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RESEARCH OF THE MASS TRANSFER AT MEMBRANE CLEANING OF BIOGAZ

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Abstract

Everyone has long known the benefits and effectiveness of biogas. Particularly, getting biogas from the agricultural waste is very promising. But, the question is if we can use such a useful and effective biogas at 100%. Today, we use only a half of the benefit, because to get the biogas we spend more energy than we get. In this regard, the work on the study of the biogas development is extremely important. The study of the biogas formation requires numerous experiments. This article analyzes the biogas mass transfer with the membrane purification and identification of the of mass transfer mechanisms through the membrane pores.

Key words**:** *biogas, biogas installation, membrane*

INTRODUCTION

The main objective of this study is to clear the biogas produced during the processing of biomass-based agricultural waste coming from anaerobic digestion [7] in the waste treatment plant.

The rational use of agricultural waste is a big and important issue of our time. [10] It is connected, on the one hand, with the possibility of using an enormous energy potential of biomass to produce liquid and gaseous fuels (biogas), and on the other hand – with the need to prevent the earth and atmosphere contamination. Every day, all we hear on the news about the global warming problem. And that the icebergs in Antarctica began to melt, the soil is not suitable for use. Also, we hear about the series of diseases with which the whole world is struggling because the air and the water are not clean. And, in addition, there is a threat that we will have the lack of gas in the future. Both of these aspects are the object of the research and experimentation.

Today a great attention is paid to the problems of methane fermentation of manure and other organic waste. The biogas facilities are being constructed and designed for the manure and agricultural waste processing into biogas and environmentally friendly fertilizers. The use of biogas facilities on the livestock farms provides extra energy in the form of biogas and high quality organic fertilizer, and it can significantly reduce the anthropogenic pressure on the environment. [6, 8].

MATERIALS AND METHODS

The animal manure can be used as a heat-power raw material to produce biogas fuel by its anaerobic methane fermentation. From 1 ton of dry manure by the anaerobic digestion and under the optimal conditions we can obtain 340 m3 of biogas, or in terms of per head of one cattle (cattle) 2.5 m3 per day, and during the year about – 900 m3.

For the experimental verification and demonstration of the renewable energy sources capabilities, as well as for working out the regimes of anaerobic digestion of the cattle manure in the laboratory there was designed and manufactured a laboratory biogas facility with the reactor's volume of 0.25 m^3 (Figure 1).

According to the scheme, the impurities were removed from the manure beforehand (wood chips, straw, stones, coarse residues of long stalked feed, etc.). Then, liquid manure purified from these impurities is sent to the

bioreactor for the anaerobic digestion.
During fermentation, a special micro-flora is developing in the manure, which successively destroys the organic materials transforming into a volatile fatty acids, and the latter under the action of syntrophic bacteria and methane are converted into the gaseous products – methane and carbon dioxide. At the same time, during the fermentation of manure its deodorization, deworming are provided, and the ability of weed seeds to germinate and translate the fertilizing substances into the mineral form is being destroyed.
The biogas is burnt in the gas units, and fermented manure is collected in a store and then it is used in the fields as fertilizer.
The biogas facility is constructed of three main units – a bioreactor for the anaerobic digestion of manure, a gasholder (the device for the manure preparation for fermentation), and assistive devices for the operation of bioreactor systems.

Table 1. Key performance of the biogas facility

Indicators	MU	Value
The total volume of the bioreactor	$м^3$	0.25
The volume of the gas space	$м^3$	0.07
Temperature processing by mesophilic - M at thermophilic - T	^oC	35-37 55-57
Duration of treatment	Days	20-22 at M 12-15 at T
Pump power for mixing manure	*кВt*	0.37
Installed capacity of electric. heater	*кВt*	2.0
Heat exchange surface area	$м^2$	0.33

The bioreactor is a cylindrical container-digester of black steel with a thickness of 7 mm. The height of the digester is 1.5 m, the diameter is 530 mm. The reactor was equipped with an electric heater with a heat transfer surface area of 0.33 m^2.
The stirring of the substrate in the reactor is hydraulic done with the help of pump and a piping system with valves. When the pump is in operation, the substrate is taken from the mixing reactor and through the pipeline system goes to its upper part. The removal of the fermented manure goes through the effluent removal conduit system when the fresh portion of the substrate is added.
To clean the reactor there is a discharge valve in its lower part. Table 1 shows the main technical indicators of a biogas facility.

Photo 1. Experimental setup for the biogas production List 1

Photo 2. Experimental setup for the biogas production List 2

To estimate the total porosity the method [2] have been used. A sample of membranes previously weighed, is saturated with a wetting liquid, and then it is weighed again and then ε_o is calculated:

$$\varepsilon_o = \frac{G'_{об} - G_{об}}{V_м \rho_ж}, \quad (1)$$

where, $G'_{об}$ - is mass of sample saturated with liquid;
$\rho_ж$ - liquid density.
The pores' radius was determined by the flow of the liquid forced through the membrane. The volume (V_p) of liquid passing through the membrane is measured during the time (τ) at a known constant pressure drop across the membrane, and then, the r is calculated, using the Poiseuille's equation:

$$r = \sqrt{\frac{8\mu q l}{S_o f_o \Delta P}}, \quad (2)$$

The area (S) needed for the filtration of membrane surface is defined by the formula:

$$S=1{,}5\,(V/v)s, \quad (3)$$

where, s – is the surface area of the control membrane;
V – is the volume of gas that must be filtered;
v – is the volume of gas filtered before the moment when there is a sharp decrease in the flow rate through the filter.
The concentration polarization is determined by the formula [6]:

$$CP = \frac{\exp\left(\frac{G_1}{\beta}\right)}{\varphi_И + (1-\varphi_И)\exp\frac{G_1}{\beta}}, \quad (4)$$

Assuming that the true selectivity φi = 1, we get:

$$CP = \exp\frac{G_1}{\beta}, \quad (5)$$

where, G1 – is a specific membrane permeability;
β – is a mass-transfer coefficient material from the membrane surface in the gas volume. Conducted researches [22] of the mass transfer make the following equation possible to determine the mass-transfer coefficient:

$$Sh = 0{,}023\, Re^{0,8}\, Sc^{1/3}, \quad (6)$$

where

$$Re = \frac{w d_э}{\nu};\quad Sc = \frac{U}{D};\quad Sh = \frac{\beta d_э}{D} \quad (7)$$

w - the average flow rate;
β - mass-transfer coefficient;
D - diffusion coefficient;
d_e - the equivalent diameter of the channel.
Permeability was calculated using the formula:

$$G = V/(St), \quad (8)$$

where, V - volume of the filtrate, L;
S - area of the work surface, m2;
t - the duration of filtration, h.
Selectivity φ was calculated according to the formula:

$$\varphi = (C_1 - C_2/C_1)\cdot 100, \quad (9)$$

where, *C1* and *C2* - concentration of substance in the feed gas, respectively, and the filtrate, %.

RESULTS AND DISCUSSIONS

The selection of the operating pressure depends on the resistance of the membrane channel. The experimental indicators of the permeability depending on the operating pressure are shown by the following characteristic features (Fig. 1).

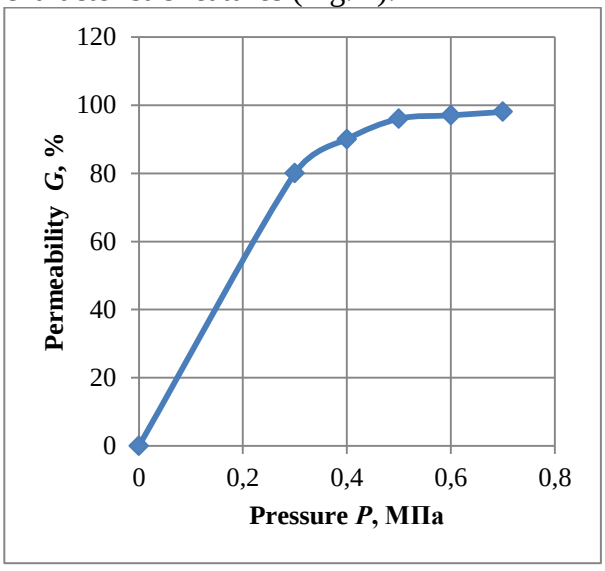

Fig. 1. The effect of pressure on the permeability.

Permeability depending on the pressure increases at the beginning, but the nonlinear relationship, and then becomes substantially constant.

Increasing the pressure increases the concentration of impurities at the surface of the membrane.

Fig. 2 shows the dependence of the selectivity of the pressure. As pressure increases, the selectivity decreases, as the pressure increases, the selectivity increases for all components, which reduces the required component.

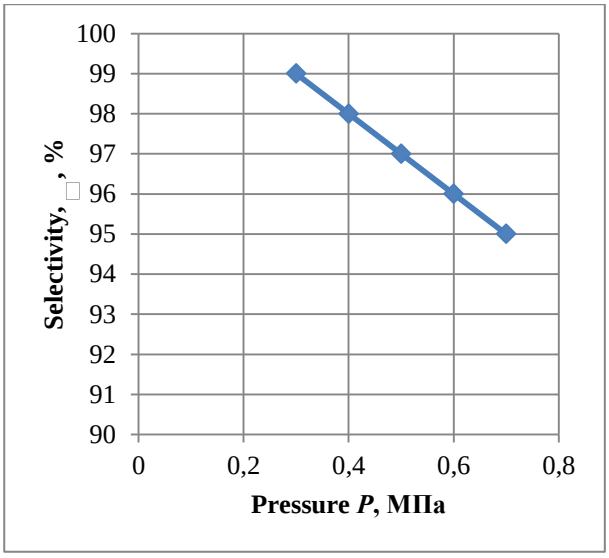

Fig. 2. Dependence of selectivity on the pressure.

In Fig. 3. shows the effect of speed on the permeability, which shows that an increase in the flow rate increases permeability to gas.

The driving force of the process is the pressure drop. Pores' sizes in the membrane or the external pressure are chosen so that the mean free path of the molecules is greater pore size, i.e. Canute was carried out in stages over Knudsen. When there is a Knudsen the flow is inversely proportional to the square root of the mass of the molecules. This relationship determines the separation factor.

In large pores, when the pore diameter is larger than the mean free path of the molecules of the adsorptive, mainly sea transport is normal, or bulk diffusion.

When we have a small size of pores, and when the mean free path of the molecules is much larger than the pore's radius, then the determinant of the rate of diffusion is the frequency of collisions with the walls of the pores. This is called the molecular diffusion or Knudsen. The collision of the adsorbed molecules to the surface at a certain time interval, they are fixed on the active sites of the adsorbent and only after that, because of thermal motion, removed in the liquid phase.

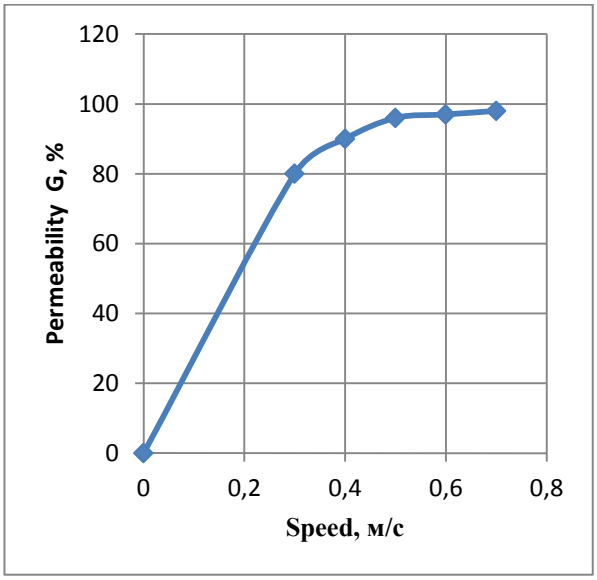

Fig. 3. Effect on the rate constant

If the pores are commensurate with the absorbing molecules, the process gets an activated character. By analogy with the ideas of Arrhenius, developed for the chemical reaction, not all molecules can penetrate the pores and be absorbed there, but only those who have some excess energy.

The basis of molecular-kinetic analysis of diffusion of small molecules (molecules of simple gases) in a polymer based on the assumption that the diffusive transport is carried out by successive periodic surges of diffusing molecules from one equilibrium position to another. The possibility of such movement is typically associated with the presence in the medium of a polymer free volume, i.e. some intermolecular gaps of different shapes and sizes due to the motions of the segments of the polymer matrix, and by moving the diffusing molecules. These provisions are taken as the basis of a number of theoretical relations obtained by researchers, which are based on different assumptions and are used to explain the experimental results to determine the

viscosity, solubility and diffusion in polymers. Therefore, when confronted with the term "free-volume theory" is often used in the qualitative interpretation of the experimental results, we must be clear that this is not a strict mathematical description of the process, and on a certain set of diverse theoretical calculations.

However, it should be recognized that the original model of the "free volume" for the qualitative analysis of the observed experimental dependencies diffusion of small molecules in polymers is productive and have sufficiently serious justification.

With increasing pressure, the diffusing gas mean free path of molecules becomes comparable and smaller pore diameter and Knudsen flow becomes either the viscous flow (Poiseuille flow) if attached to the membrane pressure gradient in either molecular interdiffusion, if both sides of the membrane constant pressure but the gas composition varies. Under the molecular interdiffusion we mean the diffusion in gases at the mean free path of the molecules much smaller than the pore size.

When there is a viscous flow then the separation of gases in the pores doesn't occur. In this case, the separation membrane can perform functions most likely as a filter only due to steric effects, i.e. delaying those molecules or aerosol particles sizes greater than the pore size.

Porous membranes, in which the regime of molecular diffusion does not seem to be used in any separation processes, although we cannot exclude such possibilities for any specific cases. Study of the processes of molecular diffusion in porous catalysts and sorbents, as well as the transition from the Knudsen diffusion to the molecular diffusion on the same objects are explored in a large number of original and review publications [9,11]. We note only that the effective diffusion coefficient in this case is usually calculated from the semi-empirical relations.

In FIG. 4 it is shown the dependence of the mass transfer coefficient of the membrane in the permeate stream from the phase velocity. The figure shows that the increase in speed increases the mass-transfer coefficient. Mass transfer rate depends on the dynamic motion of the gas mode, providing faster delivery of molecules to the outer boundary layer than their diffusion through the layer to the inner border. The higher intensity within a certain range of mixing gas is, the shorter the path of the molecules diffusing to the surface of the membrane is, and the sooner you deliver them to the surface, which is consistent with previous findings [1].

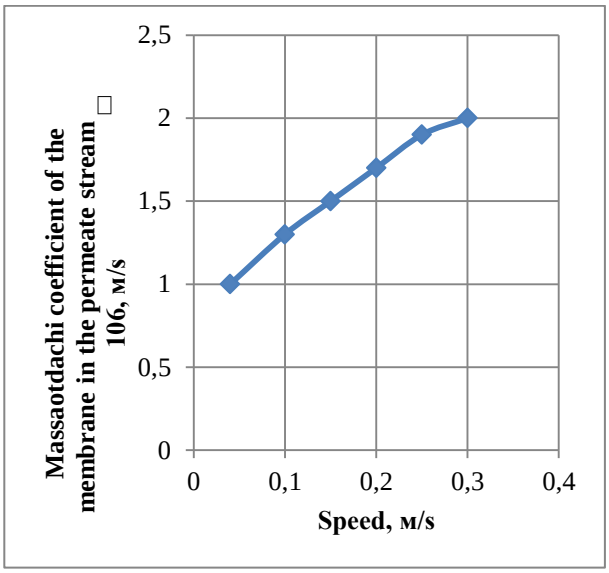

Fig. 4. Coefficient of mass transfer from the membrane to the permeate flow rate from the liquid phase.

In Fig. 5 it is shown the dependence of coefficient of mass transfer to the pores of the membrane from the inner the diffusion coefficient.

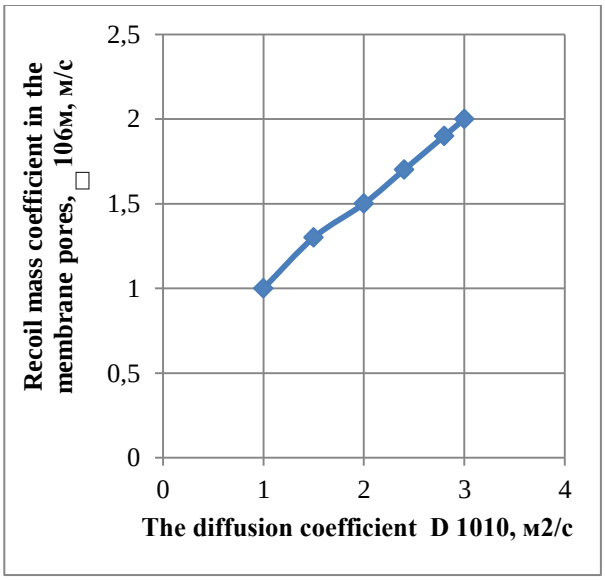

Fig. 5. Dependence of the mass-transfer coefficient in the membrane pores by internal diffusion coefficient.

The figure shows that as long as the overall speed of the process determines the resistance of the external mass transfer, the process can be intensified by increasing the intensity of mixing of the gas, which is consistent with the published data [4,5].

CONCLUSIONS

The results of this study show that the biogas facility is beneficial from an economic point of view of agriculture, provided that the technical support for the installation and its method of operation is optimally matched to the structural properties of the substrate, and its location is selected with the effective provision of biomass and allows efficiently dispose of the product gas. Besides having least-cost substrates, the key to economic success is, first of all, serviceable, not prone to frequent failures operation of the equipment, full use of the potential of the substrate, as well as optimum load of the entire system. In many areas, you can achieve significant improvements that will ensure efficient operation of the system and obtain higher profits.

Study of membrane purification of biogas makes it possible to determine the optimum process parameters affecting the efficiency of permeability and selectivity of membrane separation. Operating pressure is in the range 0.6 MPa. There were clarified the regularities of the membrane cleaning gas in a membrane unit. The dependence of permeability on the concentration, the effect of pressure on the permeability was found.

There was made the mechanism of mass transfer through the membrane pores and the main requirements for the material and structure of the membrane and the principle of membrane processes for cleaning gas. Depending on the mass transfer coefficient of the membrane in the permeate stream on the velocity of the liquid phase mass transfer coefficient in the membrane pores by internal diffusion coefficient showed that the increase in speed increases the mass transfer coefficient, as well as the fact that while the overall rate of the resistance determines the external mass transfer process can be intensified.

We got the equation for an impurity stream passing through the membrane, depending on its full and diffusive permeability, and also the equation to calculate the speed scale on the characteristic deformation of the macromolecule. Based on the set of mass transfer mechanism, the equation for determining the gas concentration and for calculating the concentration of carbon dioxide, hydrogen sulfide, ammonia, water vapor in the area of concentration polarization was proposed. The equations were derived for the coefficient of concentration polarization mass transfer coefficient taking into account the gas flow and permeate and selectivity for ultrafiltration.

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