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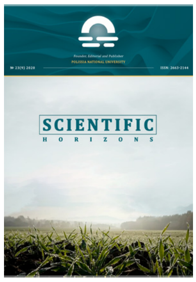

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Utilisation of livestock by-products for resource-saving biogas production in industrial pork production

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Abstract. Modern energy systems are complex multi-component systems that use mechanical, thermal, and electrical energy. As fossil fuel reserves decline, interest in renewable energy sources is growing everywhere, which is driving research into biogas production technologies. The purpose of this study was to evaluate technological approaches to reduce resource costs to produce renewable energy sources from organic waste (manure) from pig farms. This study employed the bibliographic method

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of research, laboratory method, biochemical methods (determination of the chemical composition of manure and wastewater), statistical, mathematical (calculation of economic efficiency), multicriteria analysis, and analytical method. Based on the conducted research, a resource-saving technology for the preparation of wastewater for use in the production of renewable energy in industrial pork production was developed, which ensures a reduction in capital and operating costs for biogas generation. It was found that the settling of the initial wastewater with a moisture content of 96.94±0.18% produces a sediment with a moisture content of 91.23±0.25% and a liquid fraction with a moisture content of 98.86±0.42%. At the same time, the organic matter in the sediment extracted from the original wastewater is about 87%, and in the liquid fraction – about 98% of the dry matter. The technological process includes centrifugal and gravity separation of the initial wastewater into fractions (sediment and liquid fraction), gravitational thickening of the sediment and its dosing for methane digestion to produce biogas. It was shown that the application of the proposed approaches can reduce capital investments by about 30%. Based on the multicriteria analysis, it was found that the proposed biogas production technology has a significant advantage in terms of the complex efficiency indicator of each of the considered options $N(C_k)$ compared to the idealised one. For this technology, the objective function is the smallest according to the criteria considered and amounts to 0.1672, while the objective function of the baseline technology is 1.9 times worse. The findings of the study on the use of livestock by-products for resource-saving biogas production are planned to be used at pork production complexes and farms

Keywords: renewable energy sources; bioenergy; wastewater; technology; sediment; resource conservation; capital investments

INTRODUCTION

Ukraine's energy sector is facing a challenging task – to reduce the consumption of natural gas and coal in electricity generation and replace them with renewable energy sources (RES) to the maximum extent possible. On the one hand, this would reduce the cost of production and improve its competitiveness in the global market. On the other hand, the combustion of fossil carbohydrates – coal, gas, oil, and their derivatives – is considered the main source of CO_2 emissions, which contributes to global warming. Therefore, the campaign to replace fossil fuels with other environmentally friendly fuels, such as biofuels (biomethane, biohydrogen, bioethanol, etc.) is growing worldwide (Dabirian *et al.*, 2023). This provides an impetus for the widespread use of RES (specifically, farm animal manure) processing plants for electricity or heat in the national economy and is a promising area (Skrylnyk *et al.*, 2020).

The need to feed humanity has contributed to the development of animal husbandry, the development of technologies for intensive farming of livestock and poultry, and the construction of complexes or large farms. As a result, a massive amount of livestock and poultry waste has been generated, which is the main source of agricultural pollution, especially in regions with a prominent concentration of livestock and poultry (Zhang *et al.*, 2019; Li *et al.*, 2022). According to M.J. Sukhesh and P.V. Rao (2019), in the United States, the amount of waste from livestock production is 130 times higher than human waste, which affects the local environment. Therefore, countries with developed livestock production need to develop and implement an effective strategy for the utilisation of livestock manure.

V. Burg *et al.* (2018) believe that manure, without quality processing, is a source of air and water pollution, but when integrated into the management chain, it can become a strong energy resource. The potential for biogas production from cattle manure in Europe is quite high, for instance, in Sweden it is estimated at about 3-6 TWh per year (Achinas & Everink, 2020). According to N. Yurchuk (2018), is an equipment that allows processing various types of organic raw materials into energy in the form of biogas and into highly effective organic fertilisers. They can also be used as wastewater treatment plants on farms, poultry farms, and processing plants, thereby improving their sanitary and hygienic conditions.

The European Union limits the amount of manure that can be applied to arable land. Therefore, in regions with a prominent concentration of livestock and a limited amount of arable land, such as large pig and poultry farms, it is necessary to remove manure or set up its processing. One of the elements of the manure processing system can be the biogas units. This will not only reduce the amount of dry matter to be exported but will also bring additional financial profit from the sale of biofuels. Studies conducted by scientists from different countries have made it possible to determine the approximate volumes of biogas output from agricultural waste processing (Lutkovska & Zelenchuk, 2023).

In Ukraine, livestock and poultry waste, specifically manure, can be another major and environmentally sound source for biofuel production. Thus, according to A. Doronin (2019), the potential biogas production in Ukraine from cattle waste in 2017 could be up to 1,920 mln m^3/year, pigs – up to 971 mln m^3/year, poultry – up to 1,863 mln m^3/year. According to G.M. Kaletnik and I.V. Honcharuk (2020), in 2020, the livestock population in Ukraine was within 3.1 mln heads of cattle, 5.7 mln heads of pigs, and 220.5 mln heads of poultry, from which about 92.8 mln t of animal by-products were produced. According to the calculations, the total potential for biomethane production from livestock waste will reach approximately 2.2 mln toe. And according to N.V. Pryshliak (2021), in 2019, about 40.65 mln t of waste was produced from animals in the private sector of Ukraine. If they are used in the biogas units, the theoretical biogas output could reach 1,760.3 mln m^3.

According to the authors, the main obstacle to the introduction of bioenergy plants in industrial pork production is the considerable cost of creating and operating such systems, as well as the suboptimal characteristics of the material for the fermentation process. Thus, the purpose of this study was to develop and evaluate approaches to reducing resource costs in the production of renewable energy sources (biogas) in industrial pork production. However, high moisture content has a negative impact on biogas production, and therefore some work is needed to increase the dry matter content of the biomass fed to the biogas unit. This will help improve the quality of the output product, increase biogas yields, and increase the economic efficiency of the plants. One of the ways to optimise the substrate for methane digestion is to separate the pig manure into sediment and liquid fraction. This became the subject of this study. The purpose of this study was to develop and evaluate approaches to reducing resource consumption during the production of renewable energy sources (biogas) in industrial pork production.

MATERIALS AND METHODS

The wastewater studies were carried out at the Hlobinskyi Pig Farm LLC, Poltava Oblast, in 2016-2018. The technology of industrial pork production at Hlobinskyi Pig Farm LLC prescribes feeding pigs with complete feed according to sex and age groups in a liquid-feeding fattening shop. The microclimate was maintained by an automated ventilation system. The receiving tank was supplied with effluent from the buildings containing machines with partially raised slotted floors placed on bathtubs with valves. When the valves were raised, the effluent flowed to the central collectors and from there to the receiving tank. The receiving tank was equipped with a hydraulic bubbling system, which operated using centrifugal pump pressure. The outgoing wastewater was separated in a filter press.

The outgoing wastewater was sampled at the complex from the receiving tank. Therewith, liquid and solid fractions were selected after separation of the initial effluent on the filter press. In laboratory conditions, the effect of the settling process on the moisture content of the sediment obtained in the laboratory plant was investigated (Fig. 1).

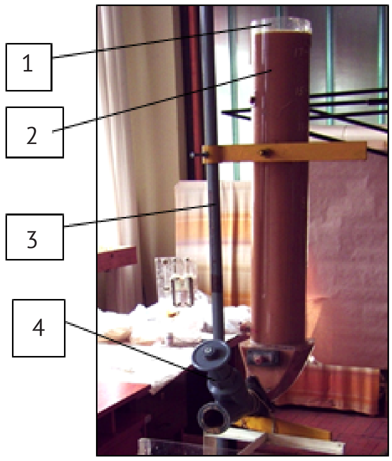

Figure 1. *Laboratory installation for studying wastewater settling*

Notes*: 1 – organic glass unit body; 2 – outlet drains; 3 – tripod; 4 – latch*

Source*: compiled by the authors*

During the experiment, the volume of the unit's body was thoriated to investigate the process of wastewater settling using a measuring cylinder. Before feeding the source wastewater to the laboratory unit, it was homogenised and sampled for moisture content. The moisture content of the sediment formed during sedimentation was monitored after 0.5; 1.0; 1.5; 2.0; 2.5; 3.0; 3.5; 4.0; 4.5; 5.0 hours. After a respective period of time, during which the initial wastewater was settled, the sediment and liquid fraction were removed through valve 4 (Fig. 1). Sediment and liquid fraction samples were taken to determine moisture content and other parameters. The moisture content of the sediment was determined following DSTU ISO 6496:2005 (2006), using the following equation (Turovsky, 1982):

$$\frac{V_1}{V_2} = \frac{100-W_2}{100-W_1}, \quad (1)$$

where V_1 is the volume of output effluents, V_2 is the volume of sediment from output effluents, W_1 is the humidity of output effluents, W_2 is the humidity of sediment from output effluents. The volume of sediment was determined as the difference between the volume of the initial effluent and the volume of the liquid fraction. The volume of the liquid fraction was determined as the product of the cross-sectional area of the laboratory vessel and the height of the liquid fraction column.

The wastewater was assessed for moisture and dry matter (DSTU ISO 6496:2005, 2006), ash (DSTU ISO 5984:2004, 2006), and crude fibre (DSTU ISO 6865:2004, 2006). During the study, a method was developed to ensure a reduction in capital investment in the production of renewable energy sources in industrial pork production, based on ensuring the optimal value of the substrate parameters for methane fermentation. The substrate for methane digestion was obtained from the original wastewater upon gravity settling and compaction. The effectiveness of the proposed approach to ensuring a reduction in capital investment in the development and implementation of technologies for the preparation of wastewater for use with the production of renewable energy sources (biogas) in industrial pork production was assessed, considering capital investment and operating costs. The annual economic effect of the proposed technology was determined according to the following formula (DSTU 46-012-2000, 2001):

$$E_{an} = (O_B + E_I K_{IB}) - (O_N + E_I K_{IN}), \quad (2)$$

where E_{an} is the annual economic effect of implementing the development; O is the operational costs in the basic ($_B$) and new ($_N$) variant; E_I is the coefficient of efficiency of innovative investments; K_I is the investments in the basic ($_B$) and new ($_N$) variant.

The method of multicriteria analysis was applied using the assessment of the integral criterion of the distance to the target. For this, an approach was used that included the aggregation of all criteria into one comprehensive performance indicator for each of the alternative variations (Piskun *et al.*, 2020).

RESULTS AND DISCUSSION

During the experiment, the effect of the settling process on the moisture content of the sediment obtained from the original wastewater in the laboratory plant was investigated (Fig. 2). With the concentrate type of feeding and the litterless technology of pig housing, outgoing effluents with a moisture content of 96.94±0.18% were obtained. During the separation of the original wastewater on the filter press, a liquid fraction with a moisture content of 98.73±0.12% was obtained, and a solid fraction with 73.16±0.18% moisture content.

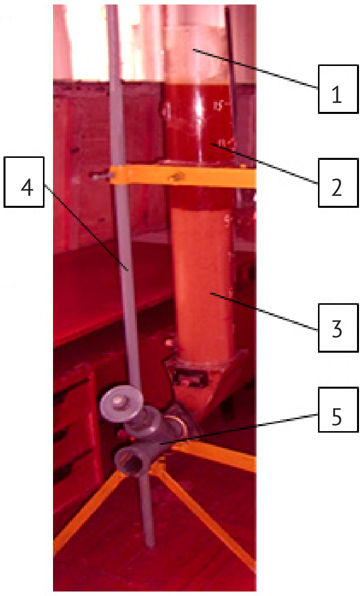

Figure 2. *Study of the effect of the settling process on the moisture content of the sediment produced in a laboratory plant*

Notes: *1 – Organic glass unit body; 2 – liquid fraction; 3 – sediment; 4 – tripod; 5 – latch*

Source: *compiled by the authors*

Studies have shown that the settling of the liquid fraction obtained during the separation produces a precipitate with a moisture content of 92.57±0.47% and a liquid fraction with a moisture content of 98.49±0.29%. That is, when the liquid fraction was stored in the storage pond, which was obtained from the original wastewater after separation in the filter press, a sediment with a moisture content of about 92% was formed. The organic matter in the effluent was 71.83±3.98% of the dry matter content. At the same time, the organic matter in the sediment that was separated from the liquid fraction after separation of the original wastewater was about 98%, and in the liquid fraction – about 99% of the dry matter. When the initial wastewater was settled with a moisture content of 96.94±0.18%, a sediment with a moisture content of 91.23±0.25% and a liquid fraction with a moisture content of 98.86±0.42% were formed. That is, during the storage of the original wastewater in the storage pond, a sediment with a moisture content of about 92% was formed. At the same time, the organic matter in the sediment extracted from the original wastewater was about 87%, and in the liquid fraction – about 98% of the dry matter.

Based on these and other studies, the provisions of the utility model patent "Method of wastewater treatment" (Piskun & Piskun, 2010), a variant of the process scheme for methane digestion of the initial wastewater in industrial pork production was developed, ensuring a reduction in construction and operation costs while generating renewable energy sources (biogas). The technological process includes centrifugal and gravity separation of the initial wastewater into fractions (sediment and liquid fraction), gravity thickening of the sediment obtained during centrifugal and gravity separation and periodic discharge of the thickened sediment for dosing when it is fed to methane digestion to produce biogas. When biogas is used in a generator, electricity and heat are produced (Fig. 3).

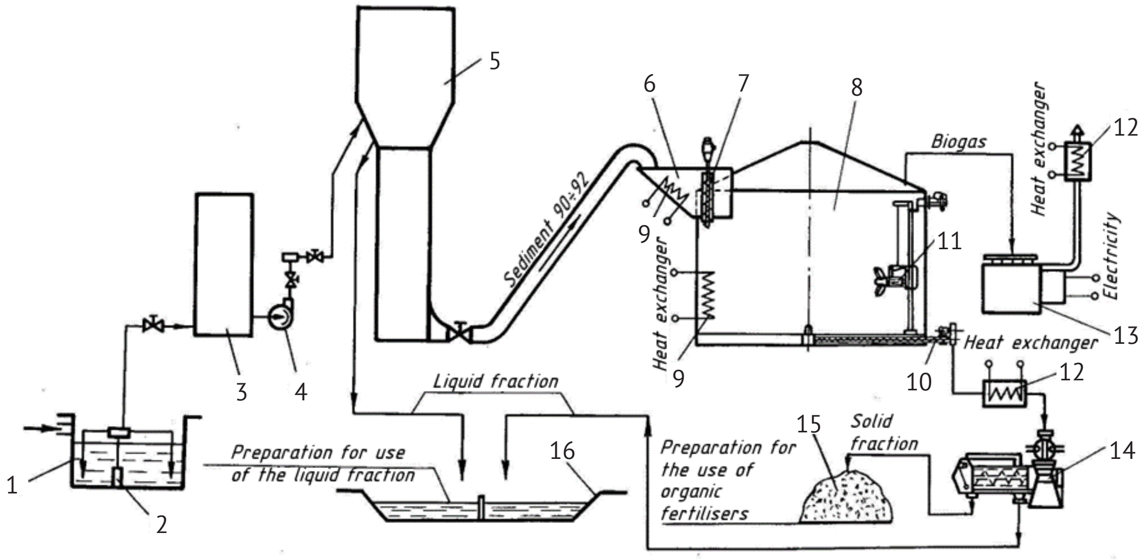

***Figure 3**. Diagram of a resource-saving biogas production line for industrial pork production*
***Notes**: 1 – receiving tank; 2, 4 – sanitary pumps; 3 – intermediate tank; 5 – device for centrifugal-gravity separation of the initial wastewater; 6 – dosing tank; 7 – device for dosed sediment supply; 8 – digester; 9 – heat exchanger; 10 – sediment discharge device; 11 – stirrer; 12 – heat recuperator; 13 – power generation unit; 14 – filter presses; 15 – solid fraction pile; 16 – storage pond*
***Source**: N.V. Piskun and V.I. Piskun (2010)*

The technological process of obtaining renewable energy sources (biogas), according to the scheme developed in this study, is as follows. The wastewater from rooms with slotted floors and bathtubs is conveyed by collectors to the receiving tank 1, from where it is transferred to the intermediate tank 3 by means of a pump 2. Subsequently, pumps 4 convey the wastewater to the device for centrifugal and gravity separation of the original wastewater 5, where the wastewater is separated into a liquid fraction and sediment, which is compacted to a moisture content of 90–92% and subsequently fed to the dosing tank 6. The liquid fraction is fed to the storage pond 16. The sediment from the dosing tank 6 is periodically fed to the methane digester 8 by the sediment dosing device 7 according to the technological regime of methane digestion. The resulting biogas is fed to the power generation unit 13. The fermented sediment from the digester 8 is fed to the filter press 14, where it is separated into solid and liquid fractions using the sediment discharge device 10. The solid fraction is delivered to the site, where a solid fraction pile 15 is formed, undergoes biothermal treatment, and is subsequently used as organic fertiliser. The liquid fraction goes to the storage pond 16 and, after quarantine, is used to fertilise agricultural land. The resulting biogas is converted into electricity and heat in the power generation unit 13. They can be used in the electrical and heating systems of an enterprise. Surplus electricity can be supplied to the external power grid through a transformer substation and a distribution point.

The design parameters of the digester, solid fraction pads, and liquid fraction storage tanks are determined using the following analytical relationships. According to the known factual data characterising the quality of separation into individual elements of the technological line, such as the mass M and moisture W of the effluents entering the treatment and received at the exit, the mass M_P and moisture W_P of the liquid fraction and the mass M_O and moisture W_O of sediment, V_O is the volume of sediment considering the approaches developed by N.G. Kovalev *et al.* (1983). Based on the balance equations for the mass flow rate of the current through the separation element, the following data are obtained:

η_P, η_O – efficiency of separation into liquid fraction and sediment; C_P, C_O – the concentration of the liquid fraction of effluents and sediment. If M, W, W_P, W_O are given, the main characteristics of the separation quality are determined according to Equations 3-7:

$$M_T = \frac{M^*(W_P - W)}{W_P - W_O}, \quad (3)$$

$$M_P = \frac{M*(W-W_O)}{W_P-W_O} \text{ or } M_P = M - M_O, \quad (4)$$

$$C_P = 1 - 0.01W_P;\ C_T = 1 - 0.01W_O;\ C = 1 - 0.01W, \quad (5)$$

$$\eta_P = 1 - \frac{(M_P*C_P)}{M*C} = 1 - \frac{M_P*(100 - W_P)}{M*(100 - W)}, \quad (6)$$

$$\eta_T = 1 - \frac{(M_O*C_O)}{M*C} = 1 - \frac{M_O*(100 - W_O)}{M*(100 - W)} \text{ or } \eta_T = 1 - \eta_P. \quad (7)$$

The presented equations make it possible to determine the volume of sediment and subsequently the volume of digesters based on factual data on the outgoing effluent, considering the digestion modes. Estimation of the cost of processing the initial wastewater in industrial pork production with bedding-free housing and renewable energy sources (biogas) for the baseline and new variants is presented in Table 1.

Table 1. *Costs of wastewater treatment to produce biogas*

Indicators	Variants			
	New		Basic	
	UAH	%	UAH	%
Volume of wastewater treated	146,000 tonnes			
Capital investments:	17,549,496	100.0	25,801,300	100.0
Production costs:				
remuneration of labour	102,000	6.19	84,000	3.58
deductions for social events	23,500	1.43	19,320	0.82
electricity costs	142,884	8.67	214,620	9.15
Heat energy costs	119,837	7.27	199,728	8.51
amortisation total	877,475	53.24	1,290,065	54.98
Maintenance – total	350,510	21.27	516,026	21.99
Low-value assets	11,500	0.69	6,000	0.25
Total production costs	20,400	1.24	16,800	0.72
Total production costs (prime cost)	1,648,106	100.0	2,346,559	100.0
Cost reduction, %	29.8		–	

Source*: compiled by the authors*

An assessment of wastewater treatment technologies for use at a pork production complex for biogas production showed that to process 146,000 tonnes per year, capital investments under the basic technology amounted to UAH 2,346,559, and under the proposed technology – UAH 1,648,106. In other words, the proposed technology for preparing liquid manure for use in renewable energy production will reduce capital investment by 29.8%. Based on the data obtained, a multicriteria analysis of wastewater treatment technologies for use in industrial pork production was conducted. The results are presented in Table 2. The analysis results suggest that the proposed biogas production technology has a considerable advantage in terms of the complex efficiency indicator of each of the considered options $N(C_k)$ compared to the idealised one. For this technology, the objective function is the smallest according to the criteria considered and amounts to 0.1672, while the objective function of the baseline technology is 1.9 times worse.

Table 2. *Results of multicriteria analysis of wastewater treatment technologies for use in industrial pork production*

Indicators	Variants	
	New	Basic
Capital investments:	1	1.4702
Production costs:		
remuneration of labour	1.2143	1
deductions for social events	1.2163	1
electricity costs	1	1.5021
heat energy costs	1	1.6667
amortisation total	1	1.4702
Maintenance – total	1	1.4722
Low-value assets	1.9167	1
Total	9.3373	10.5617
N(Ck)	0.1672	0.3223

Source*: compiled by the authors*

The current research is consistent with the findings of other authors, but is more in-depth in determining the effectiveness of using pig by-products for biogas production. The vast majority of authors publish fragmentary research results. For instance, N. Pantsyreva (2019) reports that one breeding pig with a litter of 20-24 piglets (weighing up to 30 kg) produces about 14.5 kg of manure per day. A fattening pig with a live weight of 30-110 kg produces an average of 4.5 kg. Up to 65 m^3 of biogas can be produced from a tonne of dry matter of pig manure. According to M. Linnuk and B. Ruban (2011), on farms and complexes with hydraulic manure removal, the moisture content of biomass is 95-97%, and in fattening shops it can reach 98-99%.

Biogas is a combustible gas mixture consisting of 50-70% methane (CH_4), which is formed from organic compounds in an anaerobic microbiological process. Biogas also contains 30-40% carbon dioxide (CO_2) and small amounts of hydrogen sulphide (H_2S), ammonia (NH_3), hydrogen (H_2) and carbon monoxide (CO) (Teng *et al.*, 2022). Biogas is a versatile renewable energy source, as it is suitable for electricity and heat production. To produce biogas in industrial pork production, it is advisable to use by-products with a moisture content of 90-92%. However, the moisture content of wastewater at pig farms can reach 97-98%. Even when pigs are kept on a slotted floor with baths, the wastewater has a moisture content of 95-97%. Therefore, the use of conventional biogas production technologies in industrial pork production leads to high capital investment and operating costs (Table 3) due to, for instance, suboptimal parameters of the fermentation effluent.

***Table 3**. Main indicators of biogas production technologies for industrial pork production ZORG and BIOTHANE*

Indicators	ZORG (Germany)	BIOTHANE (Netherlands)
Process duration, days	30	1
Bioreactor volume, m^3	3,600	3,000
Number of bioreactors, pcs./volume	9/400	3/1000
Volume of wastewater for treatment, m^3	945	945
Process temperature, °C	35/55	35

***Source**: authors' development based on technical data from biogas unit manufacturers*

Upon analysing the practices of implementing the biogas units (based on the technology and equipment of BTG, the Netherlands) by the "Agro-Oven" company on a farm with a population of 14,000 pigs, Yu. Matveev and G. Geletukha (2004) found that the construction costs amounted to USD 413.3 thous. Two methane tanks with a volume of 1,000 m^3 each were built to process 80 t of manure per day. The average fermentation time is 25 days. Practical experience has shown that wastewater with a moisture content of 97-98% can be subjected to the fermentation process. At the same time, the amount of dry matter in the fermentation substrate was increased to only 6-7%, which was achieved through the use of recycled materials. According to M. Lyubin *et al.* (2011), the best results of fermentation of fermentable raw materials are achieved at 30-32°C and humidity of 90-95%. As reported by T.L.I. Vergote *et al.* (2020), the dry matter content of pig manure in commercially managed pigs is usually less than 10%.

One of the producers of biogas units, the Public Foundation "Fluid" (n.d.), also believes that the composition of feedstocks affects biogas production. The moisture content of the raw materials loaded into the biogas unit must be at least 85% in winter and 92% in summer. If pig manure alone is used, the cycle will take 10-12 days, and if the liquid manure is optimised by adding plant material, the time required for fermentation will increase to 40 days or more. This approach will increase the required volume of digesters, which will lead to a considerable increase in the cost of equipment. It is estimated that the price increase will be about 4.4-6.7 times. Obtaining the optimum moisture content of the methane digestion substrate by thickening allows reducing capital investments in the construction of biogas units. This coincides with the data provided by the authors of the study in Table 1. According to H.V. Zhuk (2022), the introduction of innovative technologies developed, among other things, at the Gas Institute of the National Academy of Sciences of Ukraine will allow for the stable production of 500 mln m^3 of methane annually. L. Sakun *et al.* (2020) report that most biogas units pay off in 4-7 years, and therefore government support in the form of guaranteed purchases of energy from bioenergy facilities is economically beneficial for investors.

Thus, the use of pig by-products for biogas generation is a promising way to increase the efficiency of the industry, reduce production costs, reduce the amount of land for manure storage, and improve the environment. The proposed approach also reduces the cost of wastewater treatment.

CONCLUSIONS

It was found that in the production of pork at the Hlobinskyi Pig Farm LLC, Poltava region, using a concentrate feeding type and litterless pig housing technology, the outgoing effluent has a moisture content of

96.94±0.18%. Settling of the initial wastewater with a moisture content of 96.94±0.18% produces a sediment with a moisture content of 91.23±0.25% and a liquid fraction with a moisture content of 98.86±0.42%. The organic matter in the sediment extracted from the effluent was about 87%. It was shown that the separation of the initial wastewater on a filter press produces a liquid fraction with a moisture content of 98.73±0.12%. When the liquid fraction obtained during the separation is settled, a precipitate with a moisture content of 92.57±0.47% and a liquid fraction with a moisture content of 98.49±0.29% are formed.

A variant of the scheme of the process of methane fermentation of the initial wastewater in industrial pork production has been developed, ensuring a reduction in construction and operation costs for the generation of renewable energy sources (biogas). The technological process includes centrifugal and gravity separation of the initial wastewater into fractions (sediment and liquid fraction), gravity thickening of the sediment obtained during centrifugal and gravity separation and periodic discharge of the thickened sediment for dosing when it is fed to methane digestion to produce biogas. When biogas is used in a generator, electricity and heat are produced. Equations are presented that allow determining the volume of sediment and subsequently the volume of digesters based on factual data on the outgoing effluent, considering the digestion modes.

Evaluation of the proposed technology of wastewater treatment for use at a complex for industrial production of pork with the production of renewable energy sources suggests that the use of the proposed technology will reduce capital investments by about 30% and obtain an annual economic effect from the implementation of the proposed technology in the amount of UAH 1 mln 255 thous. Based on a multicriteria analysis, it was found that the proposed biogas production technology has a substantial advantage in terms of the complex indicator of efficiency of each of the alternative options $N(C_k)$ compared to the ideal one. For this technology, the objective function is the smallest according to the criteria considered and amounts to 0.1672, while the objective function of the baseline technology is 1.9 times worse. Further work on the use of livestock by-products for resource-saving biogas production in industrial pork production is aimed at implementing and investigating the proposed approaches in production conditions.

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CONFLICT OF INTERESTS

The authors of this study declare no conflict of interest.

REFERENCES

[1] Achinas, S., & Euverink, G.J.W. (2020). Rambling Facets of manure-based biogas production in Europe: A briefing. *Renewable and Sustainable Energy Reviews*, 119, article number 109566. doi: 10.1016/j.rser.2019.109566.

[2] Burg, V., Bowman, G., Haubensak, M., Baier, U., & Thees, O. (2018). Valorization of an untapped resource: Energy and greenhouse gas emissions benefits of converting manure to biogas through anaerobic digestion. *Resources, Conservation and Recycling*, 136, 53-62. doi: 10.1016/j.resconrec.2018.04.004.

[3] Dabirian, E., Hajipour, A., Mehrizi, A., Karaman, C., Karimi, F., Loke-Show, P., & Karaman, O. (2023). Nanoparticles application on fuel production from biological resources: A review. *Fuel*, 331(1), article number 125682. doi: 10.1016/j.fuel.2022.125682.

[4] Doronin, A. (2019). The potential of bigas production in the field of animals of Ukraine. *Food Resources*, 12, 202-209. doi: 10.31073/foodresources2019-12-21.

[5] DSTU 46-012-2000. (2001). *Agricultural machinery. Methods of economic evaluation of equipment for animal husbandry*. Retrieved from http://www.leonorm.lviv.ua/DG/2008/DSTU_2.HTM.

[6] DSTU ISO 5984:2004. (2006). *Animal feeding stuffs. Determination of crude ash*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=89455.

[7] DSTU ISO 6496:2005. (2006). *Animal feeding stuffs. Determination of moisture and other volatile matter content.* Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=86445.

[8] DSTU ISO 6865:2004. (2006). *Animal feeding stuffs. Determination of crude fibre content. Method with intermediate filtration*. Retrieved form https://online.budstandart.com/ua/catalog/doc-page?id_doc=91087.

[9] Kaletnik, G.M., & Honcharuk, I.V. (2020). Economic calculations of the potential of renewable bioenergy production in formation of energy independence of the agro-industrial complex. *Ekonomika APK*, 27(9), 6-16. doi: 10.32317/2221-1055.202009006.

[10] Kovalev, N.G., Kovalenko, V.P., Shevtsov, H.G., & Sagaidak, O.N. (1983). *Methodological recommendations for calculation and optimization of liquid manure fractionation systems*. Zernograd.

[11] Li, G., Hu, R., Wang, N., Yang, T., Xu, F., Li, J., Wu, J., Huang, Z., Pan, M., & Lyu, T. (2022). Cultivation of microalgae in adjusted wastewater to enhance biofuel production and reduce environmental impact: Pyrolysis performances and life cycle assessment. *Journal of Cleaner Production,* 355, article number 131768. doi: 10.1016/j.jclepro.2022.131768.

[12] Linnuk, M., & Ruban, B. (2011). The ways of improvement of technologies and technical means for obtaining organic fertilizer. *Proceedings TSATU*, 11(5), 10-16.
[13] Lutkovska, S., & Zelenchuk, N. (2023). Assessment of the potential of biogas production by personal peasant farms. *Economic Bulletin of NTUU "Kyiv Polytechnical Institute",* 25, 15-20. doi: 10.20535/2307-5651.25.2023.278409.
[14] Lyubin, M.V., Tokarchuk, O.A., Lyubyn, V.S., & Smalkivskyi, S.V. (2011). Analysis, classification and use of simple biogas plants. *Collection of Scientific Works of the Vinnytsia National Agrarian University. Series: Technical Sciences*, 8, 69-77.
[15] Matveev, Yu., & Geletukha, G. (2004). Biogas plant: Ukrainian experience. *Green Energy*, 1, 4-6.
[16] Pantsyreva, H.V. (2019) Technological aspects of biogas production from organic raw materials. *Bulletin of the Kharkiv National Technical University of Agriculture,* 199, 276-290.
[17] Piskun, N.V., & Piskun, V.I. (2010). Patent utility model No. 52109 Ukraine, IPC C02F 11/04. Wastewater treatment method/No. u201002515.
[18] Piskun, V.I., Yatsenko, Yu.V., & Yatsenko, Yu.Yu. (2020). The concept of optimization of technological solutions of agricultural production. *Modern Engineering and Innovative Technologies,* 12(1), article number 511. doi: 10.30890/2567-5273.2020-12-01-015.
[19] Pryshliak, N.V. (2021). Evaluation of the efficiency of using individual biogas plants for processing biowaste of peasant farms. *Ekonomika APK,* 28(3), 50-60. doi: 10.32317/2221-1055.202103050.
[20] Public Fund "Fluid". (n.d.) Retrieved from http://www.fluid-biogas.com/?page_id=127.
[21] Sakun, L., Riznichenko, L., & Vielkin, B. (2020). Prospects of biogas market development in Ukraine and abroad. *Economics and Organization of Management,* 1(37), 160-170. doi: 10.31558/2307-2318.2020.1.16.
[22] Skrylnyk, Ye., Kutova, A., & Hetmanenko, V. (2020). Influence of anaerobic fermentation of organic waste to change the content of biogenic elements in the effluent biogas plant. *Bulletin of Agricultural Science,* 98(3), 71-76. doi: 10.31073/agrovisnyk202003-10.
[23] Sukhesh, M.J., & Rao, P.V. (2019). Synergistic effect in anaerobic co-digestion of rice straw and dairy manure – a batch kinetic study. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects,* 41(17), 2145-2156. doi: 10.1080/15567036.2018.1550536.
[24] Teng, J.H., Yang, J., Dou, M.Y., Zou, S., Feng, Q., Li, H.M., & Huang, F.C. (2022). Research progress of biogas decarbonization. *IOP Conference Series: Earth and Environmental Science*, 1011, article number 012033. doi: 10.1088/1755-1315/1011/1/012033.
[25] Turovsky, I.S. (1982). *Treatment of sewage sludge*. m.: Stroyizdat.
[26] Vergote, T.L.I., De Dobbelaere, A.E.J., Willems, B., Leenknegt, J., Buysse, J., Volcke, E.I.P., & Meers, E. (2020). Stability of thermophilic pig manure mono-digestion: Effect of thermal pre-treatment and separation. *Frontiers in Energy Research*, 8, article number 40. doi: 10.3389/fenrg.2020.00040.
[27] Yurchuk, N. (2018). Modelling assessment the of biogas plants competitiveness in the energy supply system of rural areas. *Efficient Economy,* 11. doi: 10.32702/2307-2105-2018.11.68.
[28] Zhang, J., Wang, Z., Lu, T., Liu, J., Wang, Y., Shen, P., & Wei, Y. (2019). Response and mechanisms of the performance and fate of antibiotic resistance genes to nano-magnetite during anaerobic digestion of swine manure. *Journal of Hazardous Materials,* 366, 192-201. doi: 10.1016/j.jhazmat.2018.11.106.
[29] Zhuk, H.V. (2022). Prospects for the production of alternative automotive fuel in Ukraine. *Bulletin of the National Academy of Sciences of Ukraine*, 8, 19-24. doi: 10.15407/visn2022.08.019.

Використання побічних продуктів тваринництва для ресурсозберігаючого отримання біогазу за промислового виробництва свинини

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Анотація. Сучасні енергетичні системи є складними багатокомпонентними системами, що використовують механічну, теплову та електричну енергію. У міру скорочення запасу викопного палива інтерес до відновлюваних джерел енергії повсюдно збільшується, що актуалізує дослідження технологій отримання біогазу. Метою дослідження було оцінити технологічні підходи для зниження ресурсовитрат за отримання відновлюваних джерел енергії з органічних відходів (гною) свинарських комплексів. В роботі було використано бібліографічний метод дослідження, лабораторний метод, біохімічні методи (визначення вмісту хімічного складу гною та стоків), статистичний, математичний (розрахунок економічної ефективності), метод багатокритеріального аналізу, аналітичний метод. На підставі проведених досліджень розроблено ресурсозберігаючу технологію підготовки стоків до використання з отримання відновлюваної енергії за промислового виробництва свинини, з забезпеченням зменшення капітальних та експлуатаційних витрат при генерації біогазу. Встановлено, що при відстоюванні вихідних стоків вологістю 96,94±0,18 % утворюється осад вологістю 91,23±0,25 % та рідка фракція вологістю 98,86±0,42 %. Одночасно, органічна речовина в осаді, який виділено з вихідних стоків, становить біля 87 %, а в рідкій фракції – біля 98 % від сухої речовини. Технологічний процес включає: відцентрово-гравітаційне розділення вихідних стоків на фракції (осад та рідку фракцію), гравітаційне згущення осаду його дозування при подачі для метанового зброджуванням із одержанням біогазу. Показано, що застосування запропонованих підходів дозволяє знизити капітальні вкладення біля 30 %. На основі багатокритеріального аналізу встановлено, що за комплексним показником ефективності кожного із розглянутих варіантів $N(C_k)$ у порівнянні з ідеалізованим, запропонована технологія отримання біогазу має значну перевагу. Для неї цільова функція за розглянутими критеріями є найменшою і становить 0,1672 при тому, що цільова функція технології базового варіанту гірша в 1,9 раза. Результати проведених наукових досліджень по використанню побічних продуктів тваринництва для ресурсозберігаючого отримання біогазу планується використовувати на комплексах і фермах з виробництва свинини

Ключові слова: відновлювані джерела енергії; біоенергетика; стоки; технологія; осад; ресурсозбереження, капітальні вкладення