Experiments have shown that resonant phenomena in Saccharomyces Cerevisiae yeast increase their growth rate by up to 15% or suppress it by 29%, depending on the frequency, that is in the range from 41.83 to 41.96 GHz. S. Banik et al. [11-15] researched the viability of Methanosarcina barkeri and Methanosarcina archaebacterium, which are involved in the biogas production process. There was a significant increase in methane concentration, which reached a maximum of 76.3% at 31.5 GHz, compared to 52.3% without this treatment.

Thus, the haphazardness and selectivity of these experimental experiments, as well as their apparently accidental nature, do not allow us to conclude on the optimality of impact characteristics in terms of energy criterion and do not take into account the complexity of the biomethanogenesis process, which is divided into stages, and the response to stimulation of each of the 190 substrate microorganisms.

Kachan Yu.G., Kovalenko V.L. and Lapikova O.I. conducted experiments to study the effect of constant electric field on the process of biogas production during anaerobic methane fermentation of cow manure. On the basis of obtained results analysis, the optimal value of electric field intensity was determined, at which the biogas output was maximal, a photo and description of the plant were given in [16]. It was found that the optimum voltage on the plates was 12.5 V, and the electric field intensity was 0.95 V/cm under the following conditions: the temperature inside the reactor was maintained at +35°C; the moisture content of substrate was 95-97%; the reactor working volume was 2 dm^3 [16]. Unfortunately, this paper did not determine the concentration of methane in biogas and the degree of destruction of dry organic matter, which does not allow to draw final conclusions about the effectiveness of the proposed electrophysical method of increasing the efficiency of biogas plants and requires additional experimental studies.

For example, in [17, 18] it is proposed to influence the substrate with high-voltage electric discharges, however, a quantitative assessment of the effectiveness of such stimulation is not given, as well as the exposure parameters are unacceptable from the point of view of electrical safety and the use of technology in industrial conditions is doubtful. In [19], the issues of intensification of biomass splitting by electrophysical methods were considered, however, only plant-based waste was used as a substrate, experiments were selective in part, rather than a complete digestion cycle, this approach was used for wastewater treatment and the needs of the food industry [20-22], and not for biogas plants operating on animal waste.

Thus, the use of the proposed method of exposure to the substrate will allow, without a significant change in the production technology and additional energy costs to create an electric field, which can be neglected, and to maintain the temperature regime inside the biogas plant, to increase the amount of energy produced and increase the overall energy efficiency of biogas plants, unconditionally relevant and practically significant from an energy point of view.

Research tasks

Therefore, the purpose of performing new experimental studies was to determine the yield of biogas, the concentration of methane in biogas, the degree of destruction of dry organic matter at a given optimal value of electric field intensity.

To study the influence of constant electric field on fermentation process, a laboratory biogas plant was created, the scheme and photos of it are shown in Figure 1.

The plant consists of thermostat 3, which houses two reactors 1, sealed with lids 2 with outlet nozzles 4, which are connected to gas holders 5. Gas holders are tightly connected to reactors by flexible tubes of transparent polyvinyl chloride. The fixed part of gas holders is exposed horizontally and filled with five percent NaCl solution to prevent the dissolution of carbon dioxide in water. The mobile part of gas holders is labeled to determine the volume of biogas. Heating and temperature control in thermally insulated thermostat was carried out using an electric heater equipped with thermostat. The temperature in thermostat was measured with a «PT-10/П01» digital thermometer. The room temperature was measured by a laboratory mercury thermometer. The atmospheric pressure in room was measured by a laboratory barometer-aneroid. Cork gas cranes were mounted in the gas analyzer for biogas sampling.

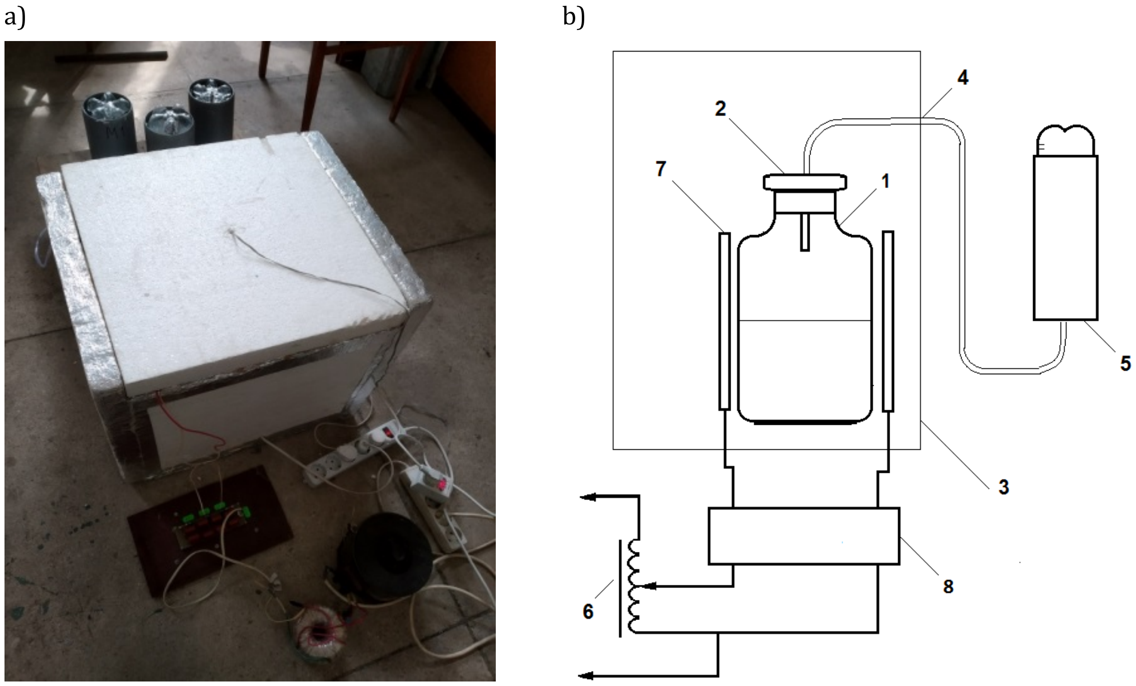

FIGURE 1. *Laboratory biogas plant: a) the plant appearance; b) laboratory biogas plant scheme: 1 – reactor, 2 – airtight lid, 3 – thermostat, 4 – pipe, 5 – gas-eodiometer, 6 – laboratory autotransformer, 7 – plates, 8 – AC rectifier*

An electric field is created by two semicircular aluminum plates 7, 13 cm high and 10 cm wide, which are arranged around reactor 1 on the insulating frame. The voltage on plates, and therefore the electric field strength is regulated by laboratory autotransformer 6 and controlled by voltmeter readings. The AC current is rectified by diode bridge 8.

The reactors had a total volume of 3 dm^3 with a volume of substrate of 2 dm^3. The maximum volume of gas holder was 2 dm^3. The experiment was performed under mesophilic mode. The temperature in thermostat was maintained at 35°C (±1°C).

During fermentation, the volume of produced biogas was measured and led to normal conditions for dry gas. The concentration of carbon dioxide in biogas was determined on the basis of measurements of carbon dioxide concentration in the gas mixture, which consisted of gas in the free space of the reactor-gasholder system and a new portion of produced biogas. The dry matter content of substrate was measured. It was also determined: the concentration of methane in biogas; the ash content of dry residue; the value of dry organic matter of fresh and processed substrates; the degree of destruction of dry organic matter.

Methods

The volume of produced biogas was measured visually according to the readings of moving part of gas holder.

The volume of produced biogas resulted in normal conditions for dry gas [23]:

$$V_{BG,nc} = \frac{T_0}{T_l}\cdot\frac{P_l}{P_0}\cdot\left(1-\frac{P_n}{P_l}\right)\cdot V_{BG} \tag{1}$$

where:

T_0, P_0 – temperature and atmospheric pressure under normal conditions, respectively, °K, kPa;

T_l, P_l – temperature and atmospheric pressure in laboratory room, where the volume of produced biogas was measured, °K, kPa;

V_{BG} – the volume of produced biogas under environmental conditions, dm^3;

P_n – saturated vapor pressure, kPa.

The concentration of carbon dioxide in new portion of biogas $C_{CO_2,NP}$ was calculated from an equation consisting of fact that the volume of carbon dioxide in gas mixture is equal to the sum of volumes of carbon dioxide in the components of gas mixture:

$$\left(V_{NP}+V_{FS}\right)=\frac{C_{CO_2,\Sigma}}{100\%}=V_{NP}\cdot\frac{C_{CO_2,NP}}{100\%}+V_{FS}\cdot\frac{C_{CO_2,FS}}{100\%} \qquad (2)$$

where:

$C_{CO_2,\Sigma}$ – the concentration of carbon dioxide in gas mixture consisting of gas in the free space of reactor-gasholder system and gas of new portion of produced biogas (measured by gas analyzer), dm^3;

$C_{CO_2,FS}$ – the concentration of carbon dioxide in the gas occupying the free space of the reactor-gasholder system, dm^3;

V_{NP} – volume of new portion of produced biogas (measured and brought to normal conditions for dry gas by formula (1)), dm^3;

V_{FS} – the volume of gas, which occupied the free space of reactor-gasholder system, dm^3.

The volume concentration of CO_2 in biogas was determined by the chemical «ГХЛ» gas analyzer. Separate analyzes of biogas composition, such us CO_2, CH_4 and other gases, were performed on «Landtec» gas analyzer.

The cumulative biogas yield Y_{BG} at time τ_n was calculated as the accumulated biogas during fermentation:

$$Y_{BG}\left(\tau_n\right)=\sum_{i=1}^{i=n}V_{NP}\left(\tau_i\right) \qquad (3)$$

The value of dry matter in substrate and the value of ash content in dry residue were measured by the standard gravimetric method [24, 25].

The content of dry organic matter in substrate f_{DOM} was calculated by the formula [26, 27]:

$$f_{DOM}=\frac{m_{dm}-m_a}{m_s}\cdot 100\% \qquad (4)$$

where:

m_{dm} – weight of dry matter, g;

m_a – ash weight in the dry residue, g;

m_s – weight of fresh substrate, g.

The concentration of methane in biogas was calculated according to [28, 29]:

$$C_{CH_4}=100\%-C_{CO_2}-C_{OG} \qquad (5)$$

where:

C_{CO_2} – volumetric concentration of carbon dioxide in biogas, %;

C_{OG} – the volume concentration of other gases than methane and carbon dioxide. It was assumed that the concentration of other gases in biogas is 2%.

The average concentration of methane in biogas accumulated over the entire fermentation period was defined as the proportion between methane content of biogas and obtained biogas:

$$C_{CH_4} = \frac{\sum_i C_{CH_4,i} \cdot V_{BG,i}}{\sum_i V_{BG,i}} \tag{6}$$

where

$C_{CH_4,i}$ – concentration of methane in biogas for *i*-th capture, %;

$V_{BG,i}$ – biogas volume for *i*-th measurement, dm³.

The degree of destruction of dry organic matter in substrate $k_{d,DOM}$, which characterizes the efficiency of substrate processing, was determined by formula [6, 9]:

$$k_{d,DOM} = \frac{DOM - DOM_r}{DOM} \cdot 100\% \tag{7}$$

Materials

Two K-0 and K-el substrates containing cow manure were prepared. Cow manure had the following characteristics: the solids content of substrate was 20.79%, the sol content of the solids was 34.35%. The substrates were diluted with water to a humidity of 92.2%. A constant electric field with intensity of 0.95 V/cm was created around the reactor with the K-el substrate.

Research results

In Table 1 are shown the measurements of volume of biogas brought to normal conditions for dry gas by dependence (1), the results of measurements of carbon dioxide concentration in gas mixture, the carbon dioxide concentration in produced biogas calculated by formula (2). The cumulative biogas yield over fermentation period was determined by (3). The content of dry organic matter in substrate was calculated by formula (4). In Figure 2 is shown the cumulative output of biogas in terms of unit of fresh (imported) dry organic matter.

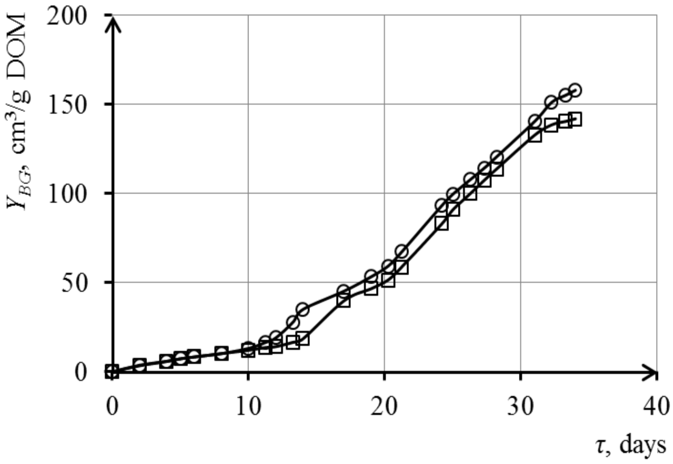

FIGURE 2. *Cumulative biogas yield per unit volume of Y_{BG} depending on the duration of fermentation (τ) for: □ – K-0; ○ – K-el*

Table 1. Biogas volume and carbon dioxide concentration in biogas during processing of control substrate

№ mes.	Duration of fermentation, days	Biogas generated over a period of time $[\tau_i, \tau_{i+1}]$		Gas in the free space of reactor-gasholder system and residual gas in gasholder		A mixture of gases	
		V_{NP}, cm³	C_{CO_2}, %	V_{FS}, cm³	C_{CO_2}, %	$V_{NP}+V_{FS}$, cm³	C_{CO_2}, %
1	5	750	19.7	1100	0	1850	8
2	12	700	40.7	1100	8	1800	20.8
3	13.25	600	42.6	1200	15	1600	24.6
4	14	450	60.5	1250	20.8	1700	31.3
5	17	2200	35.1	1250	31.3	3450	33.7
6	19	700	34.5	1250	33.7	1950	34
7	20.25	500	35.1	1250	34	1750	34.3
8	21.25	750	39.6	1250	34.3	2000	36.3
9	24.2	2500	37.1	1250	36.3	3750	36.8
10	25	800	59.9	1250	36.8	2050	45.8
11	26.3	950	47	1250	45.8	2200	46.3
12	27.3	750	45.8	1250	46.3	2000	46.1
13	28.2	650	46.1	1250	46.1	1900	46.1
14	31	1950	37.7	1250	46.1	3200	41
15	32.25	600	29.6	1250	41	1850	37.3
16	34	200	30.8	1250	37.3	1450	36.4

From the graph data shown in Figure 2 it follows that the duration of lag phase for fermentation of substrates K-0 and K-el is 14 and 12 days, respectively. This indicates a more rapid adaptation of microorganisms to environment under influence of electric fields and contributes to prerequisites for transition to an exponential growth phase, which is almost identical in both cases. The pH of the substrate is inherent in these steps and varies in the amplitude of 6.6 to 8 during the cycle.

It was found that on the 34th fermentation day, 141.9 cm³/g of DOM (dry organic matter) and 157.9 cm³/g of DOM of biogas were obtained during the processing of K-0 and K-el substrates, respectively. The reliability of obtained results is confirmed by their comparison with results of other researchers under the same fermentation conditions. In particular, O. Dennis has shown that biogas output from cow manure without inoculum is 130 cm³/g DOM on the 30th day of fermentation [30].

Discussion

In Table 2 are shown the measurements of the volume of biogas brought to normal conditions for dry gas by dependence (1), the results of measurements of carbon dioxide concentration in gas mixture, the carbon dioxide concentration in produced biogas calculated by formula (2).

A total of 16 measurements were made during the processing of test substrate.

TABLE 2. *Biogas volume and carbon dioxide concentration in biogas during processing of test substrate*

№ mes.	Duration of fermentation, days	Biogas generated over a period of time $[\tau_i, \tau_{i+1}]$		Gas in the free space of reactor-gasholder system and residual gas in gasholder		A mixture of gases	
		V_{NP}, cm^3	C_{CO_2}, %	V_{FS}, cm^3	C_{CO_2}, %	$V_{NP}+V_{FS}$, cm^3	C_{CO_2}, %
1	5	750	19.5	1100	0	1850	7.9
2	12	1200	41.6	1100	7.9	2300	25.5
3	13.25	900	57.5	1250	25.5	2150	38.9
4	14	750	53.1	1250	38.9	2000	40.2
5	17	1050	29.9	1250	40.2	2300	35.5
6	19	880	37.4	1250	35.5	2130	36.3
7	20.25	620	40.8	1250	36.3	1870	37.8
8	21.25	830	43.3	1250	37.8	2080	40
9	24.2	2670	38.7	1250	40	3920	39.1
10	25	650	44.4	1250	39.1	1900	40.9
11	26.3	850	47.6	1250	40.9	2100	43.6
12	27.3	650	49.2	1250	43.6	1900	45.5
13	28.2	650	51.9	1250	45.5	1900	47.7
14	31	2050	42.5	1250	47.7	3300	44.5
15	32.25	900	32.6	1250	44.5	2150	39.5
16	34	400	34.1	1250	39.5	1650	38.2

The methane concentration in biogas was calculated according to (5). The average concentration of methane in biogas was determined by formula (6). The biogas composition of the K-0 and K-el substrate processing was: 39.2% of CO_2, 58.8% of CH_4, 2% of other gases; 40.9% of CO_2, 57.1% of CH_4, 2% of other gases respectively. The content of gases other than CO_2 and CH_4 in biogas did not exceed 2%. Considering the biogas output and its composition, we have determined, that the methane output in substrate processing, to which constant electric field was applied, increased by 8.2% compared to control substrate. In Table 1 are shown the measurements of volume of biogas brought to normal conditions for dry gas by formula (1), the results of measurements of carbon dioxide concentration in gas mixture, the concentration of carbon dioxide in produced biogas calculated by formula (2). A total of 16 measurements were made during the processing of control substrate.

In Figure 3 is shown the concentration of methane in biogas depending on duration of fermentation.

The degree of destruction of dry organic matter was calculated according to (7). The destruction of dry organic matter is 33.5% and 37.6% in the processing of substrates K-0 and K-el, respectively.

In Table 3 are collected integrated indicators of fermentation process.

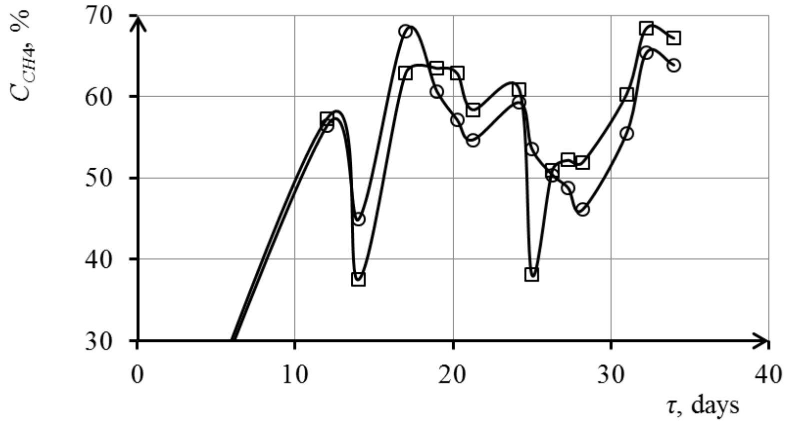

FIGURE 3. *Concentration of methane in biogas (C_{CH4}) depending on duration of fermentation (τ) for: □ – K-0; ○ – K-el*

TABLE 3. *Integral indicators of fermentation process*

Denomination	K-0	K-el
Duration of the lag phase	14 days	12 days 16.7% shorter
Biogas output from a unit of dry organic matter	141.9 cm^3/g DOM	157.9 cm^3/g DOM 11.3% more
The average concentration of carbon dioxide in biogas	39.2%	40.9%
Total biogas excluding carbon dioxide (methane and other gases)	8880	9600 8.2% more
Destruction of dry organic matter	33.5%	37.6% 12.2% more

Conclusion

Therefore, according to indicators of the process of conversion of cow manure organic matter into biogas, a constant electric field in the inner space of reactor has a positive effect on the process during the processing of substrate K-el, in particular established:

- 11.3% more biogas was generated;
- 8.2% more methane was produced;
- decomposed by 12.2% more organic dry matter;
- lag phase duration is 16.7% shorter compared to control substrate.

The obtained results indicate that constant electric field in reactor interior space increases the biogas and methane yield, increases the destruction of dry organic matter and reduces the lag phase of fermentation process. Establishing the mechanisms of metabolic processes in the substrate under this kind of electrophysical effect is a separate area of research and requires additional specific experimental studies, and is also not the goal of the work. However, the proposed approach makes it possible to increase the overall efficiency of biogas plants and, in addition to increasing the specific amount of biogas produced per unit mass of the substrate, partially or even completely refuse to heat the substrate in the climatic conditions of Ukraine [31].

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