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The Effect of Mixing During Laboratory Fermentation of Maize Straw with Thermophilic Technology

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ABSTRACT

The interest in biogas production in Poland is growing rapidly. This is mostly due to the fact that there is a need for handling and managing the increasing quantities of diverse bio-waste generated by industry and agriculture. Therefore, good laboratory practices and correct preparation of batch tests are very important for planning of a full-scale biogas plant. The aim of the paper was to determine the effect of mixing in the laboratory batch reactors on the biogas yield of maize straw under thermophilic conditions. The scope of this work included: (1) the analysis of basic physical and chemical parameters and (2) laboratory determination of biogas and methane yield from anaerobic digestion of maize straw with different frequencies of mixing. The obtained biogas and methane yield from the thermophilic fermentation of maize straw mixed every day was 381.89 $m^3 \cdot Mg^{-1}$ FM and 184.97 $m^3 \cdot Mg^{-1}$ FM, respectively. The results of this study confirmed the effect of no mixing inside reactors. In the batch test a decrease in biogas and methane yields was observed, by approx. 60 $m^3 \cdot Mg^{-1}$ and approx. 28 $m^3 \cdot Mg^{-1}$, respectively.

Keywords: renewable energy sources, biogas, biogas efficiency, anaerobic digestion test, mixing of substrates

INTRODUCTION

In recent years, we have observed the increased demand for electricity, heat and conventional fuels. This is caused by the intensive development of civilization and technology in the last century. This in turn, has contributed to the increase in the environmental pollution. However, in the last decades, the interest in renewable energy sources, also including the conversion of biomass to electricity and heat production, has been observed [Wiater and Horysz 2017, Lewicki et al. 2013]. One of the ways of converting biomass into energy is anaerobic digestion (AD) [Czekała et al. 2017]. This process allows obtaining energy as well as fertilizers [Czekała et al. 2015b, Kazimierowicz 2017].

The biogas production in Poland has received a lot of attention due to the potential of agriculture residues that can be converted to biogas [Dach et al. 2014a]. It is estimated that Germany has similar biogas potential as Poland. According to the literature, Poland demonstrates high agricultural potential that comes from the area of 14.5 million hectares, in addition to well-structured and developed cattle, pig and poultry farms. This gives many opportunities for developing agricultural biogas and composting plants [Lewicki et al. 2015]. Therefore, it is crucial to determine the biogas and methane yield from anaerobic digestion (AD) under laboratory conditions prior to full scale biogas production.

AD is a complex biotechnological process that allows obtaining a product – biogas which is a mixture of methane (45–74%), carbon dioxide (25–54%) and some trace amounts of sulphide, ammonia, hydrogen, nitrogen and oxygen which content do not exceed 1–2% of the total volume

[Dach et al. 2014b]. The efficiency of the anaerobic digestion depends on many process parameters such as temperature [Appels et al. 2008], pH [Ward et al. 2008], C/N ratio [Choong et al. 2016; Mao et al. 2015], hydraulic retention time (HRT) [Choong et al. 2016] and reactor organic load rate (OLR) [Nagao et al. 2012].

The AD research, in the field application of biomass and bio-waste and for its use in such industries as waste water treatment and in agriculture, were studied intensively over the last few decades [Gunaseelan 1997, Chandra et al. 2012a, Appels et al. 2008, Mata-Alvarez et al. 2000, Ward et al. 2008]. Understanding the importance of the process parameters is essential for the optimization of anaerobic digestion and the increase in the biogas and methane yield on an industrial scale [Lindmark et al. 2014, Czekała et al. 2015a].

Mixing during laboratory anaerobic digestion

Mixing of liquid fraction in the digestion reactors is an important parameter that affects the final biogas yield. [Satjaritanun et al. 2016]. The DIN 38 414-S8 standard is commonly applied for the determination of biogas potential from various substrates [Cieslik et al. 2016, Oslaj et al. 2010, Wellinger et al. 2013]. This standard takes into account the mixing of the eudiometric sets by careful movement of the circular motions [DIN 38 414/S8]. These sets are used by many accredited laboratory units. Unfortunately, due to the uniform construction eudiometric reactors, mixing of their contents can be difficult, which can significantly affect the final result of the biogas and methane yields. One of the solutions could include using sets equipped with a magnetic or mechanical mixing system or reactors to allow accurate manual mixing with an independent gas storage system (fig. 1).

Mechanical stirrers are mainly used in fermentation stations operated in a continuous process [Lindmark et al. 2014, Deublein and Steinhauser 2008]. However, potential problems can be associated with the gas seal placed inside of the stirrer which prevents oxygen from entering the reactor. In this case, it is important to use fermentation sets equipped with an independent gas storage system and the possibility of free manual mixing of the contents. Such reactors were constructed in the Department of Environmental Engineering at the Institute of Biosystems Engineering at Poznan University of Life Sciences (Figure 2).

The aim of the research

The aim of the paper was to determine the effect of mixing in the laboratory batch reactors on the biogas yield of the maize straw under thermophilic conditions. The scope of this work included: (1) the analysis of basic physical and chemical parameters and (2) the laboratory determination of biogas yield from anaerobic digestion of maize straw with different frequencies of mixing.

MATERIALS AND METHODS

Research material

The tested material was maize straw, which was obtained from Przybroda Agricultural-Orchard Experimental Farm belonging to the Poznan University of Life Sciences (PULS). The fermentative inoculum – a liquid fraction obtained after dry mass separator was sampled from

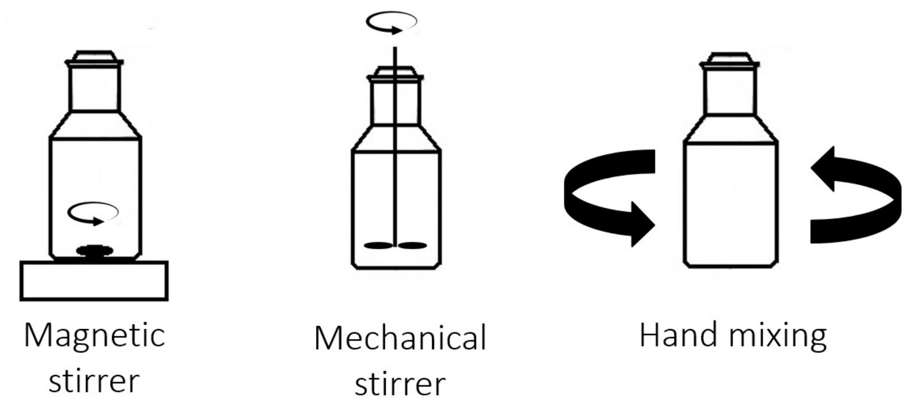

Fig. 1. Mixing systems for a batch test

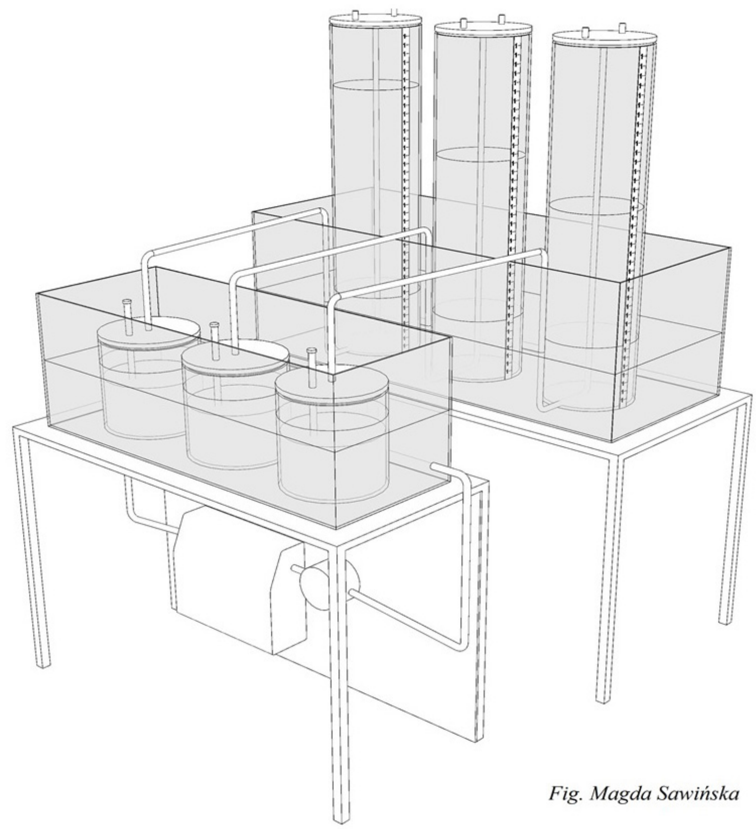

Fig. 2. The set of anaerobic digesters designed, constructed and used in the Laboratory of Ecotechnologies at Poznan University of Life Sciences [Cieślik et al. 2016, Dach et al. 2016]

the operating agricultural biogas plant in Dzialyn (Poland). After sampling from digestate tank, the inoculum was stored under anaerobic conditions at 52°C (thermofilic temperature).

Characteristic of maize straw

The analyses of basic physicochemical parameters of the maize straw and inoculum were conducted according to the Polish standards: total solids (PN-75 C-04616/01), volatile solids (PN-Z-15011–3) and pH (PN 90 C-04540/01). These parameters were measured to determine the appropriate ratios of the fermentation mixtures. On the basis of these parameters, the biogas efficiency on Mg of fresh matter, dry matter and dry organic matter of the substrate was calculated.

Determination of the biogas efficiency

Determination of the biogas efficiency from the maize straw in batch culture technology (under thermofilic conditions of 52°C) were carried out in the Laboratory of Ecotechnologies at the Institute of Biosystems Engineering at the Poznan University of Life Sciences. It was performed on the basis of internal procedures, based on the adapted standards: DIN 38 414-S8 and VDI 4630 which are commonly used in Europe. Detailed methodology was presented by Cieslik et al. [2016] and Dach et al. [2016, 2014b].

In order to determine the effect of stirring in the reactors on the biogas yield of maize straw, the individual reactors were subjected to circular stirring at different intervals: daily, twice a week (Monday and Thursday) and without mixing throughout the experiment.

RESULTS AND DISCUSSION

Physical and chemical parameters

In the first stage of the experiment, basic physical and chemical parameters of the substrate and inoculum were analyzed (Table 1). These parameters were necessary to determine the appropriate fermentation mixtures and subsequent calculations of the biogas yield.

The inoculum used in the experiment was characterized by organic matter in fresh weight of about 2.29%. The total solids and volatile total solids content of maize straw used in the experiment were 77.80% FM and 89.78% TS, respectively. The determination of basic parameters of substrates is necessary for correct preparation of anaerobic digestion in a continuous test. At this stage, some potential problems with using different substrates can be predicted.

Daily dynamics of biogas and methane production

The diagrams of daily dynamics of methane production and cumulative production of biogas can show regularity and potential inhibition in the fermentation process. The figure 3 shows the dynamics of methane production in the fermentation reactors. During the process, some differences in the dynamics of gas production were observed, influenced by the mixing frequency in the reactors.

During the thermophilic fermentation, three distinct gas production peaks were observed. They were visible on the 2nd, 10th and 19th day of the process. The local peaks of biogas production are the result of the chemical composition of the analyzed material. During anaerobic digestion, sugars, proteins and lipids differ in respect to the times of decomposition [Cieślik et al. 2016]. During the test, some differences in the intensity of biogas production peaks between the samples were observed. They were particularly visible in the samples mixed twice a week. In the research, the influence of mixing into reactors on shortening the digestion time was not observed. For this purpose, is necessary to carry out additional tests in batch system. According by Lindmark et al. [2014], accurate distribution of microorganisms in fermentation liquid fraction allows for the formation of a consortium of bacteria.

Table 1. Physical and chemical parameters of maize straw and inoculum.

Substrate	pH	Conductivity [mS]	Total Solids [%]	Volatile Solids [% TS]
Maize straw	9.66	1.41	77.80	89.78
Incoulum	7.84	17.72	3.58	64.03

Biogas and methane efficiency

The determination of biogas and methane yields, in calculated on fresh matter, total solids and volatile solids, is necessary for compare of energetic potential between substrates. The table 2 shows the biogas yield and methane concentration in biogas from the anaerobic digestion of the investigated substrate under thermophilic conditions.

In the process of thermophilic digestion of maize straw mixed every day, (in calculation to Mg of fresh mass of substrate) 381.89 m^3 of biogas with the average methane content of 48.44% was produced (table 2). Between the daily mixing of samples and reactors, which have been mixed twice a week, no significant reduction of biogas yield was found (for biogas – 6.89 m^3·Mg^{-1} and for methane only 1.54 m^3·Mg^{-1}). However, in the case of maize straw without mixing, the yields of biogas and methane production were significantly lower by 59.59 m^3·Mg^{-1} FM and 27.86 m^3·Mg^{-1}, respectively.

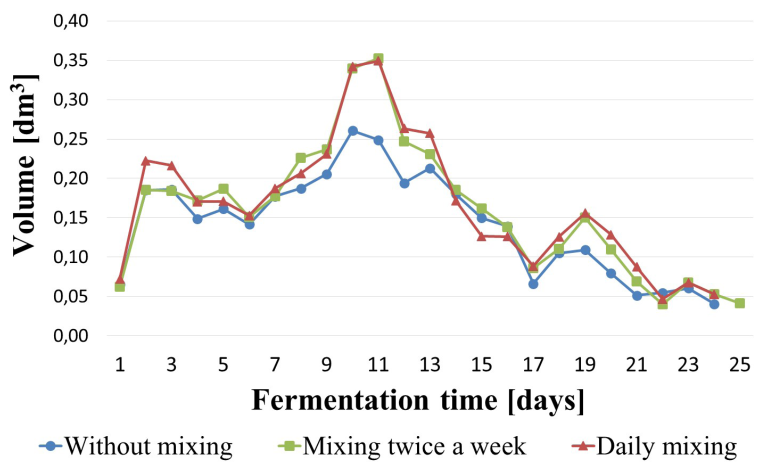

Figure 3. Daily dynamics of methane production from reactors

Table 2. The biogas and methane yield

Sample	Methane [%]	Fresh matter		Total Solids		Volatile Solids	
		Cumulated methane [m^3·Mg^{-1} FM]	Cumulated biogas [m^3·Mg^{-1} FM]	Cumulated methane [m^3·Mg^{-1} TS]	Cumulated biogas [m^3·Mg^{-1} TS]	Cumulated methane [m^3·Mg^{-1} VS]	Cumulated biogas [m^3·Mg^{-1} VS]
Daily mixing	48.44	184.97	381.89	237.76	490.86	264.82	546.73
Mixing twice a week	48.92	183.43	375.00	235.77	482.00	262.61	536.87
Without mixing	48.75	157.11	322.30	201.94	414.25	224.93	461.43

The results of the presented research confirmed that the mixing of the reactors influences the efficient production of biogas [Casey 1986, Kaltschmitt and Hartmann 2001, Lee et al. 1995, Smith et al. 1996]. In the samples without mixing of fermentation liquid, the formation of layers on the surface of the fermentation mixture was observed. It is important to point out that the mass containing methanogenic bacteria is stored in the lower part of the reactor due to higher density, while the substrate is collected in the upper layer [Maurer and Winkler 1980]. However, too intensive mixing of the reactor contents can also have an adverse effect on the fermentation bacteria [Lindmark et al. 2014, Deublein and Steinhauser 2008].

CONCLUSIONS

1. The research has confirmed the effect of mixing in the fermentation reactor and the increase the biogas and methane yields in the samples which were mixed everyday (approx. 60 m^3·Mg^{-1} for biogas, and approx. 28 m^3·Mg^{-1} for methane) when compared to the samples with no mixing.
2. In the fermentation process, the influence of mixing into reactors on shortening the digestion time of the substrate was not observed.
3. Lower biogas yields due to the lack of mixing of reactors during laboratory testing may have a significant impact on the estimation of the economic analysing of the planned real scale investment.

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