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Zh. K. Bakhov[1], K. U. Sultangalieva[2], N. B. Zhumadilova[3]

[1]S. Seifullin Kazakh Agrotechnical University, Astana, Kazakhstan,
[2]M. Auezov South Kazakhstan state university, Shymkent, Kazakhstan,
[3]Al-Farabi Kazakh National university, Almaty, Kazakhstan.
E-mail: zhbakhov@mail.ru, swallwda@ mail.ru, naziko29-81@mail.ru

CONSTRUCTION SOLUTION FOR INTENSIFICATION OF GASEOUS ENERGY CARRIER PRODUCTION IN BIOREACTOR

Abstracts. The issues of processing organic waste with the purpose of solving urgent environmental problems in rural areas are considered. In order to intensify and optimize the processes of methane fermentation of biomass, the effect of immobilization of methane-forming bacteria on the surface of polymer compositions on the anaerobic processing of organic waste has been studied. The structural improvement of bioreactors implies the introduction of an immobilization device. Biofilm formed in the immobilization device, keeps from washing away slowly growing biomass cells. This leads to neutralization of the acidic products of bacterial hydrolysis that forms and promotes deeper processing of biomass, eliminating the causes that inhibit the process of fermentation. At the same time, the efficiency and productivity of the bioreactor for the production of a gaseous energy carrier - biogas - is increasing.

Keywords: ecological situation, waste processing, cattle manure, poultry manure, anaerobic fermentation, biogas, bioreactor, immobilization.

Introduction. Intensification of livestock and poultry production poses a problem of waste treatment and use, as they have high biological activity and contain a significant amount of weeds' seeds and microorganisms, including pathogenic microflora. One of the most widespread and environmentally safe methods of processing such wastes is their anaerobic fermentation in bioreactors with obtaining a methane-containing gaseous energy carrier and highly effective organic fertilizer. Effective production of energy on a biogas plant is possible only if the total energy of the biogas obtained is significantly greater than the energy expenditure for its production. The technical solutions available in this issue are still not effective, since they do not allow full compliance with the norms and rules of environmental measures. In conditions of a constant increase in the amount of organic waste generated, the development of more refined and optimized methods of processing them does not lose its relevance [1-3]. Intensification of the processing of organic waste, depending on the type of raw materials being processed, the necessary technological conditions, environmental parameters, and environmental and energy-saving tasks are being carried out in several directions [4].

The raw material for biogas production can be a wide range of organic waste. From all types of organic waste, the most effective use of biogas technologies for processing waste from livestock and poultry farms of sewage sludge is due to the persistence of the waste stream in time.

Numerous studies [5-7] have established such regularity as: the higher the temperature, the faster the biomass decomposes, and, accordingly, the volume of biogas production is also higher. When using the thermophilic regime, organic waste is better disinfected than with mesophilic, so it is more appropriate to apply it in cases where ensuring sanitary and ecological safety is paramount. At the same time, the implementation of fermentation of biomass at higher temperatures leads to a decrease in methane content in biogas, which is associated with an intensive transition of carbon dioxide dissolved in the substrate to the gas phase [8-10]. Both the mesophilic and thermophilic regimes of anaerobic fermentation of biomass require the supply of thermal energy from outside and the stable maintenance of the specified temperature parameters throughout the entire fermentation cycle. To obtain the necessary temperature and, if possible, maintain it at a constant level, the substrate usually is heated in order to supply the reactor.

Considerable interest in bioenergetic installations on a global scale is associated with the possibility of resource saving and reducing the use of fossil energy resources [11]. Biogases plants that process organic waste under anaerobic conditions, despite the positive aspects, have a relatively low energy efficiency in the production of biogas, since up to 60% of the produced biogas is spent for the plant's own needs. Analysis of the technological schemes of BEPs developed and applied in various countries of the world shows that an increase in the intensity of gas evolution at a commensurate fullness of the decomposition of the organic constituent of the substrate is associated with ensuring an optimal thermal regime of fermentation [12-14].

In the matter of increasing the efficiency of anaerobic processing of organic waste, considerable reserves are available in improving the design of bioreactors, which is the main apparatus in which anaerobic fermentation of biomass occurs.

Materials and methods. Cattle and pig manures, bird droppings and exhaust biogas substrate based on agriculture waste have been selected as research objects.

Currently, there are different types and designs of bioreactors, which can vary depending on the type of material being processed. We previously developed a new design for a biogas plant with an immobilization deviceto intensify the anaerobic fermentation of organic waste [15].

The organic waste substrate and the culture of methane-forming bacteria are loaded into the bioreactor and the temperature and pH index are maintained optimal values during the fermentation of the substrate. The bioreactor is equipped with an electric heater with area of heat exchange of 0.33 m^2, pipelines for supply and removal of the fermentation medium, pipelines for feeding and collection of the initial liquid substrate, and a recirculation pump. The upperpart of the bioreactor is connected by a pipeline with a collector of biogas - gasholder. The volume of biogas produced is measured using a gas flow meter. The gas content is analyzed using an infrared spectrophotometer for continuous gas monitoring. pH meter was also used to measure redox potential.

The initial liquid fraction inflows to the bioreactor through a pipeline valve from the storage tank with a recirculation pump until it reaches the level of the upper removable grating of the immobilization device. The initial solid fraction of manure is transferred when the lid is opened into the bioreactor on the surface of the immobilization device. The process of liquid fraction mixing is proceed with using a recirculation pump. The circulationis directed towards the top of the reactor and the liquid is sprayed onto the surface of the solid fraction through the feed line of the fermentation medium. The liquid fraction is enriched with nutrientswhile passing through the solid substrate. The process of methane fermentation and the decomposition of organic substancesis carried by two groups of microorganisms - acid and methanogens in the bioreactor under anaerobic conditions.Biofilm (microflora) developsduring the fermentation on the surface of the carrier in the immobilization device, which serves to prevent the flushing of slowly growing cells and ensure biomass retention regardlessof the time of hydrolytic confinement.

The immobilization device is populated with microorganisms, forming a mucous layer (biofilms) and microorganisms. Formed microorganisms that immobilized in rings are less subjected to wound stress and cell damage by gas bubbles. The upper removablecell is packed with a fine mesh net to hold up fibrous and coarse manure and bird droppings. The process of anaerobic fermentation of the substrate lasts for 30 days of hydrolytic retention time (VGU) in the mesophilic regime (at a temperature of 40 ± 0.2 °C). The experiments were carried out in three repetitions of two launches. At the first start, 95 liters of liquid fraction were poured into the reactor, after which 15 kg of solid manure from the top of the reactor was loaded. Biogas obtained from anaerobic fermentation of livestock and poultry wastes contains 60-90% of methane (CH4) and 15-30% of carbon dioxide (CO2), which accumulates through the pipeline in the gas tank.

Results and Discussion. Samples of fresh material (SM) of manure and recirculating liquid were analyzed for dry matter (CB), organic dry matter (oCB) and ash content according to standard APHA (1995) methods.

Three samples from each substrate were dried overnight at 105 °C in an oven to determine the content of dry matter and moisture. Dried samples were burned at 505 ° C for 12 hours in an oven to determine the content of organic dry matter and ash. The results of the analysis of substrates are given in table 1.

Table 1 – Results of the analysis of cattle manure

Substrate samples	Parameters (%)			
	Dry matter content (in fresh matter)	Organic dry matter content (in fresh matter)	Ash (in fresh matter)	Humidity of substrate
Manure KPC	28,6±0,71	86,3±0,84	3,12±0,61	71,4
Manure slurry	0,52±0,002	32,3±0,75	0,37±0,004	99,48

Table 2 shows the quantitative characteristics of the loaded manure of cattle in the bioreactor. In the first run, a reactor was loaded with 15 kg of cattle manure with 4.29 kg of dry manure, 3.7 kg of organic dry matter and 95 liters of prepared slurry. In the second run, 15 kg of litter manure was also loaded in excess of the fermented residue from the first run.

Table 2 – Quantitative characteristic of the raw material

Parameters	First load	Second load
Mass of raw manure KPC (kg)	15	15
Dry matter (kg)	4,29	4,48
Organic dry matter (kg)	3,7	3,62
Added slurry (l)	95	–
Continuation of fermentation	30	28

The experiments were carried out in three repetitions with two starts. At the first start, 19 liters of inoculum, taken from a 400-liter reactor operating in a continuous mode, were inoculated into the reactor. After that, 3 kg of cattle manure was loaded from the top of the reactor. The liquid fraction is continuously recirculated every 2 hours for 15 minutes during the entire fermentation cycle by the introduction of fermentation liquid. The circulation proceeds towards the top of the reactor. When the output of biogas from the first pilot start is reduced, the next batch of manure cattle (3 kg) is loaded from above.

In the second run the inoculum does not change and is not added additionally e.g. the second start is initiated by the first run's liquor. All experimental repetitions of two launches have shown similar data. The daily methane output reaches 0.002 Nm^3/kg of organic dry matter by the second day, and decreases to 0.001 Nm^3/kg of organic dry matter at the end of the second day. After the third day, it increases to 0.006 Nm^3/kg of organic dry matter on the seventh day and gradually decreases to the end of the cycle, showing a methane yield of between 0.006 Nm^3/kg of organic dry matter - 0.004 Nm^3/kg of organic dry matter. The average total combined methane yield is 0.148 Nm^3/kg of organic dry matter. The percentage of methane after the 3 days of launch was 26.5%, on the 5th day it increased to 50% and was higher than 55% by the end of the sixth day. The peak of methane percent in the first run was 56.1% on the 8th day.

The second start, initiated by the liquor liquor of the first run, showed intensive formation of biogas. At the same time, methane formation reaches 0.004 Nm^3/kg of organic dry matter in a day, decreases to 0.002 Nm^3/kg of organic dry matter at the beginning of the second day, and rises gradually to a maximum on the fifth day (0.009 Nm^3/kg of organic dry matter). After this, during the formation of methane, a gradual decrease to 0.003 Nm^3/kg of organic dry matteris observed. The total average cumulative methane yield is 0.150 Nm^3/kg of organic dry matter. The percentage of methane in biogas after the second day is 35%, which gradually increases to 66% on the seventh day, while achieving a peak percentage of methane content in biogas.

The cumulative yield of biogas (A) and methane (B) is shown in figures 1 and 2.

The final cumulative methane output is reached at the first start at the end of the 28-day VSU, and in the second start at the end of the 21-day VSU. The pH ranged between 7 and 7.53during anaerobic fermentation. In the first run, the pH rose from 7.1 to 7.37 before the tenth day and then fell to 7.33 by the 15th day. After that, until the end of the cycle, it rose to 7.5. In the second run, the initial pH was 7.2, but rose to 7.67 before the end of the process.

The production rate of biogas and methane is shown in figures 3 and 4. The performance of the bioreactor with the immobilization device is shown in table 3.

Table 4 presents the technical parameters of the bioreactor.

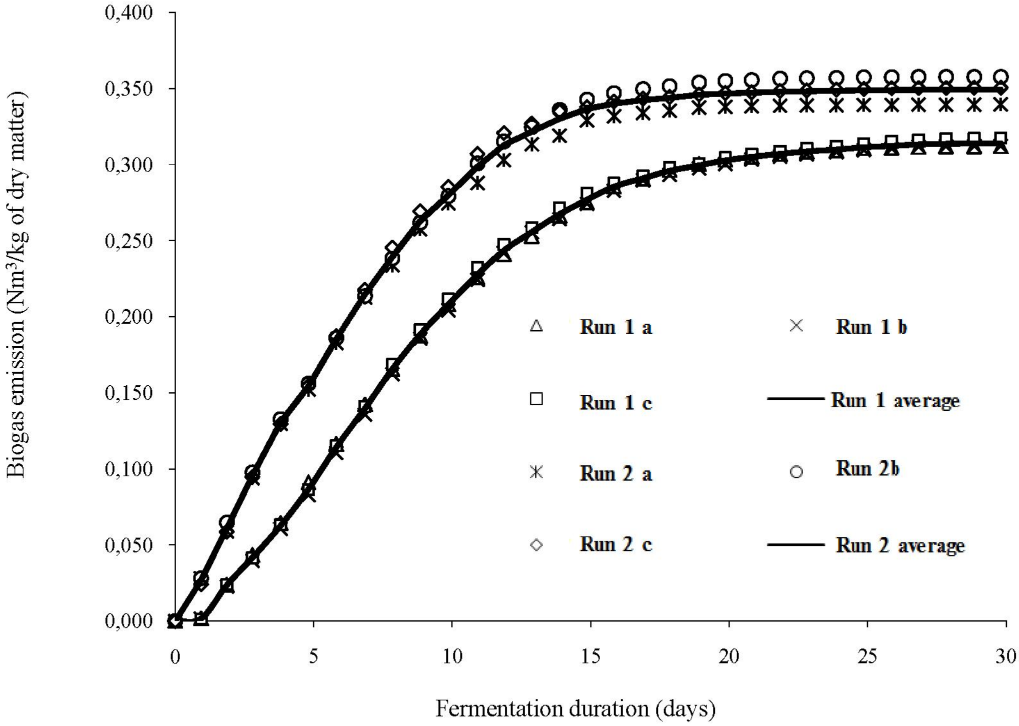

Figure 1 – Cumulative biogas emission

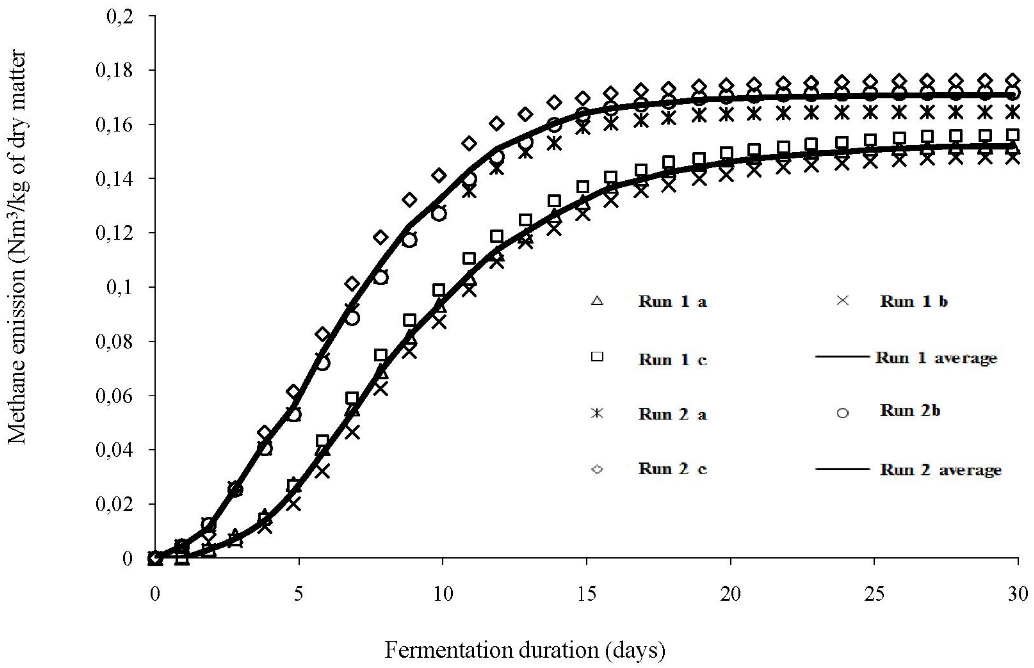

Figure 2 – Cumulative methane emission

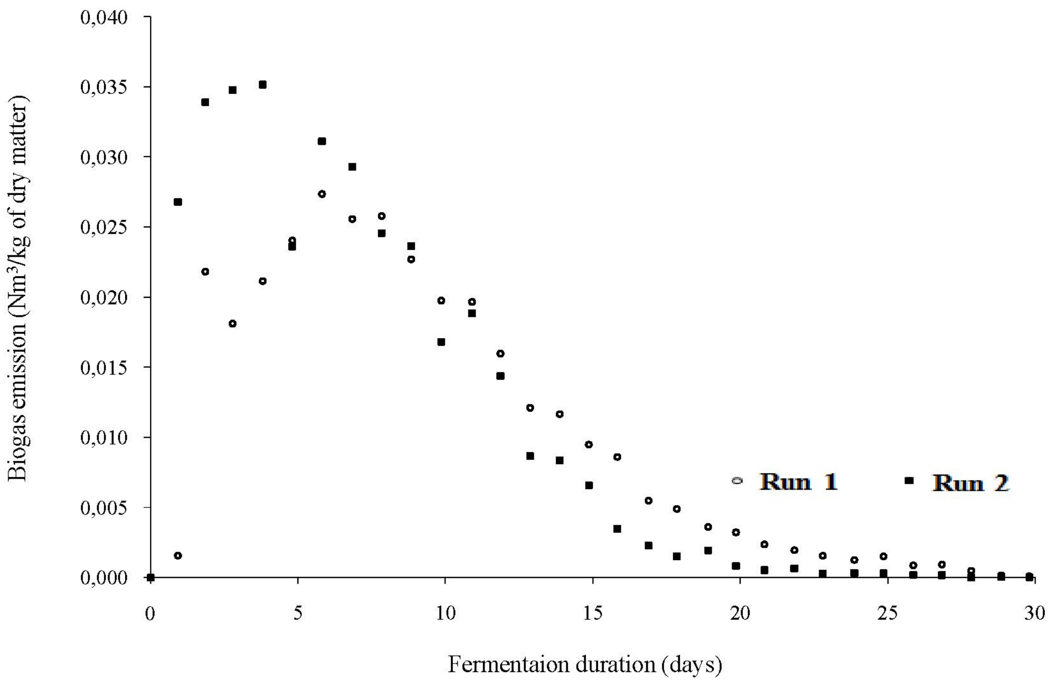

Figure 3 – Production rate of biogas

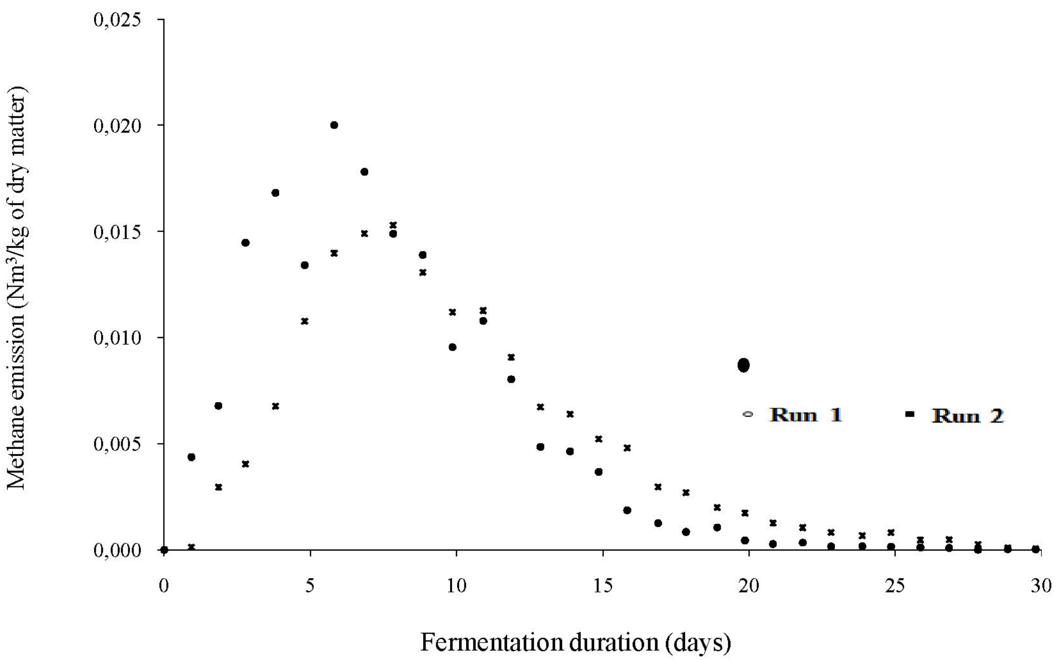

Figure 4 – Production rate of methane

The high initial biogas and methane production in all starts to the third day is explained by the fact that due to selective fermentation of rapidly decomposable organic substances can lead to a temporary decrease in the production of biogas and methane between the third and fourth days.

Table 3 – The productivity of a bioreactor with an immobilization device

Experiments/Runs	Finas pH	Final cumulative methane emission (Nm^3/kg of organic dry matter)	Gomperse constants			Duration to reach 95% emission potential of methane (days)
			P (Nm^3/kg of ODM-1)	R_m (Nm^3/kg of ODM-1d)	λ (days)	
Experiment 1						
Run 1		0,153	0,153	0,014	1,9	17,7
Run 2		0,165	0,165	0,018	0,6	14,1
Average		***0,159***	***0,159***	***0,016***	***1,25***	***15,9***
Experiment 2						
Run 1		0,148	0,148	0,014	2,4	18,2
Run 2		0,172	0,172	0,018	0,6	14,5
Average		***0,16***	***0,16***	***0,016***	***1,5***	***16,35***
Experiment 3						
Run 1		0,156	0,156	0,015	2	17,6
Run 2		0,176	0,176	0,021	0,7	12,5
Average		***0,166***	***0,166***	***0,018***	***1,35***	***15,05***
Final main value		0,162	0,162	0,017	1,37	15,8
Stand. Error		0,002	0,002	0,0007	0,07	0,38
Snand. Deviation		***0,0038***	***0,0038***	***0,0010***	***0,0130***	***0,6600***
Final range		0,162 ± 0,0038	0,162 ± 0,0038	0,017 ± 0,001	1,37 ± 0,013	15,8 ± 0,66
F-critical						
α		**0,05**				
Accuracy level (%)		**95**				

Table 4 – Basic technical parameters of bioreactor

Index	Unit of measurement	Value
Total volume of bioreactor	m^3	0,25
Volume of gas space	m^3	0,07
Processing temperature when mesophilic regime – M with thermophilic regime – T	 ^0C ^0C	 35-37 55-57
Processing time	days	20-22 on M 12-15 on T
Pump power for manure mixing	kW	0,37
Installed power. heater	kW	2,0
Heat trans fersurface area	m^2	0,33
Performance* on initial manure M-T forbiogas MT	 l/day 1/day	 10-15 100-170
Net weight	kg	450
*Calculation of M – mesophilic regime of fermentation; T – thermophilic regime of fermentation.		

Thus, a promising direction for increasing the yield of methane and biogas during processing of biomass is the structural improvement of bioreactors. The technical result achieved with the use of a bioreactor with an immobilization device is to increase the efficiency and productivity of a bioreactor for the production of a gaseous energy carrier - biogas by deeper processing of the original biomass through the use of a leaching layer and the immobilization of microorganisms. Immobilization of methanogenic bacteria prevents the flushing of slowly growing cells and ensuring the retention of biomass, regardless of the time of hydrolytic confinement. Re-use of the fermentation medium and immobilization of microorganisms in polymer carriers in the reactor makes it possible to initiate methanogenesis quickly and reduce the VGU due to the formation of biofilms, the stages of grinding raw materials, additional acidification and hydrolysis.

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Ж. К. Бахов[1], К. У. Султангалиева[2], Н. Б. Жумадилова[3]

[1]С. Сейфуллин атындағы Қазақ агротехникалық университеті, Астана, Қазақстан,
[2]М. Әуезов атындағы Оңтүстік Қазақстан мемлекеттік университеті, Шымкент, Қазақстан,
[3]Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан

БИОРЕАКТОРДАҒЫ ГАЗ ТӘРІЗДІ ЭНЕРГИЯ ТАСЫМАЛДАУШЫЛАРЫН ӨНДІРУДІ КҮШЕЙТУГЕ АРНАЛҒАН КОНСТРУКЦИЯЛЫҚ ШЕШІМДЕР

Аннотация. Ауылдық жерлердегі шұғыл экологиялық проблемаларды шешу мақсатында органикалық қалдықтарды өңдеу мәселелері қарастырылады. Биомасса метан ферменттеу процестерін жеделдету және оңтайландыру мақсатында органикалық қалдықтарды анаэробты өңдеуге полимерлік композициялар бетінде метан құратын бактериялардың иммобилизациясының әсері зерттелді. Биореакторлардың құрылымдық жақсарту иммобилизациялау құрылғысын енгізуді білдіреді. Иммобилизация қондырғысында пайда болған биоқабыршақ, биомасса жасушаларының баяу өсіуін тоқтатады. Бұл бактериялық гидролиздің қышқылдық өнімдерін бейтараптандыруға әкеледі, ол биомассады тереңдете өңдеуге ықпал етеді, ашыту процесін тежейтін себептерді жоққа шығарады. Сонымен қатар, биоресурстардың өндірісі үшін биореактордың тиімділігі мен өнімділігі артып келеді.

Түйін сөздер: экологиялық жағдай, қалдықтарды қайта өңдеу, ірі қара мал, құс саңғырығы, анаэробты ашыту, биогаз, биореактор, иммобилизация.

Ж. К. Бахов[1], К. У.Султангалиева[2], Н. Б. Жумадилова[3]

[1]Казахский агротехнический университет им. С. Сейфуллина, Астана, Казахстан,
[2]Южно-Казахстанский государственный университет им. М. Ауэзова, Казахстан, Шымкент,
[3]Казахский национальный университет им. Аль-Фараби, Алматы, Казахстан

КОНСТРУКЦИОНЫЕ РЕШЕНИЯ ДЛЯ ИНТЕНСИФИКАЦИИ ПРОИЗВОДСТВА ГАЗООБРАЗНОЙ ЭНЕРГИИ В БИОРЕАКТОРЕ

Аннотация. Рассмотрены вопросы переработки органических отходов с целью решения неотложных экологических проблем в сельских районах. Для интенсификации и оптимизации процессов метановой ферментации биомассы изучено влияние иммобилизации метанообразующих бактерий на поверхности полимерных материалов на анаэробную обработку органических отходов. Структурное улучшение биореакторов подразумевает введение иммобилизационного устройства. Биопленка, образованная в иммобилизационном устройстве, не позволяет смыть медленно растущие клетки биомассы. Это приводит к нейтрализации кислотных продуктов бактериального гидролиза, который образует и способствует более глубокой обработке биомассы, устраняя причины, препятствующие процессу ферментации. В то же время эффективность и производительность биореактора для производства газообразного энергоносителя - биогаза - возрастает.

Ключевые слова: экологическая ситуация, переработка отходов, навоз крупного рогатого скота, птичий помет, анаэробная ферментация, биогаз, биореактор, иммобилизация.