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METHOD OF DETERMINING VOLUME YIELD OF BIOGAS DURING EXPERIMENTAL RESEARCH IN BIOGAS TECHNOLOGIES

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Abstract. *The article deals with the issue of determining the volume of biogas produced during experimental studies during the entire cycle of anaerobic fermentation of organic matter in biogas reactors. The design of the device for determining the volume of biogas produced during the period of the complete cycle of anaerobic fermentation of organic matter in biogas reactors is proposed and given. The use of the proposed device is aimed at both small and large biogas plants, in laboratory conditions and at production facilities.*

Mathematical dependences are presented, which allow to calculate the volume of biogas determined by the device given in the work. The results of the study of the device using 3D modeling in the Solidworks application program in the Flow Simulation package are presented. The result of the 3D modeling is the graphical dependence of the pressure distribution in the tubes of the measuring device, namely the gas pipeline and the Pitot tube, with the subsequent establishment of the amount of biogas passed through the measuring device in a certain time interval.

The work noted a high convergence of the comparative analysis of the data obtained during 3D modeling and calculated analytically. Considered in the article, the main issues of the proposed method of determining the produced volume of biogas during experimental research will allow to increase the accuracy of the research work of scientists, organizations and enterprises in the field of biogas technologies and registration of the produced volume of biogas.

Keywords: Pitot tube, biogas, research methodology, eudiometer, ultrasonic meter, Solidworks, Flow Simulation.

Introduction. The increase in farm and agricultural land, together with the growth of the animal population, leads to the accumulation of plant and animal waste – biomass. This prompts the population to search for alternative methods of disposal and processing of the received waste, since storage systems are sources of dangerous emissions of methane and nitrogen oxides [1]. This leads to air pollution and increased climate change and the greenhouse effect. Aerobic and anaerobic treatment in special tanks – biogas reactors [2] has become the most widespread for the disposal of household and industrial waste and sewage wastewater. Biogas can be obtained from agricultural waste using anaerobic treatment. Purify it and obtain biomethane, which can replace natural gas for use both for the own needs of farm enterprises and for supply to utility enterprises. The profitability of using biogas plants directly depends on the energy efficiency of the biogas generation process and recording its volume [3].

Analysis of research and publications. In the course of conducting experimental studies of electrotechnical, physico-chemical, thermal and other processes in biogas technologies, the main criterion for evaluating the efficiency of this or that equipment and the processes it affects is the determination of the volume of biogas produced during the entire cycle of anaerobic fermentation of organic biomass.

To date, during experimental studies of processes in biogas technologies, due to the cheapness and speed of installation, the method of measuring the volume of separated biogas, which works on the principle of an eudiometer – a moving pipe in a pipe with a hydraulic valve, has become widespread [4-6], which is shown in Fig. 1 [5].

Fig. 1. Study of biogas output according to the eudiometer principle [5].

Using this method, the determination of the yield of biogas volume is possible only for research with relatively small doses of loading of biomass, up to several litres. Also, the use of this method is not suitable for determining the exact volume of biogas produced during a certain period of time and recording relatively small doses of biogas release that occur at the initial and final moments of fermentation.

Another method of determining the output of biogas is the use of a gas lamp, the use of which does not allow to establish even the approximate volume of produced biogas and serves only for visual observation of the combustion process.

A large amount of simultaneously fermented organic biomass requires an innovative approach in order to accurately determine the amount of biogas produced during the entire fermentation cycle. One of these methods can be considered ultrasonic gas meters [7]. However, due to their high cost, they are not widely used in experimental research, and the accuracy of the measurement depends on the specific conditions of the flow, its speed, swirl, temperature and humidity.

Since the intensity of biogas release during anaerobic fermentation is constantly changing due to different degrees of decomposition of organic biomass [7], the use of ultrasonic gas meters to register untreated biogas requires the presence of several gas meters. Each of them is designed for a different range of biogas flow rate, which requires significant capital investments.

The literature [7] provides information on the use of turbine flowmeters to determine gas volume. The disadvantage of such a device is the presence of moving parts that are highly sensitive to contamination. Which makes this measurement method unreliable and requires constant cleaning and adjustment. Also, the disadvantage is the difficulty of determining the produced biogas at relatively low flow rates through the gas pipeline, which leads to an inaccurate determination of the full volume of the generated biogas, as a result distorting the results of experimental studies.

Having considered the available methods for determining the volume of biogas output, it can be stated that today the need to develop an innovative, inexpensive and highly sensitive method for determining the volume of biogas during experimental studies of both small and large tanks is an urgent issue.

Purpose. Develop a method for determining the volume of biogas produced during the full cycle of anaerobic fermentation of organic biomass, both for small and large biogas plants.

Materials and methods. During the anaerobic fermentation of organic biomass, biogas is released. Its volume is variable over time and depends on the physical and chemical composition, the uniformity of the temperature field in the reactor, and the frequency of mixing of the substance being fermented [8-10]. Considering the above, determining the volume of biogas is an extremely difficult task for scientists.

Therefore, to determine the volume of biogas produced during experimental research, it is proposed to use the method of measuring the flow of biogas in combination with a Pitot tube, a biogas temperature sensor, a differential pressure sensor, a gas analyser and a microcontroller. The design of the measuring device is shown in Fig. 2.

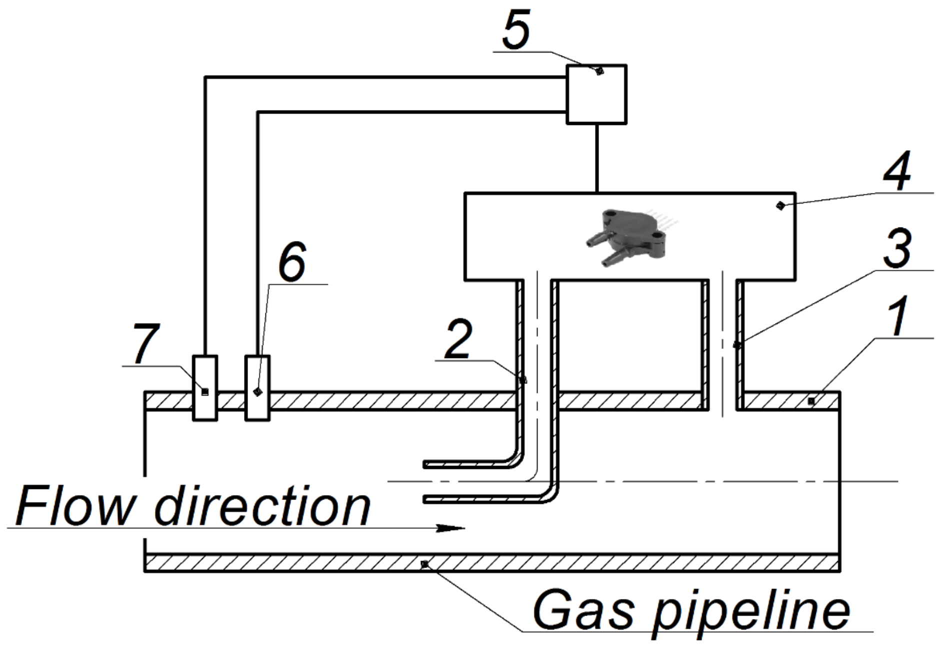


Fig. 2. Design of the measuring device for determining the produced volume of biogas: 1 – gas pipeline; 2, 3 – dynamic and static pressure measurement tubes; 4 – differential pressure sensor; 5 – microcontroller; 6 – temperature sensor; 7 – methane (CH_4) and carbon dioxide (CO_2) gas analyser.

The principle of measurement using a pitot tube, a temperature sensor, a differential pressure sensor, a gas analyser and a microcontroller is as follows. A tube is installed in the gas pipeline, the open end of which is brought out towards the gas flow in such a way as to increase the pressure in the middle of the tube compared to the static pressure of the environment, the other end of which is connected to the input channel of the pressure sensor. The other output of the pressure sensor is used to measure the static pressure of the environment. Thus, the dynamic pressure, which is the differential pressure, is measured ΔP (Pa) and depends on the flow rate ϑ (m/s) and the area of the smallest cross-section of the gas channel S (m^2). The data received from the differential pressure sensor (4), temperature sensor (6), gas analyser (7) are processed in the microcontroller (5) and stored on the memory card in the format «txt».

The separated biogas contains 50–75% methane (CH_4), 25–50% carbon dioxide (CO_2) and 1–2% of other impurities, among which the most common are: hydrogen sulphide (H_2S), ammonia (NH_3), nitrogen (N_2), hydrogen (H_2). This amount of impurities does not have a significant effect on the amount of methane produced, therefore, by measuring the volume fraction of methane and carbon dioxide, it is possible to determine the total content of the remaining gases using the formula:

$$\Delta_o = 100 - (\Delta_{CH_4} + \Delta_{CO_2}), \tag{1}$$

where Δ_o – total content of other gases in biogas, %; Δ_{CH_4}, Δ_{CO_2} – the content of methane (CH_4) and carbon dioxide (CO_2) in the volume of biogas, %.

According to the proposed method of measuring the volume of biogas produced, the biogas flow rate is determined by the formula:

$$\vartheta = \sqrt{\frac{2 \cdot \Delta P}{\rho_{av}}}, \tag{2}$$

where ρ_{av} – average density of biogas, kg/m^3; ΔP – differential pressure, Pa.

$$\Delta P = P_1 - P_2, \tag{3}$$

where P_1, P_2 – pressure measured in the biogas flow zone and static pressure, respectively, Pa.

The density of gases depends on the temperature, therefore, in order to avoid measurement errors, a temperature sensor is introduced into the system, which measures the temperature of the biogas flow and transmits this information to the microcontroller. The gas analyser measures the volume fraction of gases contained in biogas, according to formula (1) we determine the total content of the remaining gases in biogas. Thus, the average density of biogas ρ_{av}, is calculated by the formula:

$$\rho_{av} = \Delta_o \cdot \rho_{av\Delta_o(t)} + \Delta_{CH_4} \cdot \rho_{CH_4(t)} + \Delta_{CO_2} \cdot \rho_{CO_2(t)}, \tag{4}$$

where $\rho_{CH_4(t)}$, $\rho_{CO_2(t)}$ – density of methane (CH_4) and carbon dioxide (CO_2) at temperature (t), kg/m^3; $\rho_{av\Delta_o(t)}$ – the average density of the remaining gases in the biogas at the temperature (t), kg/m^3:

$$\rho_{av\Delta_o(t)} = \frac{\sum \rho_{j(t)}}{n}, \tag{5}$$

where $\sum \rho_{j(t)}$ – the sum of the densities of the j-th gases that are in the volume of biogas at the temperature (t), kg/m^3; n – the number of types of gases that are in the volume of biogas.

To determine the volume of biogas produced, it is necessary to know the time during which the biogas flow rate remained constant. Mathematically, it will have the following form:

$$V_i = \vartheta_i \cdot S_i \cdot t_i, \tag{6}$$

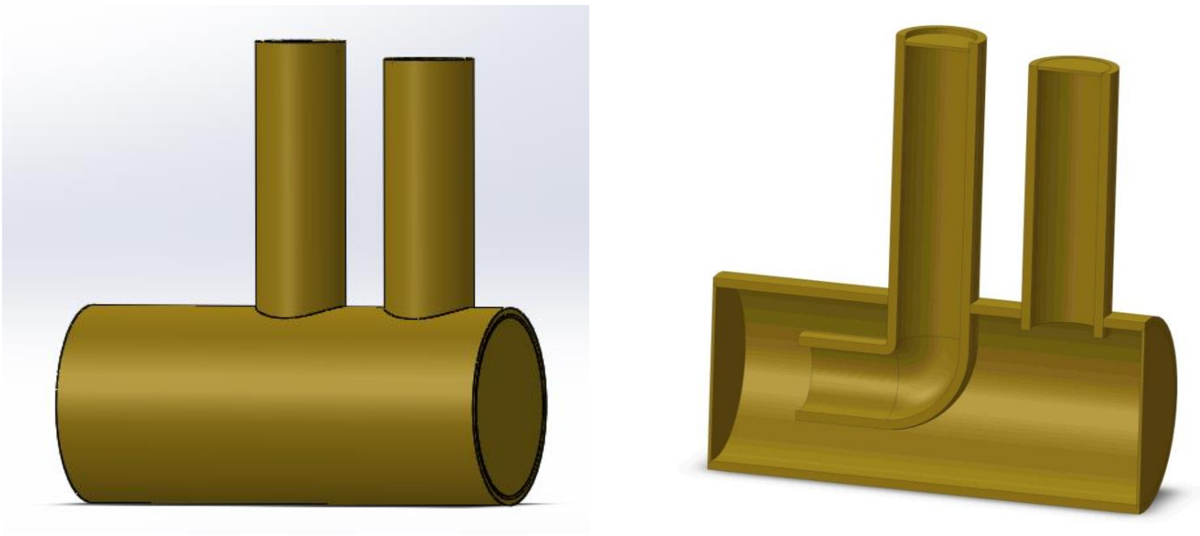
where V_i – i-th volume of produced biogas, m^3; ϑ_i – i-th biogas flow rate, m/s; S – the area of the smallest cross-section of the gas channel, m^2; t_i – the time during which the biogas flow rate remained constant, s.

Then, the total produced volume of biogas V we find using the following expression:

$$V = \sum V_i \tag{7}$$

The use of the proposed method makes it possible to continuously register the volume of produced biogas during the i-th time interval (dependency 6). Determine the total volume of biogas produced during all or part of the fermentation cycle (dependency 7) in the biogas reactor during experimental research.

Results and discussion. In order to evaluate the adequacy and accuracy of the proposed method of determining the initial volume of biogas, simulation was carried out in the SolidWorks program in the Flow Simulation package. The 3D model is shown in Fig. 3.

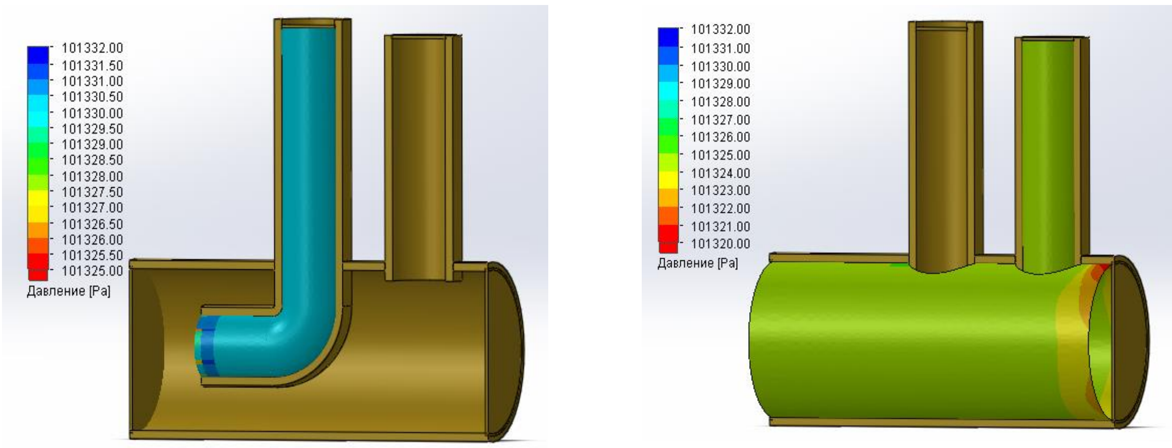


a) b)

Fig. 3. Developed 3D model: a) appearance; b) cross section.

The simulation was carried out under the following initial conditions: biogas with 100% methane content flows through the pipeline; volume flow of biogas at the entrance and exit of the gas pipeline 0.0012 m^3/s; the temperature of biogas is constant 35 ^0C; atmospheric pressure 101325 Pa; gas pipeline diameter 20 mm; the specific density of biogas is 0.68 kg/m^3.

The results of the 3D modeling are shown in Fig. 4.



a) b)

Fig. 4. Results of 3D modelling: a) pressure distribution in the Pitot measuring tube; b) pressure distribution in the gas pipeline.

According to the obtained pressure data in the gas pipeline and Pitot tube, a calculation was made using formulas (1-3) to determine the volume flow of biogas through the gas pipeline during a time of 1 second.

Flow speed, m/s:

$$\vartheta = \sqrt{\frac{2 \cdot 5}{0{,}68}} = 3{,}83$$

Differential pressure, Pa:

$$\Delta P = 101330 - 101325 = 5$$

Volume flow of biogas through a gas pipeline with a diameter of 20 mm in 1 second, m^3/s:

$$V = 3{,}83 \cdot 0{,}000314 \cdot 1 = 0{,}0012$$

In the course of 3D modelling, the volume flow rate of biogas at the inlet and outlet was determined to be 0.0012 m^3/s, calculated to be 0.0012 m^3/s.

As a result of analytical calculations and 3D modelling by the authors, it was found that the results coincide, which indicates the accuracy of the method of measuring the volume of biogas, considered in the work.

Conclusions. Using the proposed method of determining the yield of biogas volume in the process of anaerobic fermentation of organic biomass, it is possible to obtain accurate results during experimental studies. This method, in combination with a personal computer and a microcontroller, allows continuous recording of the measured volume of biogas produced. Considered in the article, the main issues of the proposed method of determining the produced volume of biogas in the course of experimental research will increase the effectiveness of the educational and research work of scientists, organizations and enterprises.

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МЕТОД ВИЗНАЧЕННЯ ВИХОДУ ОБ'ЄМУ БІОГАЗУ ПІД ЧАС ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ У БІОГАЗОВИХ ТЕХНОЛОГІЯХ

М.М. Заблодський, М.О. Сподоба, О.О. Сподоба

Анотація. *У статті розглянуто питання визначення об'єму виробленого біогазу у ході експериментальних досліджень протягом усього циклу анаеробного зброджування органічної речовини у біогазових реакторах. Запропоновано та наведено конструкцію пристрою для визначення об'єму виробленого біогазу за період повного циклу анаеробного зброджування органічної речовини у біогазових реакторах. Використання запропонованого пристрою націлене, як на малі так і великі біогазові установки, у лабораторних умовах та на виробничих об'єктах.*

Наведено математичні залежності, що дозволяють провести розрахунок *визначеного, наведеним у роботі пристроєм, об'єму біогазу. Наведено результати дослідження пристрою за допомогою 3D моделювання у прикладній програмі Solidworks у пакеті Flow Simulation. Результатом 3D моделювання є графічні залежності розповсюдження тиску у трубках вимірювального приладу, а саме газопроводі та трубці Піто, з подальшим встановленням кількості пройденого через вимірювальний пристрій біогазу за певного проміжку часу.*

У роботі відмічена висока збіжність порівняльного аналізу отриманих даних під час 3D моделювання та розрахованих аналітичним шляхом. Розглянуті у статті основні питання запропонованого методу визначення виробленого об'єму біогазу у ході експериментальних досліджень дозволять підвищити точність дослідної роботи науковців, організацій та підприємств у сфері біогазових технологій та реєстрації утвореного об'єму біогазу.

Ключові слова: ***трубка Піто, біогаз, методика дослідження, евдіометр, ультразвуковий лічильник, Solidworks, Flow Simulation.***