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INFLUENCE OF THE AMOUNT OF LOADED SUBSTRATE ON THE ENERGY EFFICIENCY OF BIOGAS PRODUCTION

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Abstract. *Today, humanity's need for energy resources increases annually. The high cost of raw materials (oil, gas, fuel) leads to the need to search for alternative energy sources. Today, the fermentation of organic agricultural waste in biogas plants is one of the most environmentally friendly and economically advantageous solutions for obtaining energy from waste in the form of biogas. Along with this, a side effect of fermentation of organic waste is the production of valuable environmentally friendly fertilizers. However, the formation of biogas is a complex technological process, since in the process of methanogenesis it is necessary to maintain artificially created microclimate parameters. The influence of external factors such as temperature, acidity level pH, humidity, the presence of chemicals in the substrate can create negative consequences for the methane formation process, up to a possible complete loss of the loaded substrate in the biogas reactor. In order to avoid such negative situations, very strict requirements are established for the technological processes of biogas formation. Domestic and foreign scientists theoretically and experimentally establish optimal conditions for the methane formation process. Among them, the greatest attention is paid to maintaining the acidity level and maintaining the temperature according to the conditions of the technological process of biogas formation. According to the conditions of the technological process, biogas formation occurs in three temperature modes: psychrophilic, mesophilic and thermophilic, for which certain limits of temperature fluctuations are established. The greatest temperature differences occur during the loading of a new substrate. In order to avoid the occurrence of a critical temperature difference during loading and unloading processes, the condition of thermal equilibrium in the methane tank was considered. Based on theoretical calculations, the ratio between the mass of the substrate present in the reactor and the loaded fresh substrate was determined.*

Key words: ***methane tank, substrate temperature, biogas, thermal equilibrium, ratio, substrate heat capacity***

Introduction. Biogas formation is a complex technological process, since in the process of methanogenesis it is necessary to maintain artificially created microclimate parameters. External factors can create negative consequences for the process of methanogenesis, up to its complete stop and loss of material resources. The works of domestic and foreign researchers are aimed at establishing the main factors influencing the process of biogas formation, theoretical and experimental substantiation of optimal conditions for the process of methane formation [1-7].

The greatest attention is paid to maintaining the required level of acidity $pH = 6{,}5 - 7{,}5$ and temperature in the installed structure [1, 7]. According to the conditions of the anaerobic digestion technological process, biogas release occurs in three temperature regimes [3-7]: psychrophilic – 15-20℃, mesophilic – 33-37℃, thermophilic – 55-57℃.

Rashed M. B. [7] As a result of studying the influence of temperature changes on the productivity of the bioreactor and the vital activity of bacteria, it was found that methane bacteria manifest their vital activity at temperatures from 0 to 70 ℃. If the temperature is higher, lower or changes its values rapidly, the bacteria die. Thus, with increasing temperature, the requirements for the permissible limits of temperature fluctuations for optimal gas release increase, which for the mesophilic regime is within ±1℃ [1, 7-9].

The influence of temperature regime on changes in methane concentration was investigated [1], as a result of which it was found that increasing temperature accelerates the course of the methanogenesis process, but at the same time the percentage of methane in biogas decreases with increasing temperature. This is due to the fact that at high temperatures the carbon dioxide dissolved in the substrate is intensively converted into the gas phase, in such a way that the relative methane content in biogas is reduced.

The works of scientists from different countries present the results of the study of biogas yield at different temperatures in the mesophilic mode, however, there are no theoretical and practical studies related to the process of establishing temperature equilibrium during loading and unloading operations in a bioreactor. It is at the moment of loading of fresh substrate that the largest temperature drops occur, since the temperature of the loaded substrate is lower than the temperature of the substrate in the biogas reactor. It is necessary to maintain a certain ratio between the volume of the loaded substrate and the volume of the substrate in the biogas reactor, so that the average temperature after loading-unloading decreases by no more than the permissible deviation from the temperature regime of anaerobic process. Loading too small a portion of fresh substrate leads to a decrease in the amount of nutrients for bacteria and, as a result, a decrease in methane formation.

Thus, from the energy point of view, the determination of a rational ratio between the volume available in the biogas reactor and the loaded fresh substrate, in which the occurrence of a critical temperature drop during loading and unloading processes in the biogas reactor is excluded, with the aim of increasing the energy efficiency of biogas production by reducing energy costs for heating the substrate is an actual and promising task.

Purpose. Determination of the permissible ratio between the amount of fresh substrate loaded and the amount of substrate remaining in the biogas reactor after unloading the spent sludge.

Materials and methods. To theoretically determine the permissible ratio between the amount of fresh substrate loaded and the amount of substrate in the biogas reactor after unloading the spent sludge, the conditions for establishing thermal equilibrium in the biogas reactor were considered.

The following initial conditions and assumptions were adopted: the course of the anaerobic process in the mesophilic temperature regime $T_{process} = 35$ °C permissible temperature deviation $T_{allow} = \pm 1$ °C per hour; total volume of substrate in the biogas reactor $V_{total} = 1$ m^3, substrate temperature in the biogas reactor $T_1 = 35$ °C, the temperature of the loaded fresh substrate is taken in the range from 15 to 25 °C.

At the time of loading and unloading operations, an assumption is made that the ambient temperature is constant and there are no heat losses. Since the relative humidity of the substrate does not change during the research and is 90%, the density and specific heat capacity of the substrate are taken equal, respectively $\rho = 1000$ kg/m^3, $c_1 = c_2 = 4200$ J/kg·°C [4-6].

The study used a batch method of loading the substrate into the biogas reactor. The volume of discharged sludge is equal to the volume of fresh substrate loaded $V_2 = V_{sl}$. The scheme of loading and unloading the substrate into the biogas reactor is shown in Fig. 1.

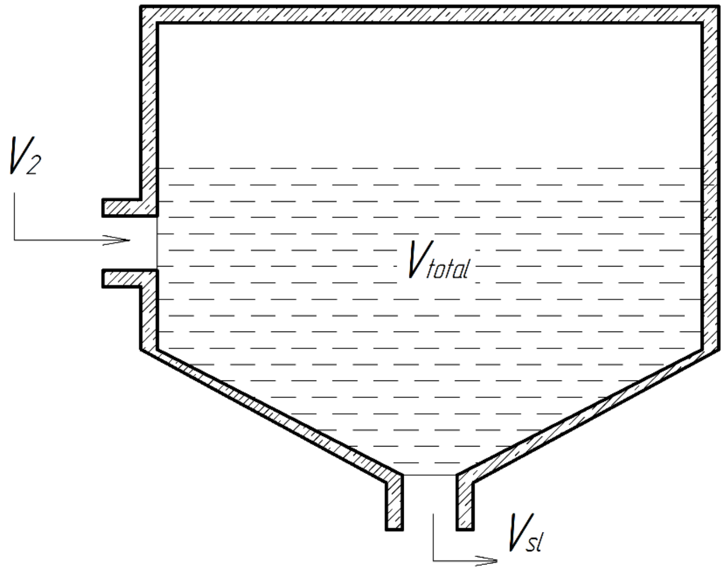


Fig. 1. Scheme of loading-unloading of substrate into a biogas reactor

Permissible temperature deviations $T_{process}$ constitute:

$$T_{process} - T_{allow} \le T_{process} \le T_{process} + T_{allow} \tag{1}$$

$$35 - 1 = 34^{O}C \le 35^{O}C \le 35 + 1 = 36^{O}C$$

When two media with different temperatures come into contact, heat transfer occurs between them, resulting in their temperatures equalizing. Mathematically, this is described as follows:

$$T_{eq} = \frac{m_1 \cdot c_1 \cdot T_1 + m_2 \cdot c_2 \cdot T_2}{m_1 \cdot c_1 + m_2 \cdot c_2} \tag{2}$$

where T_{equil} – equilibrium temperature, °C; m_1, m_2 – mass of substrate that is in the biogas reactor and is being loaded, kg; T_1, T_2 – temperature of the substrate in the biogas reactor and being loaded, °C; c_1, c_2 – specific heat capacity of the substrate in the biogas reactor and the freshly loaded, J/kg·°C.

The corresponding substrate masses are determined by the formulas:

$$m_1 = V_1 \cdot \rho \tag{3}$$

$$m_2 = V_2 \cdot \rho \tag{4}$$

$$V_1 = V_{total} - V_2 \tag{5}$$

where V_1 – volume of substrate in the biogas reactor after unloading the sludge volume V_{sl}, and taking into account the freshly loaded substrate V_2, m^3; ρ – substrate density, kg/m^3.

The ratio between the volume of the biogas reactor and the fresh substrate loaded is:

$$\frac{m_1}{m_2} \leq 9 \tag{6}$$

According to the above methodology, a study was conducted for different initial temperatures of the fresh substrate loaded into the reactor. The substrate was loaded in a single volume in the range from $V_{load} = 0{,}1 \cdot V_{total}$ to $V_{load} = 0{,}9 \cdot V_{total}$. After each loading of a new portion of fresh substrate and establishing the equilibrium temperature (2), the substrate in the biogas reactor was brought to the temperature of the anaerobic process $T_{process}$ = *35* °C, after which a new, increased portion of substrate was loaded and the study was repeated.

Results and discussion. As a result, we obtained data at different loading volumes and initial temperatures of the fresh substrate, on the basis of which the temperature change dependences were constructed, which are shown in Fig. 2, Fig. 3.

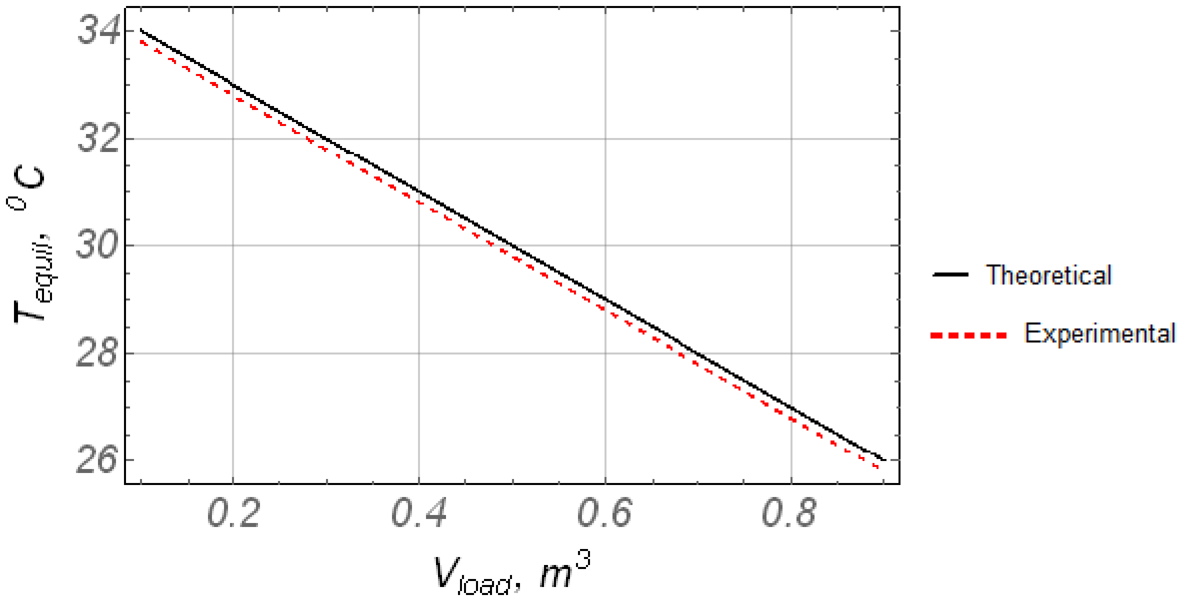
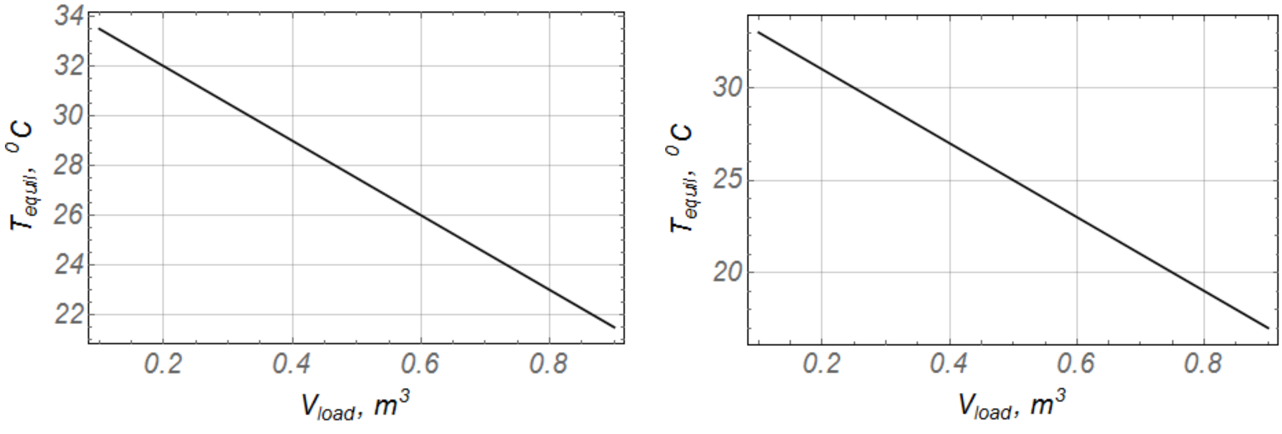


Fig. 2. Dependence of the equilibrium temperature in the biogas reactor on the volume of substrate loading at its initial temperature 25 °C



a) b)

Fig. 3. Dependences of the equilibrium temperature in the biogas reactor on the volume of substrate loading, at its initial temperature: a) 20 °C; b) 15 °C.

Analysis of graphical dependencies (Fig. 2 and Fig. 3) showed that with an increase in the fraction of the volume of substrate being loaded from the volume of substrate available in the biogas reactor, the equilibrium temperature in the latter decreases. This is described by dependency (2). It should be noted that when the volume of the substrate being loaded changes and regardless of its initial temperature, the change in the equilibrium temperature T_{equil}, (2) occurs according to a linear law (Fig. 2 and Fig. 3 a, b).

According to the results presented in [3], the substrate heating system in a biogas reactor with a volume of 50 liters consumes $178{,}360 \cdot 10^3$ J, for heating the substrate with 34 °C to 36 °C. Whereas, on heating the substrate with 9,5 °C to 35,8 °C is spent $4{,}99 \cdot 10^6$ J [4].

When loading fresh substrate with a volume of $0{,}1 \cdot V_{total}$, but at different initial temperatures, ranging from 15 °C to 25 °C, the equilibrium temperature may shift into the zone of unacceptable levels for the fermentation temperature regime (Fig. 3 a, b).

Based on the above, to ensure the establishment of the equilibrium temperature in the biogas reactor within T_{allow}, during loading and unloading processes, the ratio m_1/m_2, is recommended to be selected based on the initial temperature of the fresh substrate being loaded.

Conclusions. As a result of the study, it was found that the stability of the permissible temperature level during loading and unloading operations is affected by deviations of such parameters as: temperature regime of anaerobic digestion; specific heat capacity; density; initial temperature of the substrate being loaded, as well as its mass. The ratio between the volumes of the available in the biogas reactor and the loaded fresh substrate, with an initial temperature of $T_2=25$ °C, should be $0{,}1 \cdot V_{total}$. In the winter period of operation, it is necessary to create conditions for the initial heating of the substrate fed into the biogas reactor and to establish its rational initial temperature.

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ВПЛИВ КІЛЬКОСТІ ЗАВАНТАЖЕНОГО СУБСТРАТУ НА ЕНЕРГОЕФЕКТИВНІСТЬ ВИРОБНИЦТВА БІОГАЗУ

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Анотація. *Нині потреба людства в енергетичних ресурсах зростає з кожним роком. Висока вартість сировини (нафти, газу, палива) призводить до необхідності пошуку альтернативних джерел енергії. Нині ферментація органічних сільськогосподарських відходів у біогазових установках є одним із найбільш екологічно чистих та економічно вигідних рішень для отримання енергії з відходів у вигляді біогазу. Разом з цим, побічним ефектом зброджування органічних відходів є виробництво цінних екологічно чистих добрив. Однак утворення біогазу є складним технологічним процесом, оскільки в процесі метаногенезу необхідно підтримувати штучно створені параметри мікроклімату. Вплив зовнішніх факторів, таких як температура, рівень кислотності pH, вологість, наявність хімічних речовин в субстраті може створити негативні наслідки для процесу утворення метану, аж до можливої повної втрати завантаженого субстрату в біогазовому реакторі. Щоб уникнути таких негативних ситуацій, до технологічних процесів утворення біогазу встановлюються дуже жорсткі вимоги. Вітчизняні та зарубіжні вчені теоретично та експериментально встановлюють оптимальні умови для процесу утворення метану. Серед них найбільша увага приділяється підтриманню рівня кислотності та температури відповідно до умов технологічного процесу утворення біогазу. За умовами технологічного процесу утворення біогазу відбувається в трьох температурних режимах: психрофільному, мезофільному та термофільному, для яких встановлені певні межі коливань температури. Найбільша різниця температур виникає під час завантаження нової основи. Щоб уникнути виникнення критичної різниці температур під час процесів завантаження та розвантаження, враховано умову теплової рівноваги в метантенку. На основі теоретичних розрахунків було визначено співвідношення між масою субстрату, що знаходиться в реакторі, і завантаженого свіжого субстрату.*

Ключові слова: ***метантенк, температура субстрату, біогаз, теплова рівновага, коефіцієнт, теплоємність субстрату***