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TECHNOLOGICAL EFFECTIVENESS OF METHANE FERMENTATION OF PRAIRIE CORDGRASS (*Spartina pectinata*)

EFEKTYWNOŚĆ TECHNOLOGICZNA PROCESU FERMENTACJI METANOWEJ SPARTINY PRERIOWEJ (*Spartina pectinata*)

Abstract: This study was aimed at identifying the feasibility of using prairie cordgrass (*Spartina pectinata*) in processes of methane fermentation. Effectiveness of the anaerobic process including the quantity and composition of biogas produced and reaction kinetics was determined based on respirometric measurements. Fermentation was run under mesophilic conditions at the initial tank loading with a feedstock of organic compounds ranging from 0.5 to 1.5 g o.d.m./dm^3 · d. Experiments were divided into two stages, with plant part being the criterion of division. At stage I, model fermentation tanks were fed the assumed quantities of pre-treated aerial part (roof), whereas at stage II - with the underground part (root) of prairie cordgrass. Before the exact process of anaerobic decomposition, the substrate was subject to mechanical disintegration in a ball grinder. For comparative purposes, maize silage (*Zea mays*) - being the main plant substrate used in agricultural biogas works, was subject to methane fermentation under the same conditions (stage III). The study demonstrated that the effectiveness of the methane fermentation process was directed influenced by the type of substrate tasted. The highest technological effects including biogas production and its qualitative composition were noted in the case of maize silage and the aerial part of prairie cordgrass. Significantly lower effectiveness of production of gaseous metabolites of anaerobes was determined at the stage when the exploited fermentation tanks were fed with biomass of the underground part of test plant. The course and final outcomes of the fermentation process were also directly affected by the applied loading of fermentation tanks with a feedstock of organic matter.

Keywords: *Spartina pectinata*, anaerobic process, biogas, methane fermentation, renewable energy

Introduction

Stimulation of the advance in renewable energy systems involves the development and implementation of economically-justified technological solutions. Examples, applied in the technical scale, are agricultural biogas works that enable organic substrates transformation into biogas. Exploitation of technological systems of this type is, principally, based on plant substrates, maize silage in particular [1, 2]. Contemporarily, the use of maize silage in the process of biogas production is cost-ineffective and, additionally, arouses great controversies linked with increased prices of plant products used for food purposes [3].

A high primary production and a significant energetic potential are typical traits of *Spartina spp.*, occurring mainly in the USA, Canada and China [4, 5]. It overgrows, most of all, coastal and boggy areas where - owing to the root system - it diminishes erosion of coastline and constitutes a natural barrier against surface flows by absorbing contaminants [6]. *Spartina spp.* is applied in practice as feedstuff or as an additive to biofood [7-9].

In Poland, cordgrass is uncommon and so far has not found wider application, except for the use of prairie cordgrass (*Spartina pectinata*) as an ornamental plant. It seems, however, that its high primary biomass production and capability to adapt to extreme

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biotopic conditions may elicit an increased interest in its application in the power industry for biofuels production.

The objective of this study was to determine technological effectiveness of the fermentation process of prairie cordgrass (*Spartina pectinata*) and to characterize biogas production kinetics under static conditions.

Methodology

Experiments aimed at determining the effectiveness of methane fermentation of prairie cordgrass (*Spartina pectinata*) were conducted in model respirometric tanks at a temperature of 35°C, at retention time of 20 days. Anaerobic sludge originating from fermentation tanks of a farm biogas works based on co-fermentation of slurry and maize silage, was used as the inoculum (Table 1).

Table 1

Characteristics of anaerobic sludge used in the experiment

Parameter	Unit	Min. value	Max. value	Mean	Standard deviation
pH	-	7.64	7.95	7.795	0.219
Hydration	[%]	96.45	96.9	96.675	0.318
Dry matter	[%]	3.1	3.55	3.325	0.318
Volatile substances	[% d.m.]	48.23	51.79	50.01	2.517
Ash	[% d.m.]	49.36	53.05	51.205	2.609
CST	[s]	472	481	476.5	6.363

The conducted experiment was divided into three stages. The criterion of division was the type of organic substrate introduced to fermentation tanks: stage I - *Spartina pectinata* (roof), stage II - *Spartina pectinata* (root), and stage III - maize silage. The characteristics of organic substrates were presented in Table 2.

Table 2

Characteristics of plant biomass used in the experiment

Parameter	**Unit**	**Type of plant substrate**					
		Spartina pectinata (root)		**Spartina pectinata (roof)**		**Maize silage**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Total dry matter	[mg/g]	620	4.04	740	4.93	280	5.06
Mineral substances	[mg/g d.m.]	62	3.63	74	2.19	28	2.71
Organic substances	[mg/g d.m.]	558	3.63	666	2.19	252	2.71

Owing to the applied loading of fermentation tanks with a feedstock of organic compounds, each stage was divided into three experimental series: series 1-0.5 g o.d.m./dm^3 · d, series 2-1.0 g o.d.m./dm^3 · d, and series 3-1.5 g o.d.m./dm^3 · d. Before being introduced to model fermentation tanks, the organic substrates used in the experiment were subjected to disintegration in a ball grinder to decrease fraction size and to unify the experimental material. Study design was presented in Table 3.

Table 3

Study design

Type of organic substrate (Stage)	**Series**	**Load [g o.d.m. /dm^3·d]**	**Amount of anaerobic sludge in reaction tanks [cm^3]**
Spartina pectinata (ground part) (I)	1	0.5	200
	2	1.0	
	3	1.5	
Spartina pectinata (roof) (II)	1	0.5	200
	2	1.0	
	3	1.5	
Corn silage (III)	1	0.5	200
	2	1.0	
	3	1.5	

Respirometric kits used in the study enabled: determination of the activity of the process, evaluation of the susceptibility of the tested substrates to degradation process under anaerobic conditions by microflora of activated sludge, as well as quantitative and qualitative characteristics of metabolites of these microorganisms. Deoxidization of tanks and anaerobic conditions were achieved by blowing the tanks through with nitrogen after substrate feeding. A complete measuring system consisted of: reaction tank and measuring-recording unit that was analyzing the value of partial pressure generated in the tank as a result of plant substrate degradation every 24 h. Model reactors were placed in a thermostatic cabinet with hysteresis not exceeding ± 0.5ºC. Two days before the end of measuring period, a 30% potassium base (KOH) was introduced to a special container (carrier) fixed inside the tank. It enabled precipitation of carbon dioxide (CO_2) from the gaseous phase.

In respirometric analyses, computations are based on the equation of perfect gas:

$$n = \frac{p \cdot V}{R \cdot T}$$

where: n - number of moles of gas [mol], p - gas pressure [Pa], V - gas volume [m^3], R - universal gas constant, 8.314 J/mol · K, T - temperature [K].

The content of carbon in the gaseous phase was computed from the following formula:

$$n_{CO_2+CH_4} = \frac{p_1 \cdot V_g}{R \cdot T} \cdot 10^{-4}$$

where: $n_{CO_2+CH_4}$ - number of produced moles of carbon dioxide and methane [mol], p_1 - difference in gas pressure in a measuring vessel at the beginning and at the end of experiment [hPa], V - volume of gaseous phase in the measuring tank [ml], R - gas constant, 8.314 J/mol · K, T - temperature of incubation [K], 10^{-4} - conversion factor: conversion of [Pa] to [hPa] and of [m^3] to [cm^3].

The content of carbon dioxide in the gaseous phase was computed from the following formula:

$$n_{CO_2} = \frac{p_1 \cdot V_g - p_2 \cdot \left(V_g - V_{KOH}\right)}{R \cdot T} \cdot 10^{-4}$$

where: n_{CO_2} - number of produced moles of carbon dioxide [mol], p_2 - p_N - p_{NaOH} [hPa], p_N - total biogas pressure recorded by the measuring system in the reaction tank [hPa], P_{KOH} - pressure of gas after KOH introduction to the tank [hPa], V_{KOH} - volume of KOH solution [cm^3].

The content of methane in the gaseous phase was computed from the following formula:

$$n_{CH_4} = n_{CO_2+CH_4} - n_{CO_2}$$

Respirometric analyses enabled determining also the rate of biogas production process (r) depending on the applied experimental variant. Reaction rate constants (k) were determined based on the achieved experimental data with the method of non-linear regression using Statistica 10.0 software. Iterative method was used where in each iterative step a function is replaced by linear differential relative to determined parameters. The coefficient of conformity φ^2 was adopted as a measure of curve fit (at determined parameters) to experimental data. This coefficient is a ratio of the sum of squares of deviations of values computed based on the determined function from experimental values, to the sum of squares of deviations of experimental values from the mean value. The lower the value of φ^2 coefficient, the better the conformity. At the adopted fitting of the model to experimental points, the coefficient of conformity did not exceed 0.2.

The statistical analysis of results achieved was carried out using STATISTICA 10.0 PL package. The hypothesis on the distribution of each analyzed variable was verified based on W Shapiro-Wilk's test. In order to determine significance of differences between variables, a one-way analysis of variance (ANOVA) was conducted. The homogeneity of variance in groups was determined using the Levene's test. In order to determine the significance of differences between the analyzed variables, use was made of the Tukey's RIR test. In tests, the level of significance was adopted at $\alpha = 0.05$.

Results and discussion

In the first series, the rate of biogas production process reached 68.7 cm^3/d at the reaction rate constant of 0.13 1/d (Fig. 1, Fig. 2). Biogas production in this series accounted for 449 dm^3/kg o.d.m. (Fig. 7), with methane content of biogas reaching 28%. Increasing the load to 1.0 g o.d.m./dm$^3\cdot$d evoked a significant decrease in methane content of biogas to 26% (Fig. 1). The observed rate of biogas production was at a level of 115.89 cm^3/d, and the reaction rate constant reached 0.13 1/d (Fig. 2). The quantity of biogas produced was lower by 15% compared with series 1 (Fig. 1). In the third series, technological effects of the process were the lowest (301.52 dm^3 biogas/kg o.d.m.) (Fig. 7). A 5% decrease was noted in the content of methane in biogas produced (Fig. 1). The reaction rate constant reached 0.17 1/d (Fig. 2).

Chen et al run the process of fermentation and co-fermentation of *Spartina alterniflora* with cattle slurry. Their study demonstrated that the process of anaerobic degradation of cordgrass was characterized by a low yield of biogas production. An alternative to this technological solution was co-fermentation of the plant substrate with cattle slurry. The best results were achieved during substrates fermentation at the ratio: 75% of *S. alterniflora* and 25% of cattle slurry. Methane production reached 176.1 cm^3/g o.d.m., which was higher by 44% than in the case of fermentation of plant biomass only. The content of methane in biogas was twofold higher than in the case of *S. pectinata* fermentation and reached 63% [10].

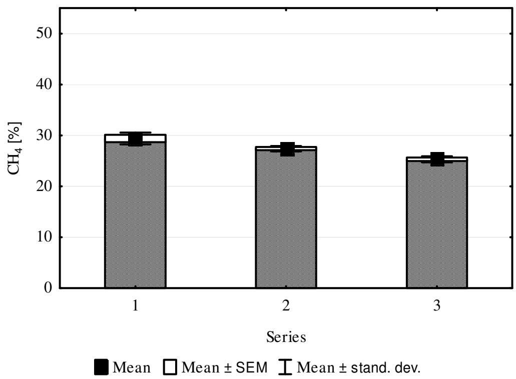

Fig. 1. The methane content in biogas in stage I

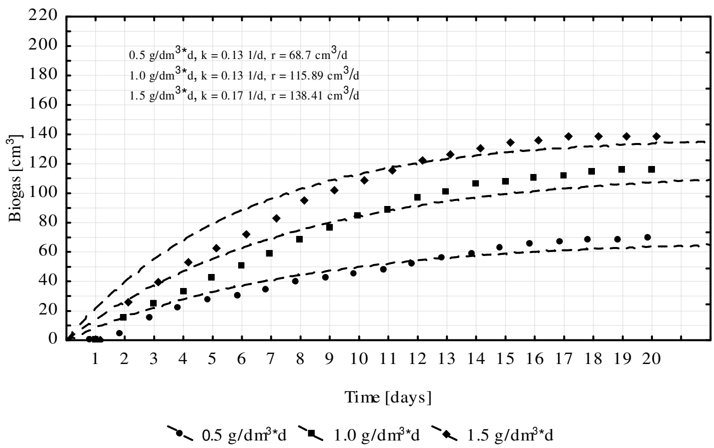

Fig. 2. Biogas production during I stage of experiment

Spartina pectinata is not widely applied in processes of anaerobic fermentation. A significantly greater interest among scientists is expressed for *Spartina alterniflora* owing to its abundant occurrence in the USA and China where it is spreading as an invasive plant especially at coastal and boggy areas [4, 11]. Yang et al conducted methane fermentation of *Spartina alterniflora* under mesophilic conditions at a temperature of 36°C, and at the initial concentration of organic compounds in the test reactor at a level of 6%. It enabled achieving biogas production yield of 358 cm^3/kg o.d.m. The effectiveness of biodegradation after 60 days of the process reached 45%. The content of methane in biogas was increasing successively along with experiment duration from 53 to 62% [12].

Stage II of the study assumed running methane fermentation of the underground part of *S. pectinata*. This stage was distinguished owing to the possibility of nutrients accumulation in *S. pectinata* rhizomes [2]. In each series of this stage, significantly poorer yield of biogas production was observed compared with stage I and stage III of the study. Likewise in the two other stages, the best technological effects of methane fermentation process were recorded in series 1. The percentage content of methane in biogas was higher by 4% on average than in biogas produced from the aerial part of *Spartina pectinata*. A similar dependency was observed in the case of the two other loads applied. The rate of biogas production in the third series accounted for 138.41 cm^3/d, at the reaction rate constant of 0.17 1/d (Figs. 3 and 4) and quantity of biogas produced at a level of 256.07 dm^3/kg o.d.m. (Fig. 7).

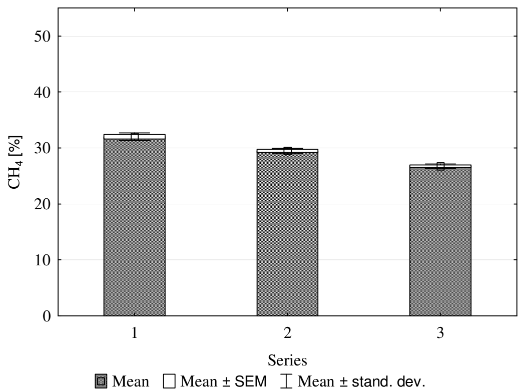

Fig. 3. The methane content in biogas in stage II

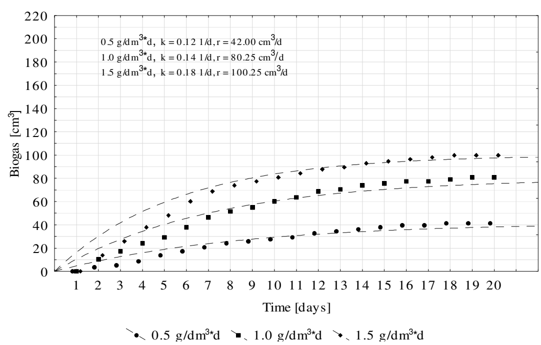

Fig. 4. Biogas production during II stage of experiment

The low effectiveness of the fermentation process noted in this study may be due to the fact that cordgrass is a plant constituted by a lignocellulose complex containing three biopolymers - cellulose, hemicellulose and lignin. During methane fermentation, structure of this type impairs availability of simple compounds to microorganisms which transform these compounds into methane-rich biogas. Nowadays, processes of pre-treatment of lignocellulose substrates are sought after, that would be economically-substantiated and would effectively improve the process of methane fermentation [13-15].

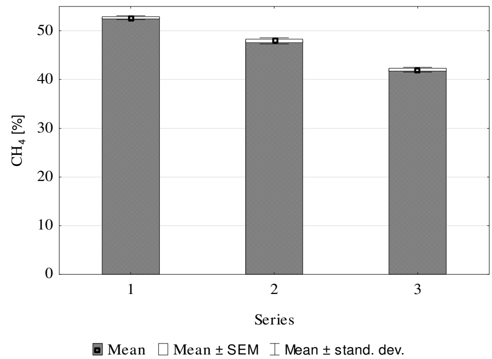

Fig. 5. The methane content in biogas in stage III

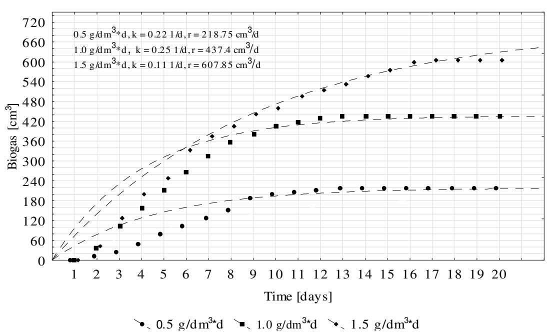

Fig. 6. Biogas production during III stage of experiment

Yang et al in their study demonstrated that co-fermentation of lignocellulose substrates with easily-biodegradable materials may improve the yield of biogas production in anaerobic processes. They carried out processes of *Spartina alterniflora* fermentation and co-fermentation with potatoes in the ratio of 4 : 1 and 6 : 1 of solid organic matter. It turned out that the co-fermentation had a positive effect on the improvement of hemicellulose degradation. In the case of *Spartina alterniflora* fermentation alone, biogas production accounted for 358.5 cm^3/g o.d.m., whereas upon the addition of the second organic substrate - for 433.6 cm^3/g o.d.m. and 460.1 cm^3/g o.d.m. at *Spartina* to potatoes ratio of 4 : 1 and 6 : 1, respectively [16].

In the last stage of the study, model fermentation tanks were fed with maize silage, which allowed to reach the best technological effects. The quantity and composition of biogas achieved during mesophilic fermentation were directly dependent on the applied loading of fermentation tanks with a feedstock of organic compounds. In the first series, when tank loading reached 0.5 g o.d.m./dm^3 · d, the mean methane content of biogas accounted for 53% at a reaction rate of 218.75 cm^3/d and the reaction rate constant of 0.20 dm^3/d (Figs. 5 and 6). Biogas production after 20 days of the experiment reached 607.63 dm^3/kg o.d.m. (Fig. 7). At the twofold higher loading, *ie* 1.0 g o.d.m./dm^3 · d, the quantity of biogas produced was at a comparable level, with a production rate of 437.4 cm^3/d (Fig. 6). In the second series, the maximum percentage content of methane in biogas reached 48% (Fig. 5). The third series of this experimental stage was characterized by the worst qualitative composition of biogas produced, in which methane constituted barely 42%, and by the lowest process yield accounting for 422.1 dm^3/kg o.d.m. (Fig. 7). The rate anaerobic bacteria metabolites production was at a level of 607.86 cm^3/d, at the reaction rate constant of 0.22 dm^3/d (Fig. 6).

Contemporarily, maize constitutes the most frequently applied substrate in the process of organic wastes biogasing owing to its high yield of biogas production [17]. Weiland conducted the process of methane fermentation of many substrates originating from the agricultural sector. Maize silage turned out to be one of the best fermenting materials which - as estimated by the author - allowed achieving biogas yield of 410 m^3 CH_4/Mg o.d.m. [18].

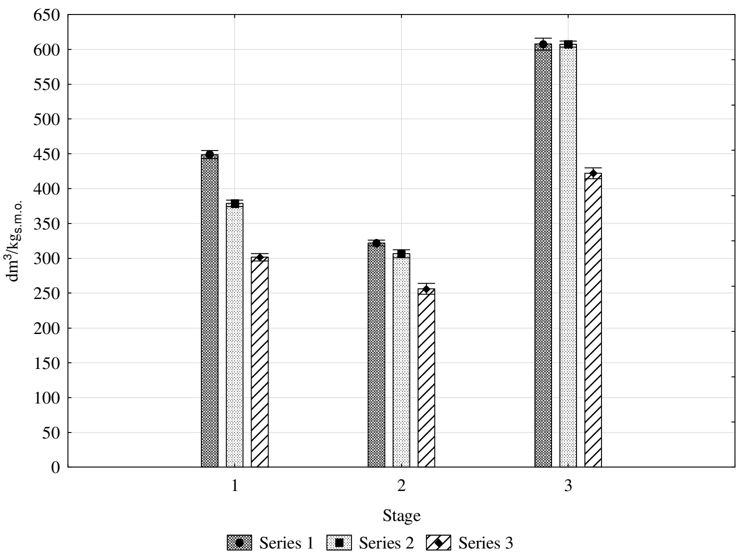

Fig. 7. Biogas production

Conclusions

Investigations aimed at establishing the technological effectiveness of methane fermentation of *Spartina pectinata* enabled determining the feasibility of its application in biogasing processes and biogas productivity of this substrate compared with other energetic plants. Prairie cordgrass exhibited lower susceptibility to the biodegradation process run under anaerobic conditions by microorganisms than maize silage did. The yield of biogasing processes turned out to be significantly affected by the applied loading of fermentation tanks with a feedstock of organic matter. The highest biogas production was determined at reaction tanks' loading with a feedstock of organic compounds reaching 0.5 g o.d.m./dm^3 · d. Increased loading caused a reduction in both biogas production and methane content of biogas. Methane fermentation of the aerial part of the plant substrate enabled achieving the highest production yield of gaseous metabolites of bacteria, even though a slightly higher methane content of biogas was noted in the case of cordgrass roots fermentation.

The conducted study confirms the feasibility of applying *Spartina pectinata* in the biogasing process. Effects achieved indicate that this process may be economically-unjustifiable, because technological effects are by 25 and 50% lower than in the case of maize silage fermentation. *Spartina pectinata* is a plant constituted by a lignocellulose complex, which could impede methane fermentation not preceded by pre-treatment that would facilitate degradation of this complex and make easily-digestible simple sugars more available to microorganisms. As indicated by literature data, it would also be advisable to run the co-fermentation process with other substrates used in biogas works.

References

[1] Beale CV, Long SP. Seasonal dynamics of nutrient accumulation and partitioning in the perennial c4-grasses Miscanthus giganteus and Spartina cynosuroides. Biomass and Bioenergy. 1997;12(6):419-428. DOI: 10.1016/S0961-9534(97)00016-0.

[2] Dębowski M, Dudek M, Zieliński M, Grala A. Effectiveness of methane fermentation of Virginia Fanpetals (Sida hermaphrodita Rusby) under mesophilic conditions. Ecol Chem Eng A. 2012;19(11):1445-1453. DOI: 10.2428/ecea.2012.19(11)140.

[3] Bauer A, Leonhartsberger Ch, Bösch P, Amon B, Friedl A, Amon T. Analysis of methane yields from energy crops and agricultural by-products and estimation of energy potential from sustainable crop rotation systems in EU-27. Clean Techn Environ Policy. 2010;12:153-161. DOI: 10.1007/s10098-009-0236-1.

[4] Zhi Y, Li H, An S, Zhao L, Zhou C, Deng Z. Inter-specific competition: Spartina alterniflora is replacing Spartina anglica in coastal China. Estuarine, Coastal and Shelf Sci. 2007;74:437-448. DOI: 10.1016/j.ecss.2007.04.026.

[5] Lu J, Zhang Y. Spatial distribution of an invasive plant Spartina alterniflora and its potential as biofuels in China. Ecol Eng. 2013;52:175-181. DOI: 10.1016/j.ecoleng.2012.12.107.

[6] Qin P, Xie M, Jiang Y, Chung CH. Estimation of the ecological-economic benefits of two Spartina alterniflora plantations in North Jiangsu. China Ecol Eng. 1997;8:5-17. DOI: 10.1016/S0925-8574(96)00227-3.

[7] Chung CH. Forty years of ecological engineering with Spartina plantations in China. Ecol Eng. 2006;27:49-57. DOI: 10.1016/j.ecoleng.2005.09.012.

[8] Wan S, Qin P, Liu J, Zhou H. The positive and negative effects of exotic Spartina alterniflora in China. Ecol Eng. 2009;35:444-452. DOI: 10.1016/j.ecoleng.2008.05.020.

[9] Qin P, Xie M, Jiang Y. Spartina green food ecological engineering. Ecol Eng 1998;11:147-156. DOI: 10.1016/S0925-8574(98)00030-5.

[10] Chen G, Zheng Z, Yang S, Fang C, Zou X, Zhang J. Improving conversion of Spartina alterniflora into biogas by co-digestion with cow feces. Fuel Process Technol. 2010;91:1416-1421. DOI: 10.1016/j.fuproc.2010.05.015.

[11] Liang Y, Zheng Z, Luo X, Si Y, Cao D, Nie E, Cheng B. Lime pretretment to improve methane production of smooth cordgrass (Spartina alterniflora). Chem Eng J. 2013;217:337-344. DOI: 10.1016/j.cej.2012.11.135.

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

[13] Liang Y, Zheng Z, Hua R, Luo X. A preliminary study of simultaneous lime treatment and dry digestion of smooth cordgrass for biogas production. Chem Eng J. 2011;174:175-181. DOI: 10.1016/j.cej.2011.08.071.
[14] Liang Y, Zheng Z, Luo XZ, Guo F-H, Wang L, Zhang J. Effect of mesophilic and thermophilic conditions on changes of physicochemical characteristics of smooth cordgrass via dry digestion process. Chem Eng J. 2011;168:544-552. DOI: 10.1016/j.cej.2011.01.020.
[15] Cybulska I, Brudecki G, Rosentrater K, Lei H, Julson J. Catalyzed modified clean fractionation of prairie cordgrass integrated with hydrothermal post-treatment. Biomass and Bioenergy. 2012;46:389-401. DOI: 10.1016/j.biombioe.2012.08.002.
[16] Yang S, Li J, Zheng Z, Meng Z. Lignocellulosic structural changes of Spartina alterniflora after anaerobic mono- and co-digestion. Int Biodeterior Biodegrad. 2009;63:569-575. DOI: 10.1016/j.ibiod.2009.02.007.
[17] Nassab ADM, Amon T, Kaul HP. Competition and yield in intercrops of maize and sunflower for biogas. Ind Crop Prod. 2011;34(1):1203-1211. DOI: 10.1016/j.indcrop.2011.04.015.
[18] Weiland P. Production and energetic use of biogas from energy crops and wastes in Germany. Appl Biochem Biotech. 2003;109:263-274. DOI: 10.1385/ABAB:109:1-3:263.

EFEKTYWNOŚĆ TECHNOLOGICZNA PROCESU FERMENTACJI METANOWEJ SPARTINY PRERIOWEJ (*Spartina pectinata*)

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Abstrakt: Celem prowadzonych badań było określenie możliwości wykorzystania spartiny preriowej (*Spartina pectinata*) w procesach fermentacji metanowej. Efektywność procesu beztlenowego, związaną z ilością oraz składem produkowanego biogazu, a także kinetyką reakcji, określono na podstawie pomiarów respirometrycznych. Fermentacja przebiegała w warunkach mezofilowych przy początkowym obciążeniu komory ładunkiem związków organicznych w zakresie od 0,5 do 1,5 g s.m.o./dm^3 · d. Doświadczenia podzielono na dwa etapy, których kryterium podziału była wykorzystana część testowanej rośliny. W etapie I do modelowych komór fermentacyjnych wprowadzono założone ilości wstępnie przygotowanej części nadziemnej, natomiast w etapie II analizowano możliwość wykorzystania części podziemnej Spartiny preriowej. Przed właściwym procesem beztlenowego rozkładu substrat został poddany mechanicznemu rozdrobnieniu w młynie kulowym. W celu porównawczym w tych samych warunkach technologicznych prowadzono proces fermentacji metanowej kiszonki kukurydzy (*Zea mays*), jako podstawowego substratu roślinnego stosowanego w systemach biogazowni rolniczych (etap III). W trakcie badań stwierdzono, iż efektywność procesu fermentacji metanowej była bezpośrednio uzależniona od rodzaju testowanego substratu. Największe efekty technologiczne związane z produkcją biogazu oraz jego składem jakościowym stwierdzono w przypadku testowania kiszonki kukurydzy oraz części nadziemnej Spartiny preriowej. Istotnie niższą wydajność wytwarzania gazowych produktów metabolizmu bakterii beztlenowych zanotowano w etapie, w którym do eksploatowanych komór fermentacyjnych dozowano część podziemną testowanej biomasy roślinnej. Bezpośredni wpływ na przebieg oraz efekty końcowe procesu miało również testowane obciążenie komór ładunkiem suchej masy organicznej.

Słowa kluczowe: *Sparina pectinata*, process beztlenowy, biogaz, fermentacja metanowa, energia odnawialna