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QUANTITATIVE REDUCTION OF FEEDSTOCK BIOMASS AS A RESULT OF CONVERSION IN ANAEROBIC DIGESTION IN AGRICULTURAL BIOGAS PLANT

REDUKCJA ILOŚCIOWA BIOMASY WSADU NA SKUTEK KONWERSJI W PROCESIE FERMENTACJI METANOWEJ W BIOGAZOWNI ROLNICZEJ

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Streszczenie. Przeprowadzono szacunkową analizę ilościową substratów i produktów fermentacji metanowej oraz określono stopień redukcji masy wsadu w procesie produkcji biogazu w biogazowni rolniczej zlokalizowanej przy fermie tuczu świń. W biogazowni prowadzony jest ciągły dwuetapowy proces produkcji biogazu w warunkach termofilnych, z wykorzystaniem gnojowicy świńskiej i kiszonki z kukurydzy jako substratów. Przez 6 miesięcy zbierano dane dotyczące dziennej ilości i składu biomasy wejściowej, biomasy wyjściowej (pofermentacyjnej) oraz objętości wyprodukowanego biogazu. Dane przeanalizowano statystycznie zgodnie z prawem zachowania masy układu. Stwierdzono, że biomasa wyjściowa jest statystycznie istotnie zredukowana w stosunku do masy wejściowej o 11,86% ($p < 0,01$). Ilość zredukowanej biomasy nie różni się statystycznie od ilości wyprodukowanego biogazu, którego masa stanowi 10,21% biomasy wejściowej. Oznacza to, że redukcja biomasy w całości jest wynikiem procesu konwersji biomasy na biogaz, przy czym układ działa hermetycznie zgodnie z prawem zachowania masy. Fermentacja metanowa umożliwia zmniejszenie ilości produktów ubocznych produkcji zwierzęcej poprzez ich zagospodarowanie na użytkach rolnych. Redukcja ilości produkowanej gnojowicy ma istotne znaczenie ekologiczne, zwłaszcza w produkcji świń na skalę przemysłową.

Key words: anaerobic digestion, pig slurry, biogas, biogas plant, biomass.
Słowa kluczowe: fermentacja metanowa, gnojowica, biogaz, biogazownia, biomasa.

INTRODUCTION

Intensive pig farming entails large amounts of by-products, especially organic wastes such as manure and slurry. Slurry is a rich source of nutrients for the plants, which is why it is used as fertilizer, but improper, excessive application can pose an environmental threat for air, soil and water, and may cause pollution, eutrophication, acidification of water with ammonia, odours emission, and contamination by pathogens. (Sánchez and González 2005; Kwaśny et al. 2011). Furthermore, pig slurry after field application emits large amounts of greenhouse gases (GHGs), such as methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) (Rodhe et al. 2012).

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It is estimated, that the annual production of pig slurry in EU reaches 150 million tons (Foged et al. 2011). Such amount of waste, far exceeding the farmlands' withstanding capacity, requires proper management. An alternative method of utilization of animal wastes is using it as a substrate in anaerobic digestion - biogas production process, which can be conducted in agricultural biogas plants located near pig farms. During anaerobic digestion large organic compounds from biomass are reduced to methane, which is converted to various types of energy immediately (Podkówka 2012). There are several benefits offered by this process, such as improving fertilizing properties of slurry, pathogen sanitization, and odours and GHGs reduction (Côté et al. 2006; Nkoa 2013; Grudziński et al. 2015).

According to Holm-Nielsen et al. (2009) it is possible to produce approximately 20–30 m^3 of methane from 1 ton of raw pig slurry with 6–8% of dry matter. Co-digestion with approximately 30% addition of maize silage increases methane yield to 40–45 m^3 from 1 ton of feedstock biomass (Amon et al. 2006). According to the law of conservation of mass, mass of feedstock should be equal to the mass of the products. One of the benefits of using anaerobic digestion as a method of slurry utilization is reduction of the total volume of waste produced by pig farm because it is converted to biogas on site. During anaerobic digestion mass of feedstock is processed in three main ways: production of biogas, production of microbial biomass, microbial biomass metabolism. In industrial scale of the process the last way is negligible (Bailey 1986).

The aim of this study was the estimated quantitative analysis of anaerobic digestion substrates and products, and estimation of feedstock biomass reduction level in agricultural biogas plant located near a pig fattening farm in West Pomerania, Poland.

MATERIAL AND METHODS

The study was conducted in small, agricultural biogas plant merged with pig fattening farm with 6680 positions for animals located in West Pomerania province in Poland. The biogas plant runs two-stage, continuous, thermophilic anaerobic digestion with maize silage and pig slurry from pig farm as a substrates. Biogas produced in fermentation process is combusted in a cogeneration unit generating electricity and heat. A biomass circulation is showed on Fig. 1.

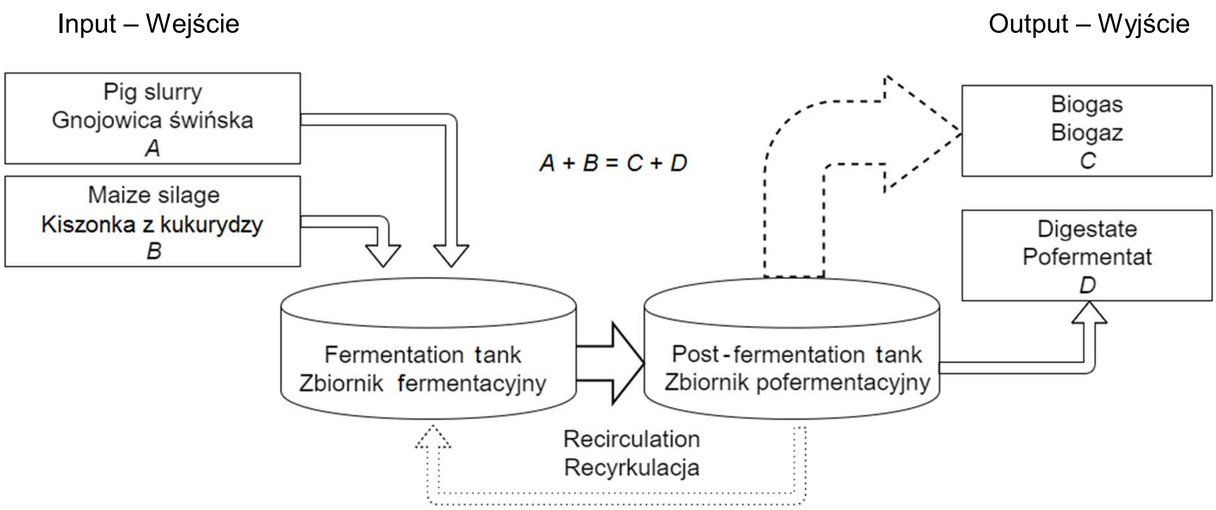

Fig. 1. Simplified scheme of biomass circulation in examined biogas plant
Ryc. 1. Uproszczony schemat przepływu biomasy w badanej biogazowni

Quantitative data regarding daily feedstock input, digestate output, and produced biogas from 6 months were collected. Weight of pig slurry and maize silage was measured by industrial scales, which are part of biogas plant installation. Amount in normal cubic meter unit (Nm^3) and the percentage composition of produced biogas were measured by built-in sensors systems. The component gases that were measured: methane (CH_4), hydrogen sulphide (H_2S) and oxygen (O_2). The rest of the composition of biogas is mainly carbon dioxide (CO_2), and trace gases, such as nitrogen, hydrogen and steam, which are negligible. A weight in normal conditions of produced biogas in each day was calculated using component gases densities according to Haynes (2009) by the following formula:

$$M_B = \sum M_X$$

when:

$$M_x = \sum V_x P_x \rho_x$$

where:

M_B – mass of daily produced biogas [kg],

M_x – mass of current component gas in daily produced biogas [kg],

V_x – volume of current component gas in daily produced biogas [N m^3],

P_x – decimal share of current component gas in biogas (percentage),

ρ_x – density of current component gas [$kg \cdot m^{-3}$].

The trace component gases have been omitted in the calculations due to small amount and a similar density of most of them to carbon dioxide.

Volume of anaerobic digestate was measured by flowmeter installed on the output of the installation. Obtained values were used to estimate digestate weight using estimated conversion rate: 1 m^3 of digestate ≈ 1000 kg (Buraczewski 1989).

Based on collected data, daily average input and output of biomass and biogas was obtained, and level of reduction of feedstock biomass in anaerobic digestion was determined. The Saphiro-Wilk test was used to check if the variables are distributed normally. The significance of differences between biomass input and biomass output (digestate) was determined by the Wilcoxon signed-rank test. Also to confirm the hypothesis about mass preservation law in examined installation, Wilcoxon signed-rank test for related samples between converted input biomass (Total input – Digestate) and mass of produced biogas was carried out. Statistical analysis of the results was performed using Statistica® 12 software (StatSoft, Inc. 2014).

RESULTS AND DISCUSSION

Average weight of 1 Nm^3 of produced biogas was 0.943 kg (S.D. = 0.016 kg) in normal conditions. This value is significantly lower than this reported by Jørgensen (2009), and higher than this reported by Energinet.dk (2010), however it results from a different percentage composition of investigated biogas. Average biogas yield was 0.108 $Nm^3 \cdot kg^{-1}$ of total input, and methane yield was 0.037 $Nm^3 \cdot kg^{-1}$. These results fall within the standard and correspond with other authors (Angelidaki and Ellegaard 2003; Weiland 2003; Amon et al. 2006). However, yield of biogas is strongly dependent on types of substrates, production techniques and others, so in a different set of experiment the results may be different. Fugol and Prask (2011) report higher biogas yields for shredded silages, and higher methane yield for maize silage. Also Wang et al. (2012) obtained different values for cattle and chicken manure.

In examined installation daily average production of biogas was 7462.5 kg (Table 1). This weight corresponds with the daily converted input biomass (Total input – Digestate), which is 9130.44 kg (S.D. = 38284.55 kg) and there are no significant differences between these values ($p > 0.01$), which means that the entire reduction of biomass takes place for the biogas.

Table 1. Biogas mass calculations
Tabela 1. Obliczenia masy biogazu

Component gas Gazy składowe	ρ [kg · m^{-3}] (Haynes 2009)	$\overline{P}$ S.D.	$\overline{V}$ [N m^3] S.D.	$\overline{M}$ [kg] S.D.
CH_4	0.71	0.49174 0.03515	3903.18 1188.63	2771.26 843.93
H_2S	1.539	0.00004 0.00008	0.27 0.58	0.41 0.90
O_2	1.43	0.01532 0.00763	115.65 49.32	165.38 70.53
CO_2 and others CO_2 i inne	1.16	0.49290 0.03644	3901.24 1149.34	4525.44 1333.23
Biogas Biogaz			7920.35 2302.87	7462.50 2148.39

The estimated average daily difference between total feedstock (input) and the digestate output was 9130.44 kg (S.D. = 38 284.55) and it was statistically significant ($p < 0.01$). The reduction of biomass in the examined biogas plant was 11.86% of total feedstock (Table 2). The estimated average mass of daily produced biogas was 10.21% of total feedstock, and there was no significant difference between biomass reduction level and mass of produced biogas. The level of biomass reduction is quite stable for anaerobic digestion, and the results are very similar with other authors' reports. Garcia (2005) obtained almost identical result – 10.25%, using cow manure, sugar-beet tops, and other organic wastes as a substrates. A similar reduction was reported also by Kalia and Joshi (1995), Habiba et al. (2009), and Sezun et al. (2010).

Table 2. Estimated quantitative analysis of input and output of anaerobic digestion process
Tabela 2. Szacunkowa analiza ilościowa na wejściu i wyjściu procesu fermentacji metanowej

Days Dni	Input – Wejście			Output – Wyjście			Reduction of biomass Redukcja biomasy [%]	M_B in total input M_B na wejściu całkowitym [%]
	pig slurry gnojowica [kg]	maize silage kiszonka [kg]	total input wejście całkowite [kg]	digestate pofermentat [kg]	biogas biogaz [kg]	total output wyjście całkowite [kg]		
(n)	$\bar{x}$ S.D.	$\bar{x}$ S.D.	$\bar{x}$ S.D.	$\bar{x}$ S.D.	$\bar{x}$ S.D.	$\bar{x}$ S.D.	$\bar{x}$ S.D.	$\bar{x}$ S.D.
181	54 607.46 21 787.06	23 064.20 3379.97	**77 671.66** 21 861.40	**68 541.22** 41 991.77	7462.50 2148.39	76 009.07 41 967.75	11.86 51.45	10.21 3.58

Bolded values shows significant differences with $p < 0.01$.
Pogrubioną czcionką wyróżniono wartości wykazujące istotne różnice przy $p < 0,01$.

CONCLUSIONS

Anaerobic digestion, in addition to other benefits, reduces amount of waste produced by pig industry due to conversion of biomass to biogas, and finally electricity and heat. Considering utilizing properties of this process, it has an ecological importance.

In examined agricultural biogas plant observed reduction of biomass was a result of conversion to biogas only, and the installation is working hermetically under the law of mass preservation. It is demonstrated by the lack of significant differences between the sum of the feedstock biomass, and the sum of the mass of biogas and digestate. Small, insignificant differences are probably consequences of microbial metabolism and estimated conversion rate of digestate volume to mass.

To determine which factors have an impact on level of the reduction, and to determine percentage of reduction concerning pig slurry exclusively a small scale research should be carried out.

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Abstract. The aim of study was the estimated quantitative analysis of anaerobic digestion substrates and products, and estimation of feedstock biomass reduction level in agricultural biogas plant located near a pig fattening farm in West Pomerania, Poland. The biogas plant runs two-stage, continuous, thermophilic anaerobic digestion with maize silage and pig slurry from pig farm as a substrates. Quantitative data regarding daily feedstock input, digestate output, and produced biogas from 6 months were collected. The data were statistically analysed in terms of the law of conservation of mass. It has been found, that biomass of digestate was statistically significantly reduced relative to feedstock biomass of 11.86% ($p < 0.01$). The amount of reduced biomass is not statistically different from the amount of produced biogas, whose mass is 10.21% of the feedstock. This means that observed reduction of biomass was a result of conversion to biogas only, and the installation is working hermetically under the law of mass preservation. Anaerobic digestion, in addition to other benefits, reduces amount of pig slurry due to conversion of biomass to biogas. It has ecological importance, especially in pig industry.

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