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Effect of chopped maize straw on the quantity and quality of biogas produced

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Abstract

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The increase in production costs of maize silage intended for biogas has led the producers to look for alternative sources of raw material. One of such materials is straw of agricultural crops, including maize. The use of lignin-cellulose materials, such as straw, by bacteria in a biogas fermenter is limited by its polymer structure. Therefore, it is required to process the straw before it is introduced into the biogas fermenter, which may allow to increase the biogas potential of straw. The simplest way of straw processing is its chopping. On the basis of the obtained results, it can be said that cutting the straw did not help increase the amount of biogas produced, but even limited the potential of this raw material.

Keywords: maize straw; fragmentation; biogas production

The most popular co-substrates in biogas production in Poland are maize silage and slurry. Increasing costs of high-quality silage production force the biogas-producing plant owners to look for other alternative substrates for biogas production. One of such materials is straw, a by-product of agricultural crops. One of the crops that can provide a significant amount of this material is maize cultivated for grain, which gains an increasing group of supporters in Poland (GUS 2014). The increase in maize production is associated with an increased demand for grain (Ranum et al. 2014), whereas higher grain production entails increased production of by-products such as straw. Numerous studies confirm the usefulness of by-products from cereal crops, maize and rice cultivation for biogas production (Urmila et al. 2012; Risberg et al. 2013; Przybył et al. 2013).

Straw is a lignin-cellulose material that, prior to introduction into the biogas fermenter, must be specially crafted using various techniques for this purpose (Sari et al. 2014). Among others, chemicals that help to loosen the lignin-cellulose structure of straw are used, resulting in biogas yield increased by 2–4% (Song et al. 2012). Other proposed method is to subject the straw to high or low temperatures treatment, microorganisms and microwave radiation (Sari et al. 2011; Vasmara et al. 2014; Zhou et al. 2016). One of the easiest methods of disintegration of lignin-cellulose materials structure is their fragmentation (Sałagan et al. 2012; Krátký, Jirout 2013). In addition to the advantages of cutting the lignin-cellulose materials prior to their introduction into the biogas fermenter chamber, this process has some drawbacks, among which there is the possibility of delicate blades damage by impurities that may be present in the processed material (Montgomery, Bochman 2014).

The aim of the study was to determine the impact of the maize straw fragmentation on the quantity and quality of the biogas produced in the methane

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fermentation process. During the studies, the profile of the biogas formation process in the biogas fermenter, including the amount of resulting biogas, as well as its quality in relation to the methane content, were determined.

MATERIAL AND METHODS

An analysis of the quality and quantity of biogas produced from the materials tested according to the standard DIN 38-414 S8:1986, and using the recommendations contained in the VDI 4630:2016, was carried out. The co-substrates used in the experiment were: swine slurry from the pig fattening house and maize straw of winter variety in the "flint" grain type. The straw was harvested 7 days after grain harvest. Position, from which the straw was harvested, belongs to the V bonity class. Prior to maize sowing, the field was fertilized with pig slurry at a dose of 30 m^3/ha, potassium salt (KCl) at a dose of 0.1 Mg/ha, and urea at a dose of 0.22 Mg/ha. During overseeding, ammonium phosphate was applied at a dose of 0.15 Mg/ha. The yield of grain harvested from such position amounted to 9.15 Mg/ha. Co-substrates used in the experiment originated from a farm located in the town of Tarnice in the West Pomeranian province. To demonstrate the effect of grinding the straw on its potential for the biogas production, it was cut into particles having a length of 5, 20, and 100 mm. In the experiment, straw length of 100 mm can be taken as a control fragmented to a minimal degree. Co-substrates mixture weighing 400 g was introduced into glass bottles of 1,000 ml capacity, which was the bioreactor with combined eudiometric burette. In order to facilitate the experiment and ensure the methane fermentation bacteria with good conditions for development, the air was displaced from the biogas fermenter already in the initial stage of the research. This was done using the compressed nitrogen.

The generating biogas ousted liquid from the burette, due to which the amount of produced biogas could be read on the scale of the burette. Its quality was analysed using a biogas analyser GA2000 plus (Geotechnical Instruments Ltd, UK). This device allows for the assessment of the quality and composition of the biogas taking into account the contents of methane, carbon dioxide, oxygen, hydrogen sulfide and ammonia. The experiment was conducted over the period of 79 days, during which measurements of quantity and quality of the biogas with a particular regard to the methane content were made daily. Proportions between the applied substrates were selected so that the overall weight of dry matter in the test mixture was 12%. Due to the periodic type of the culture in the fermenter, all physicochemical measurements of the fermentation mixture were carried out before and immediately after the experiment. These measurements included determination of pH, dry matter in substrates and dry organic matter. The pH measurements were made by means of the conductometric method, and measurements of dry matter and dry organic matter according to the Polish standards: PN-EN 12880:2004 and PN-EN 12879:2004. Quantity and quality assessment of biogas produced was carried out according to the guidelines of German standard DIN 38 414 S8:1986 and VDI 4630:2016. Volume of the biogas was read out of the eudiometric burette scale. Concentration measurements of methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), hydrogen sulphide (H_2S)and ammonia (NH_3) were performed applying the biogas analyser GA 2000 Plus according to producer's recommendations. Normalization of results from measurement of the biogas amount produced in laboratory scale was carried out according to the above-mentioned standards and relating to: normal biogas volume (1), corrected concentration of carbon dioxide and methane in the biogas (2), fraction of the normal volume produced from inoculum (3), net gas volume from the sample (4) and biogas yield (5):

– normal biogas volume:

$$V_0 = V \times [(p_L - p_w) \times T_0)/(p_0 \times T)] \quad \text{(ml)} \quad (1)$$

where: V_0 – normal biogas volume (ml); V – read biogas volume (ml); p_L – air pressure at the time of reading (mbar); p_w – vapor pressure depending on ambient temperature (mbar); T_0 – normal temperature, T_0 = 273.15 K; p_0 – normal pressure, p_0 = 1,013 mbar (hPa); T – biogas temperature or ambient temperature (K)

– corrected concentration of carbon dioxide and methane in the biogas:

$$C^{tr}_{corr} = C_{CH4\,(CO2)}\,[100/(C_{CH4} + C_{CO2})] \quad \text{(\% vol.)} \quad (2)$$

where: C^{tr}_{corr} – corrected concentration of a component (methane, carbon dioxide) in dry biogas (% vol.); $C_{CH4\,(CO_2)}$ – measured methane (or carbon dioxide) concentration in biogas (% vol.); C_{CH_4} – measured methane concentra-

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tion in biogas (% vol.); C_{CO_2} – measured carbon dioxide concentration in biogas (% vol.)

– fraction of the normal volume produced from inoculum:

$$V_{\text{in corr.}} = (\Sigma V_{is} \times m_{is})/m_M \quad \text{(ml)} \quad (3)$$

where: $V_{\text{in corr.}}$ – volume of biogas produced from the sludge used for inoculation (ml); ΣV_{is} – total volume of biogas produced in the experiment with the sludge to be inoculated during considered period of experiment (ml); m_{iS} – inoculation sludge weight used to prepare the mixture (g); m_M – inoculation sludge weight used in the control sample (g)

– net gas volume from the sample:

$$V_n = V_0 - V_{\text{in corr.}} \quad \text{(ml)} \quad (4)$$

where: V_0 – normal biogas volume (ml); $V_{\text{in corr.}}$ – biogas volume produced from the sludge used for inoculation (ml)

– biogas yield:

$$V_S = (\Sigma V_n \times 10^4)/(m \times w_T \times w_V) \quad \text{(Nl/kg DOM)} \quad (5)$$

where: V_s – unit of biogas production during the experiment related to the combustion loss (Nl/kg DOM); ΣV_n – net volume of biogas from the sample during a considered period of experiment (ml); m – mass of weighed sample (g); w_T (DM) – dry matter of sample (%); w_V (DOM) – combustion loss of sample dry matter (%); DOM – dry organic matter

RESULTS AND DISCUSSION

The pH measured for the fermentation mixture just after completing the methane fermentation ranged from 8.28 (straw of 5 mm length) to 8.42 (straw of 20 mm length). When analysing the course of methane fermentation process, it should be noted that maize straw is a material that can be used for the production of agricultural biogas. The particle size of the straw used as the substrate for biogas production determined the amount of biogas generated. The largest amounts of biogas were produced by straw with a length of 100 mm. Straw of 5 and 20 mm length produced by 6% and 8% lower yields of biogas, respectively. The average methane content calculated for the whole experiment was the highest in treatments with the shortest chop length, which amounted to 57.1% (Table 1).

Table 1. Fermentation parameters

Length of chopped straw (mm)	Accumulated amount of produced biogas (Nl/kg DOM)	Average methane content (%)	pH
5	368	57.1	8.28
20	360	54.4	8.42
100	390	52.9	8.35

The analysis of the methane fermentation process revealed that it is of a step-wise nature. On the first day of experiment, there was a large yield of biogas ranging from 4.8 Nl/kg DOM in a sample containing straw cut to 20 mm long chops to 9.4 Nl/kg DOM in sample composed of chopped straw of 5 mm length. This quantity quickly dropped till the 5th day of the process, then rapidly increased reaching a maximum level of 9.9 Nl/kg DOM on the 9th day of fermentation. After reaching the maximum, the yield of biogas from straw in all analysed treatments decreased. From the 18th to 31st day of the experiment, the use of straw by methane fermentation bacteria disappeared. It could be observed in the case of straw chopped to 20 and 100 mm particles, for which the use of straw was virtually nil. Methane fermentation during this period did not stop, and the microflora in fermenter used the organic matter accumulated in the slurry. Since the 32nd day of methane fermentation, microorganisms again began to use the energy stored in the maize straw, while the yield of biogas was initially low. On the 38th (chops of 20 mm length) and 39th (chops of 5 and 100 mm length) day of the process, the use of straw and biogas yield again reached the maximum at an average level of 12.7 Nl/kg DOM, then gradually decreased until termination of the experiment on day 79. When analysing the methane fermentation process, the diauxic growth phenomenon is noticeable, which results from a change in organic compounds that are used by microflora in the biogas fermenter. At the initial stage of the experiment, microorganisms preferentially use one of the compounds available in the surroundings. After its use, they switch their metabolism in order to adapt to the use of other available sources of energy and carbon (Singleton 2000). Table 1 shows the parameters of fermentation (Fig. 1).

On the first day of the methane fermentation process, the methane content in biogas produced from straw in all experimental treatments was at Singleton similarly low level of 2.6% (straw of 5 mm

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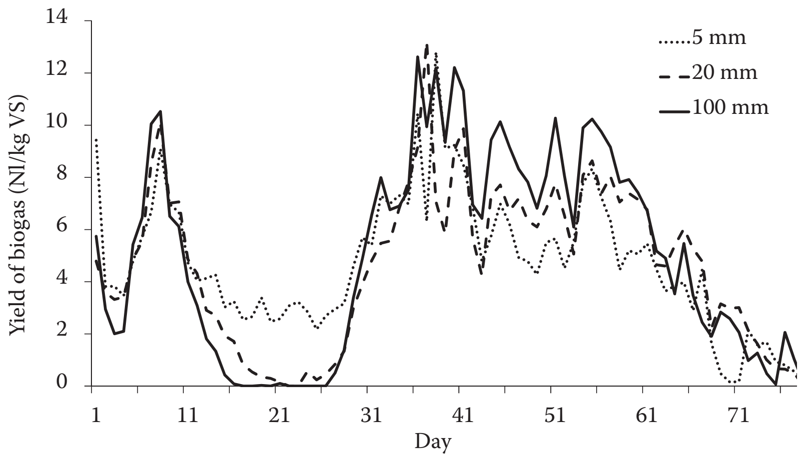

Fig. 1. Process of methane fermentation depending on the fragmentation degree

length) to 2.9% (straw of 20 mm length). These values, however, grew rapidly to reach the maximum value on the 41st day of experiment (chopped straw of 5 mm length), 53rd day (chopped straw of 20 mm length), and 39th day (chopped straw of 100 mm length). After reaching the maximum value of methane content in biogas, it maintained or slightly decreased to the last day of the experiment ranging from 61.1 % (straw of 20 mm length) to 69.9% (straw of 5 mm length). The course of the methane fermentation process taking into account the methane content in the biogas produced is shown in Fig. 2.

Fragmentation of straw did not contribute to the increase in the yield of biogas produced from the analysed materials. Similar conclusions were reached by Pang et al. (2011), who analysed the cumulative yield of biogas generated from a mixture of maize stalks and slurry, and reported that the largest amounts of biogas were produced when the maize straw was slightly chopped. Sochr et al. (2014) also found that the optimal length of chaff in terms of production and energy content of the biogas was 13 mm, compared to 5 and 22 mm lengths.

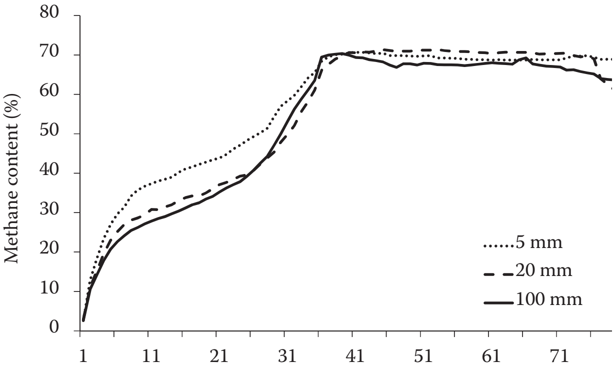

Fig. 2. Changes in the methane content in biogas depending on the fragmentation degree

CONCLUSIONS

The average content of methane in the produced biogas increased with the degree of straw fragmentation from 52.9% for the 100 mm long chops to 57.1% for the 5 mm long chops;

The highest yield of biogas was found in the treatment with straw fragmented to the lowest degree; the differences between the two other options were minimal;

In the course of methane fermentation process using straw, the biogas production from straw stopped after the initial period of intensive use of this resource and then an intensive use of this material by microflora of the fermenter was restarted.

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