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EFFECTIVENESS OF METHANE FERMENTATION OF VIRGINIA FANPETALS (*Sida hermaphrodita* Rusby) UNDER MESOPHILIC CONDITIONS

EFEKTYWNOŚĆ PROCESU FERMENTACJI METANOWEJ ŚLAZOWCA PENSYLWAŃSKIEGO (*Sida hermaphrodita* Rusby) W WARUNKACH MEZOFILOWYCH

Abstract: This study was aimed at determining the technological effectiveness of methane fermentation process of plant biomass from Virginia fanpetals (*Sida hermaphrodita* Rusby) in continuous reactors at a temperature of 37 ^{o}C. The experiment was divided into four experimental series differing in the feeding of reactor's volume with a load of *organic dry matter* in the range of 1.0 kg o.d.m./m^3 · d to 4.0 kg o.d.m./m^3 · d. The highest technological effectiveness, including the quantity and qualitative composition of the biogas produced, was reached at substrate loading range of 1.0 kg o.d.m./m^3 · d to 2.0 kg o.d.m./m^3 · d. The reactors' loading with the higher feedstocks of biomass resulted in diminished effects of the fermentation process.

Keywords: virginia fanpetals, methane fermentation, biogas, energetic biomass

Introduction

In the Member States of the EU, including Poland, a rapid advance is being observed in technologies that enable the practical exploitation of renewable energy sources. One of the key elements of a system based on pure energy is the utilization of biomass, including plants that originate from dedicated energetic crops. Taking into account the currently applied technical and technological solutions for biomass processing, including combustion, gasification, and pyrolysis, a very prospective solution in this respect is the process of methane fermentation. The outcome of this technology is the production of biogas with a high concentration of methane that may be exploited in production processes of electric energy and heat [1].

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One of the restrictions to the extensive application of agricultural gas-works systems is the availability and price of organic substrate which is a feed to bioreactors. Very often, biogas is produced from biodegradable organic wastes originating from the municipal, industrial and agricultural sectors. A number of installations have been operating based on slurry, sewage sludges, wastewaters from the food industry or the organic fraction of municipal wastes. Nevertheless, the quantity of those wastes is not equivalent to the demand for organic substrate and therefore, it is necessary to seek for corresponding alternative amongst energetic crops. The greatest success so far has been achieved from maize silage fermentation, however other plants with a similar energetic potential are still being searched after [2–4].

Biomass Research and the intensive farming of trees, herbaceous plants and aquatic species indicate the specific development. Some of these species appear to be economically viable as energy crops. Commercialization of biomass and waste incineration systems are becoming more popular as a potential replacement of conventional energy sources [2–4].

This study was aimed at determining the technological effectiveness of methane fermentation process of plant biomass from Virginia fanpetals (*Sida hermaphrodita* Rusby) in continuous reactors in terms of the volume of biogas produced and its methane content.

Materials and methods

The experiment was conducted at the Department of Environmental Protection Engineering, University of Warmia and Mazury in Olsztyn. The plant material used in the process of methane fermentation was fresh, pretreated (mechanically disintegrated) biomass of Virginia fanpetals (*Sida hermaphrodita* Rusby). The basic characteristics of the plant substrate was provided in Table 1.

Table 1

Characteristics of biomass applied in the experiment

Parameter	Unit	Virginia fanpetals
Dry matter	mg/g fresh weight	449.0
Mineral matter	mg/g fresh weight	61.4
Organic matter	mg/g fresh weight	337.6

In the experiment, the inoculum to be used in model anaerobic reactors originated from fermentation tanks of an agricultural gas-works fermenting swine slurry and maize silage. The characteristics of the anaerobic sludge applied was presented in Table 2.

The experiment was divided into four experimental series differing in the feeding of reactor's volume with a load of organic dry matter:

Series I – 1.0 kg o.d.m./$m^3 \cdot$ d,
Series II – 2.0 kg o.d.m./$m^3 \cdot$ d,
Series III – 3.0 kg o.d.m./$m^3 \cdot$ d,
Series IV – 4.0 kg o.d.m./$m^3 \cdot$ d.

Table 2

Characteristics of anaerobic sludge applied in the experiment

Parameter	Unit	Min. value	Max. value	Mean	Standard deviation
pH	—	7.89	8.08	7.98	0.10
Hydration	[%]	96.40	96.80	96.60	0.20
Dry matter	[%]	3.20	3.60	3.40	0.20
Volatile substances	[% d.m.]	47.32	51.04	49.18	2.63
Ash	[% d.m.]	48.96	52.68	50.82	1.86
CST	[s]	466	479	472.5	9.2

In all the series, the tested plant biomass was prehomogenized using a device for mechanical destruction of organic substrate structures and thereafter, hydrated to a respective level with tap water. The degree of hydration resulted from the adopted technological solutions of the experiment, namely:

– hydraulic retention time: 40 days,

– the feeding of reactor's tank with organic substrate load: in the range of 1.0 to 4.0 kg o.d.m./$m^3 \cdot$ d,

– temperature of the process: 37 ^{o}C.

The basic experimental data of the conducted study are collected in Table 3.

Table 3

Study design under dynamic conditions

Experimental series	Reactor's volume [dm^3]	Expected feedstock of o.d.m. [g o.d.m./$dm^3 \cdot$ d]	Biomass quantity [g/d]	Dry matter quantity [g/d]	Organic dry matter quantity [g/d]	Hydration applied [%]	Volume of hydrated biomass [cm^3/d]
Series I	4.0	1.0	10.3	4.83	4.03	95.17	100
Series II	4.0	2.0	20.6	9.66	8.06	90.34	100
Series III	4.0	3.0	30.9	14.49	12.09	85.51	100
Series IV	4.0	4.0	41.2	19.32	16.12	80.68	100

The experiment was carried out with continuous-stirred anaerobic reactors with the active volume of 4.0 dm^3 (total volume of 5.0 dm^3). The initial concentration of anaerobic sludge in the exploited anaerobic tanks was kept at the level of 3.40 g d.m./dm^3. The characteristics of the sludge applied in the experiment was presented in Table 2. The reactors were fixed in a thermo-isolated tank equipped in a heating system and a hot air circulation system (Fig. 1). The reactors were additionally equipped in temperature sensors, stirring system, substrate feeding system, process products discharge system and system for biogas quantity measurements and biogas analysis. In the exploited reactors, the time of heating was remaining in the function of temperature. As a result of heating system operation, the temperature inside the exploited anaerobic reactors was increasing. Following the experimental assumptions, the study was

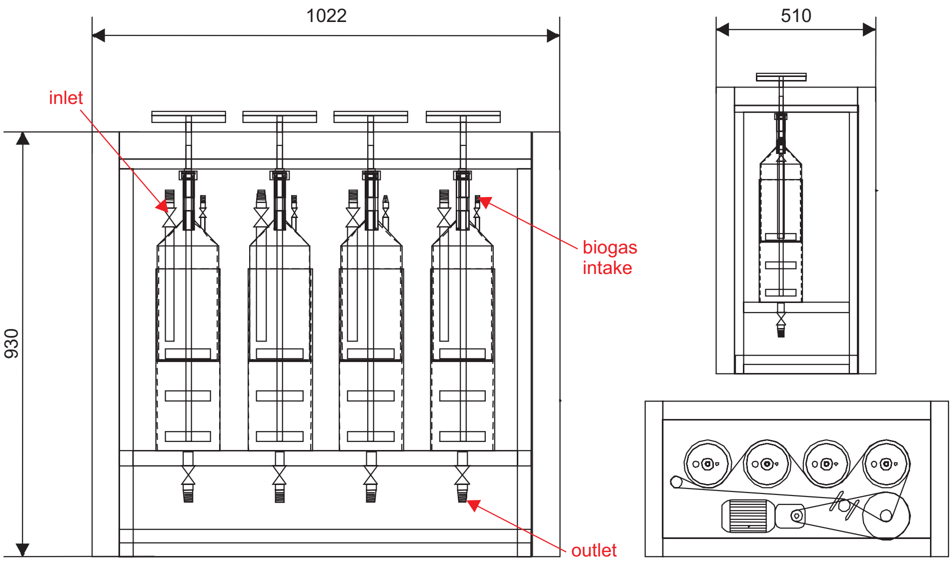

Fig. 1. Scheme of experimental installation used for analyses under dynamic conditions

conducted at a temperature of 37 °C. The heaters' operation was initiated by a thermal controller in direct response to indications of the temperature sensors located inside the exploited model reactor. Once the temperature dropped below the assumed value of 37 °C, the heating systems were initiated. Once the temperature sensor fixed inside the reactor displayed the accurate value of temperature, the supply of heaters was cut off automatically. The hysteresis was adopted as ±1 °C.

The substrate's hydraulic retention time in the reactor reached 40 days in all experimental variants. The loading with a feedstock of organic compounds ranged from 1.0 kg o.d.m./m^3 · d to 4.0 kg o.d.m./m^3 · d. Once a day, 100 cm^3 of fermented substrate were collected and subjected to physicochemical analyses. With the same frequency, the tested organic substrate (Virginia fanpetals, sorghum silage) was fed to the technological system in the quantity of 100 cm^3/day. At the moment of reactor's feeding, the flow in the valve discharging biogas was cut off in order to eliminate adulteration in the quantity of biogas produced.

A temporary or total flow of biogas was measured in a continuous mode using a flowmeter by Allborg SS-Body company. Simultaneously, the qualitative composition of biogas was evaluated daily by means of an Lxi analyzer by GasData company. The inflow and outflow of the substrate was always below the level of sludge in the reactor, so as to avoid introduction of accidental air into the reactor. To this end, the inlet was additionally equipped in a gate. The applied method of reactor's content stirring was based on vertical stirrers operating with the yield of 50 rpm.

The study was focused on determining the effectiveness of biogas production as affected by the technological variant applied. The conducted analyses involved the determination of methane content in gaseous metabolites of anaerobic bacteria as well as effectiveness of biogas production from the plant biomass fed.

Results

In the course of the experiment, the effectiveness of biogas production expressed per Mg (ton) of organic matter fed to the technological system was observed to diminish along with the increasing loading of carbonic compounds feedstock. In the first series, in which reactor's loading reached 1.0 kg o.d.m./$m^3 \cdot d$, the mean quantity of biogas produced accounted for 470 m^3/Mg o.d.m.. This part of the study demonstrated also that a stable level of biogas production effectiveness was achieved after 50 days of technological system exploitation. From the beginning of the experiment, the production of biogas was observed to increase successively from the initial value of *ca* 290 m^3/Mg o.d.m. to *ca* 470 m^3/Mg o.d.m. (Fig. 2). The content of methane in biogas produced ranged from 65 % at the beginning of the experiment to the value of 47 % reached after 50 days of feeding the model fermentation tanks (Fig. 3). The mean yield of methane production in that part of the study accounted for *ca* 230 m^3CH_4/Mg o.d.m. (Fig. 5).

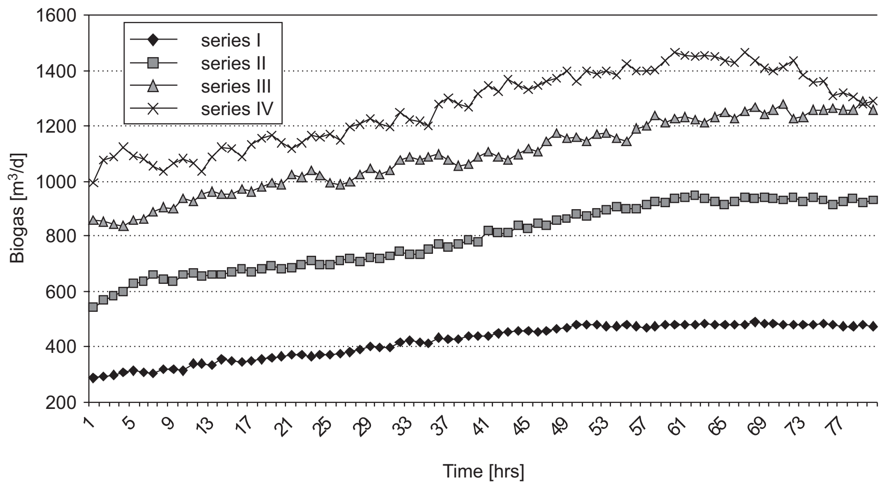

Fig. 2. The efficiency of biogas per Mg (ton) of input to the technological system of Sida organic matter depending on the experiment series

In the second experimental series, in which the system was fed with 2.0 kg o.d.m./$m^3 \cdot d$ of organic substrate, the production of biogas ranged from 280 m^3/Mg o.d.m. at the beginning of the experimental cycle to 460 m^3/Mg o.d.m. at the end of the experiment. This effectiveness of the fermentation process enabled biogas production at a level of *ca* 920 m^3/d (Fig. 2). The ultimate effectiveness of biogas production was achieved after *ca* 60 days of the process. It was found that in this experimental series, the content of methane in the gaseous metabolites of fermentation bacteria was comparable with the results noted in the first series of this stage of the study (Fig. 3). The daily yield of methane production was at a level of 450 m^3CH_4/d (Fig. 4).

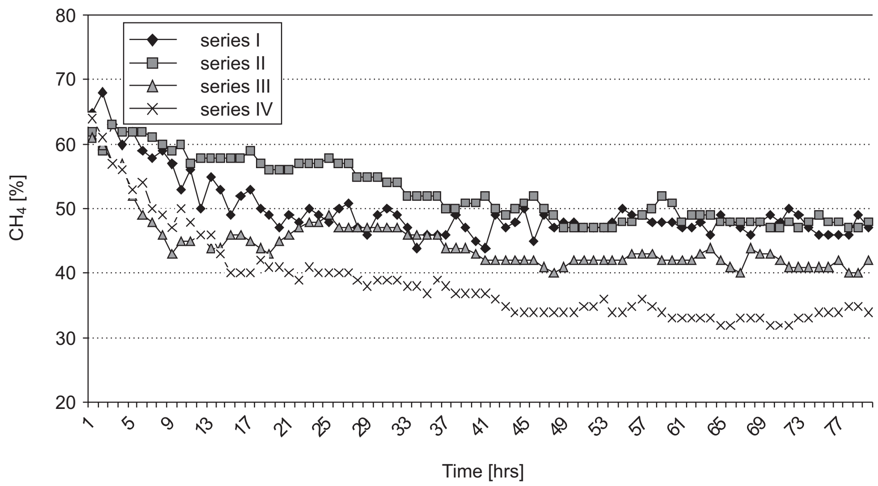

Fig. 3. The content of methane in the biogas produced, depending on the series of experiments

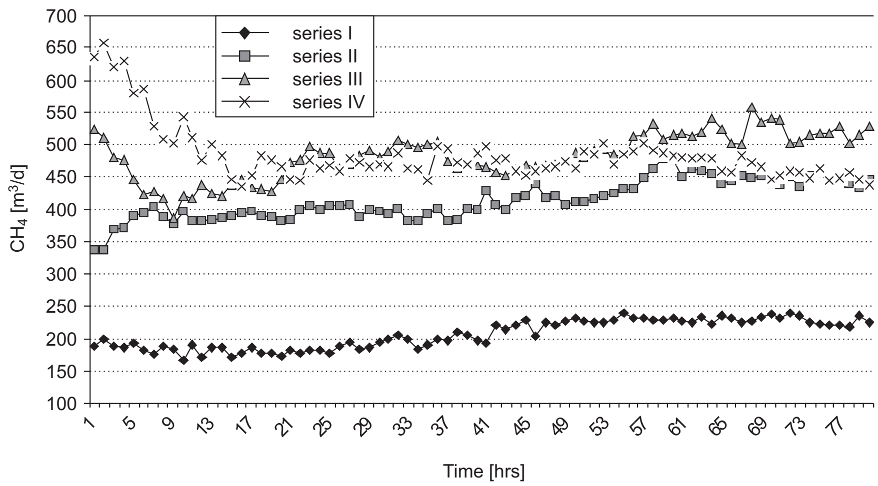

Fig. 4. The efficiency of biogas production per day of biomass of Sida, depending on the experiment series

The lower final effects including the intensity of biogas production and its qualitative composition were observed when the tank's loading with a feedstock of organic compounds reached 3.0 kg o.d.m./$m^3 \cdot$ d. The application of this technological variant was demonstrated to assure biogas production at a level of *ca* 420 m^3/Mg o.d.m., which resulted in reaching the daily production of sewage gas at the level of 1260 m^3/d (Fig. 2). The content of methane in the gaseous phase was negligibly over 40 % (Fig. 3).

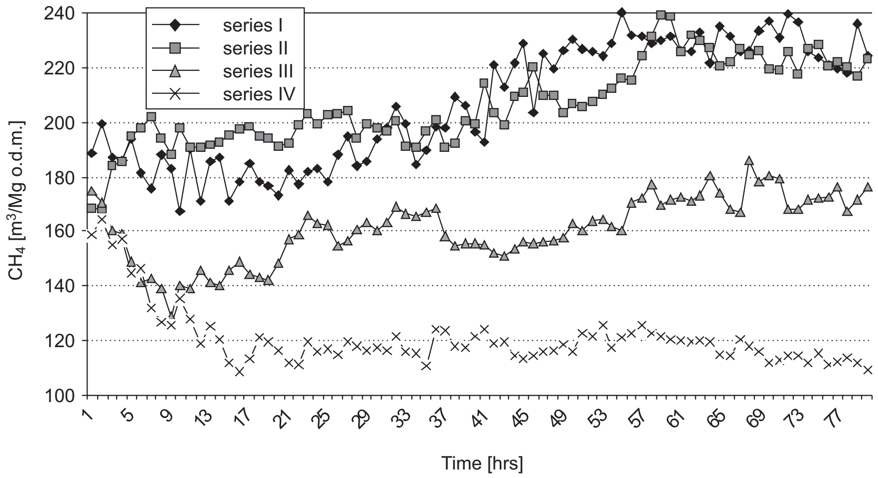

Fig. 5. The efficiency of production of methane per tonne of input to the technological system of Sida organic matter depending on the experiment series

A remarkably lower effectiveness of sewage gas production was obtained in the fourth series with the model reactor's loading of 4.0 kg o.d.m./m^3 · d. In this technological solution, the final effects of methane fermentation were as follows: effectiveness of biogas production at the end of the experiment – 320 m^3/Mg o.d.m., and methane concentration in the gaseous phase – 35 %. In this part of the experiment, the daily effectiveness of methane production accounted for *ca* 450 m^3CH_4/d and for as little as around 110 m^3CH_4/Mg o.d.m. (Fig. 4, 5).

Discussion

In many publications are presented experiments in which the authors present the possibility of processing of biomass energy with different characteristics in the process of methane fermentation. In one of the experiments were used corn stalks, oat straw and wheat straw. Tests were conducted under anaerobic conditions at 37 ^oC. Biomass used has undergone a process of anaerobic digestion of manure and swine. The best results were achieved for corn stalks where the amount of produced biogas was 12 dm^3/d gives the percentage of methane in the biogas 68 %. For the oat straw and biogas production yield obtained oscillate around the level of 9 dm^3/d at 57 % methane content. The results achieved in the fermentation of Sida, which recorded the best performance of biogas of approximately 650 m^3/d at a load of 1.0 kg · d smo/m^3 during the first 15 days of process [5].

Weiland presents the possibility of obtaining biogas from plants such as ryegrass, clover or alfalfa. The amount of harvested biogas ranges from 300 to 400 m^3CH_4/Mg of tar depending on technological solutions and the type of raw material. In the case of an investigation to determine the efficiency of biogas production values are oscillating at a level lower than 230 m^3CH_4/Mg of tar in the first series with a load of 1.0 kg · smo/m^3 [6].

Dinuccio fermenting biomass in the form of corn, straw, rice, grapes, whether obtained in the biogas methane content at 50–60 %. The content of methane obtained from Sida as a result of anaerobic fermentation in this study ranges on average from 30 to nearly 70 % taking into account the whole experiment. However, focusing on the series I and II, which gave the best quality parameters of biogas can be compared with results obtained by the earlier article [7].

Zheng and others used in the process of anaerobic digestion of two types namely wild rygrass and Leymus triticoides. The use of hydraulic retention time of 33 days obtained 251 m^3 of biogas/Mg tar methane content of 65 % [8]. These figures are lower than those obtained by the authors in the fermentation process Sida, where the load of 1.0 kg · d smo/dm^3 reported productivity 470 m^3/Mg of tar the highest methane content of 65 % and its average production rate was very comparable and amounted to 230 m^3CH_4/Mg tar.

Fermentation of leafy grass (Alterniflora Spartina) at 35 ^oC and retention time of 60 days allowed to obtain 80 % efficiency of biogas. At the end of the experiment the total biogas yield was 358 dm^3/kg^{-1} solids. The content of methane has increased from 53 to 61 % from 3 to 13 days to the end of the process and remained practically at the level of 62 % [9].

Others of the authors took into account the corn, cereals (triticale, rye and wheat) and grass. Plants were grown on 60 ha and the parameters that were determined in the experiment were the biogas and methane yield, quality, biogas, biomass processing and energy, biogas and coal for energy. Duration of the study was 6 weeks, during which time biogas was tested 10 times, capacity was 1 dm^3 chambers and the temperature of process 38 ^oC. Research has shown failed to reach an average methane yield of 398 dm^3 CH_4/kg^{-1} corn solids. In the case of mixtures of cereals were the values from 140 to 343 dm^3 CH_4/kg^{-1} solids. However, for grass, this value was in the range 190–392 dm^3 CH_4/kg^{-1} [10].

Conclusions

The study demonstrated that the achieved technological effects including the quantity of biogas produced and its methane content were directly affected by the applied loading of the anaerobic tank with a feedstock of organic compounds. It is especially tangible in the case of biogas production yield and in respect of the substrate organic matter fed to the tank. The highest level of methane production expressed per Mg of organic matter fed to the reactor, *ie* 240 m^3CH_4/Mg o.d.m., was noted with the loading range of 1.0 kg o.d.m. /m^3 · d to 2.0 kg o.d.m./m^3 · d. The application of the higher values of this technological parameter affected directly a decrease in methane production. Analogous results were obtained for the percentage content of methane in biogas produced. Values approximating 50 % were achieved in the first and second experimental series. In the case of the higher loading of the tank with the feedstock of organic matter, a significant decrease was observed in the content of methane in biogas.

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References

[1] Jingura RM, Matengaifa R. Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe. Renew Sustainab Energy Rev. 2009;13:1116-1120. DOI: 10.1016/j.rser.2007.06.015.

[2] Howaniec N, Smolinski A. Steam gasification of energy crops of high cultivation potential in Poland to hydrogen-rich gas. Inter J Hydro Energy. 2011;36:2038-2043. DOI: 10.1016/j.ijhydene.2010.11.049.

[3] Venkateswara RP, Baral SS, Dey R, Mutnuri S. Biogas generation potential by anaerobic digestion for sustainable energy development in India. Renew Sustainab Energy Rev. 2010;14:2086-2094. DOI: 10.1016/j.rser.2010.03.031.

[4] Hoogwijka M, Faaij A, Broek R, Berndes G, Gielen D, Turkenburg W. Exploration of the ranges of the global potential of biomass for energy. Biomass Bioenerg. 2003;25:119-133. DOI: 10.1016/S0961-9534(02)00191-5.

[5] Wua X, Yao W, Zhu J, Miller C. Biogas and CH_4 productivity by co-digesting swine manure with three crop residues as an external carbon source. Bioresour Technol. 2010;101:4042-4047. DOI: 10.1016/j.biortech.2010.01.052.

[6] Weiland P. Production and Energetic Use of Biogas from Energy Crops and Wastes in Germany. Appl Biochem Biotechnol. 2003;109:263-274.

[7] Dinuccio E, Balsari P, Gioelli F, Menardo S. Evaluation of the biogas productivity potential of some Italian agro-industrial biomasses. Bioresour Technol. 2010;101:3780-3783. DOI:10.1016/j.biortech.2009.12.113.

[8] Zheng Y, Pan Z, Zhang R, El-Mashad HM, Pan J, Jenkins BM. Anaerobic digestion of saline creeping wild ryegrass for biogas production and pretreatment of particleboard material. Bioresour Technol. 2009;100:1582-1588. DOI: 10.1016/j.biortech.2008.08.048.

[9] Yang S, Li J, Zheng Z, Meng Z. Characterization of Spartina alterniflora as feedstock for anaerobic digestion. Biomass and Bioener. 2009;33:597-602. DOI: 10.1016/j.biombioe.2008.09.007.

[10] Amon T, Amon B, Kryvoruchko V, Machmuller A, Hopfner-Sixt K, Bodiroza V, Hrbek R, Friedel J, Potsch E, Wagentristl H, Schreiner M, Zollitsch W. Methane production through anaerobic digestion of various energy crops grown in sustainable crop rotations. Bioresour Technol. 2007;98:3204-3212. DOI:10.1016/j.biortech.2006.07.007.

EFEKTYWNOŚĆ PROCESU FERMENTACJI METANOWEJ ŚLAZOWCA PENSYLWAŃSKIEGO (*Sida hermaphrodita* Rusby) W WARUNKACH MEZOFILOWYCH

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Abstrakt: Celem badań było określenie efektywności technologicznej procesu fermentacji metanowej biomasy roślinnej ślazowca pensylwańskiego (*Sida hermaphrodita* Rusby) w reaktorach o pracy ciągłej w temperaturze 37 °C. Eksperyment podzielono na cztery serie badawcze różniące się wielkością obciążenia objętości reaktora ładunkiem *suchej masy organicznej* w zakresie od 1,0 kg s.m.o./m^3 · d do 4,0 kg s.m.o./m^3 · d. Najwyższe efekty technologiczne związane z ilością oraz składem jakościowym powstającego biogazu obserwowano w zakresie obciążeń od 1,0 kg s.m.o./m^3 · d do 2,0 kg s.m.o./m^3 · d. Wprowadzenie do reaktorów większych ilości biomasy skutkowało obniżeniem uzyskiwanych efektów procesu fermentacji.

Słowa kluczowe: ślazowiec pensylwański, fermentacja metanowa, biogaz, biomasa energetyczna