Evaluation of the influence of fermentation input substrates preparation on biogas production intensity

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Abstract

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The article is aimed at verification of the effect of chaff length of fermented material and duration time of the contact of material with oxygen before dosing into the fermenter, on production and energy content of biogas. The results of the verification showed an effect of chaff length in the fermented material on production and energy content of the biogas at processing grass silage with high content of dry-matter and especially maize silage. When processing maize silage, optimal length of chaff in terms of production and energy content of biogas was 13 mm, with grass silage it was from 69 to 112 mm. Verification of the influence of time of grass silage and maize silage contact with air oxygen before dosing into the fermenter did not confirm our hypothesis. It was demonstrated that production and energy content of the biogas increase together with the length of duration of 7 days compared to fermentation of material after max. 3 h of contact with air oxygen.

Keywords: biogas plant; energy crop; grass silage; maize silage; energy content

Our works were aimed at verification of the effects of grass silage and maize silage particle sizes and contact of these substrates with air oxygen before dosing into a fermenter on the intensity of production and quality of biogas. The purposely grown energy crops can be best applied in biogas plants (BP) mixed in certain ratios and shapes. The task of our works was to find the optimal particle sizes of both substrates for use in BP in form of anaerobic digestion and to determine the effect of contact of these substrates with air oxygen before dosing into a fermenter on overall biogas production efficiency. To reach these tasks there were numbers of fermentation tests performed with the following results.

Grasses belong to ecologically most successful plants. When in favourable conditions, they have a dominant position in permanent grasslands. It can be assumed that, like abroad, there will be an increase in social pressure on property owners, especially in tourist areas, to carry out regular maintenance of all grasslands due to aesthetics and landscape maintenance. According to the Czech Statistical Office, the areas of permanent grass vegetation in the Czech Republic rise up gradually in the long term. Since 1990, their area has grown by almost 140,000 ha (e.g. 3.3%). Use of grass silage in BP has recently greatly expanded, mainly due to low demands and availability of large areas of permanent grasslands. The disadvantage of grass silage lies in frequent content of impurities (stones, clay) due to poor condition of the vegetation. Production of grass silage does not bring negative consequences for the land under cultivation since grass lands do not require chemical treatment and they create a suitable cover that prevents soil erosion. Use of grass silage in BP brings increased demands on proper handling of BP and preparation of substrate; it is especially about compliance with right size of chaff (Pastorek et al. 2004).

Maize silage is most often used and purposely grown energy crop. Literature sources (Herout et al. 2011) show that the total amount of maize silage on all substrates used in BP in Europe is approximately 34%. Reasons for widespread use of maize silage consist in high yields, suitable composition and dry-matter and also experience with growing the maize. Good-quality harvest, preparation and storage of the substrate prior to dispensing into the fermenter may sometimes be a problem. Major problem in growing the maize lies in a negative impact on soil erosion and intensive treatment with chemical products. We can therefore expect some reduction in maize production as purposely grown energy crop, and its replacement by alternative perennial crops.

Impact of particle size of the silage materials on quality of silage and formation of methane was dealt with in Herrman et al. (2012). They stated that the silage had higher content of lactic acid with the length of chaff 6–33 mm and that methane production increased by 11–13% compared to production of methane in longer lengths of the chaff. Masahiko and Kengo (2012) reported, that larger surface and higher rate of porosity of materials are important factors affecting degradation of the material and production of biogas at BP. Transportation alternatives and optimizing of logistics chains of major energy crops for BP in terms of financial costs, biogas production and impact on the environment, that was dealt with in Miao et al. (2012). They placed a particular emphasis on configuration of BP equipment.

MATERIAL AND METHODS

Subject of the examination consisted in the following points:

– impact of the length of chaff in grass silage and maize silage on production and energy content of the biogas;
– impact of duration time of grass silage and maize silage contact with air oxygen before dosing into the fermenter on production and energy content of the biogas.

When verifying the length of chaff, chaff lengths of 220, 112 and 69 mm were monitored in grass silage. Maize silage was cut to the lengths of 22, 13 and 5 mm. A fermentation test was carried out with individual samples, with the residence time of 43 days. There were samples of the total weight of 1 kg weighed in the laboratory fermenter (1 l laboratory fermenter; Research Institute of Agricultural Engineering, Prague, Czech Republic). Regarding the grass silage, the ratio of BP digestate and silage dry-matter was 1:1. Regarding the maize silage, the dry-matter contained 60% of silage and 40% of BP digestate. Always 3 equal samples were fermented in order to eliminate errors in their establishment. The fermentation tests were performed at the experimental fermentation facility in the Research Institute of Agricultural Engineering (1 l laboratory fermenter, Research Institute of Agricultural Engi-

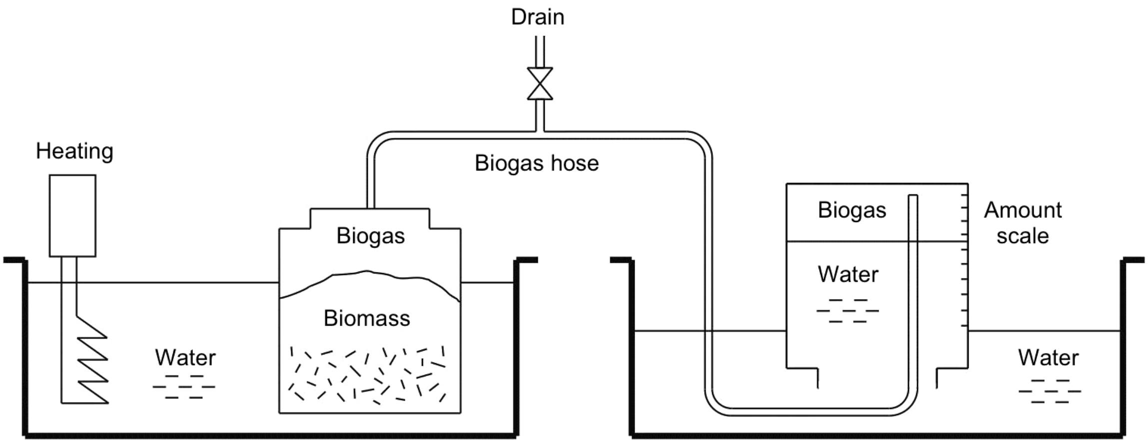

Fig. 1. Experimental fermentation facility scheme

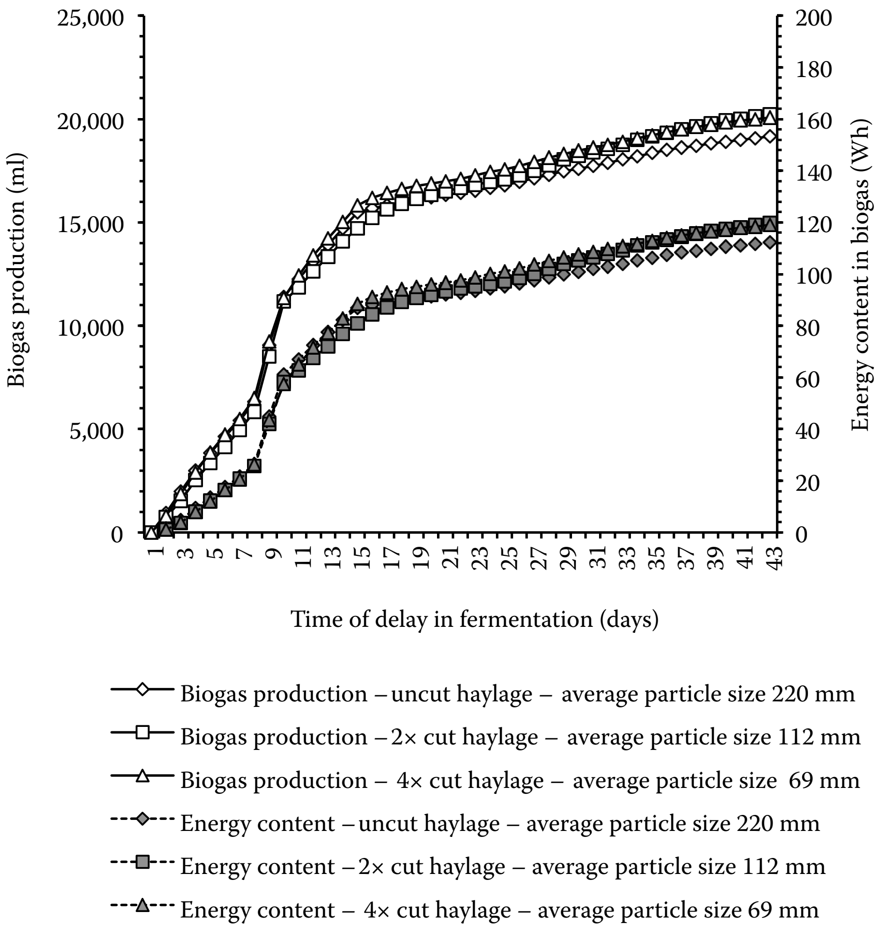

Fig. 2. Cumulative amount of biogas and energy content of biogas at different lengths of grass silage

neering, Prague, Czech Republic), Prague, Czech Republic. The experimental fermentation facility scheme is shown in Fig. 1.

When verifying the influence of time of grass silage and maize silage contact with air oxygen, the fermented samples were to be tested:

– immediately after removal from the storage space, the residence time before dosing in experimental fermenters did not exceed 3 h;
– after simulated 7-day delay in air oxygen;
– after simulated 14-day delay in air oxygen.

During fermentation tests, we monitored:

– amount of biogas produced;
– biogas composition in terms CO_2, CH_4 and O_2 content;
– calorific value of the biogas produced.

Of the total amount of produced biogas and content of CH_4 energy content of individual samples was calculated and consequently also cumulative energy content for all the time of material delay in the fermenter was given.

The length of chaff of both materials was modified by cutting in the electric chipper Viking GE 150 (Viking AG, Langkampfen, Austria). Biogas composition was analysed by infrared biogas analyser Aseko Air LF (ASEKO s.r.o., Vestec u Prahy, Czech Republic).

RESULTS AND DISCUSSION

Grass silage

Results of monitoring the cumulative biogas production from grass silage and energy content of the biogas at the levels of verified lengths are shown in Fig. 2. Fig. 2 shows that the differences in biogas production and energy content of the biogas gained with individual lengths of chaff are negligible. Verification confirmed the hypothesis saying that grass silage has, unlike maize silage, substantially longitudinal character. It means that increase of specific surface of chaff particles does not occur in case of chaff length reduction.

The dependence graph of the biogas energy content on sizes of chaff of grass silage (Fig. 3) clearly shows that the changeable size of the chaff has no significant effect on the energy content. For correct sizing of the chaff, it is advisable to use em-

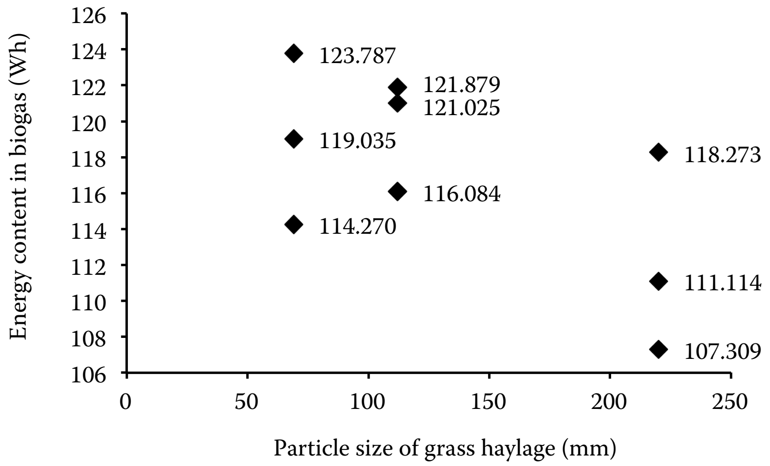

Fig. 3. Dependence of the biogas energy content on the length of chaff in grass silage (always 3 identical samples for each size of chaff)

pirical knowledge which is based mainly on good workability, transport and especially easy use in BP. Practice shows that the ideal size of the chaff in grass silage, which does not clog components of BP or does not form floating layers in the fermenter, ranges from 50 to 70 mm.

Results of monitoring the cumulative biogas production from grass silage and energy content of the biogas at verified duration times of contact with air oxygen are shown in Fig. 4.

Measurement results show that the cumulative biogas production and its energy content increase when compared to the expected hypothesis at delay of material in air oxygen. The increase of the total received energy in the biogas obtained from the sample of 7-day delay was 67%, compared to the sample without delay. At 14-day delay of material, some reduction of the total gained energy by 16% was recorded, compared to the sample of 7-day delay. This fact can be explained by increase of other biologically well-degradable biomass

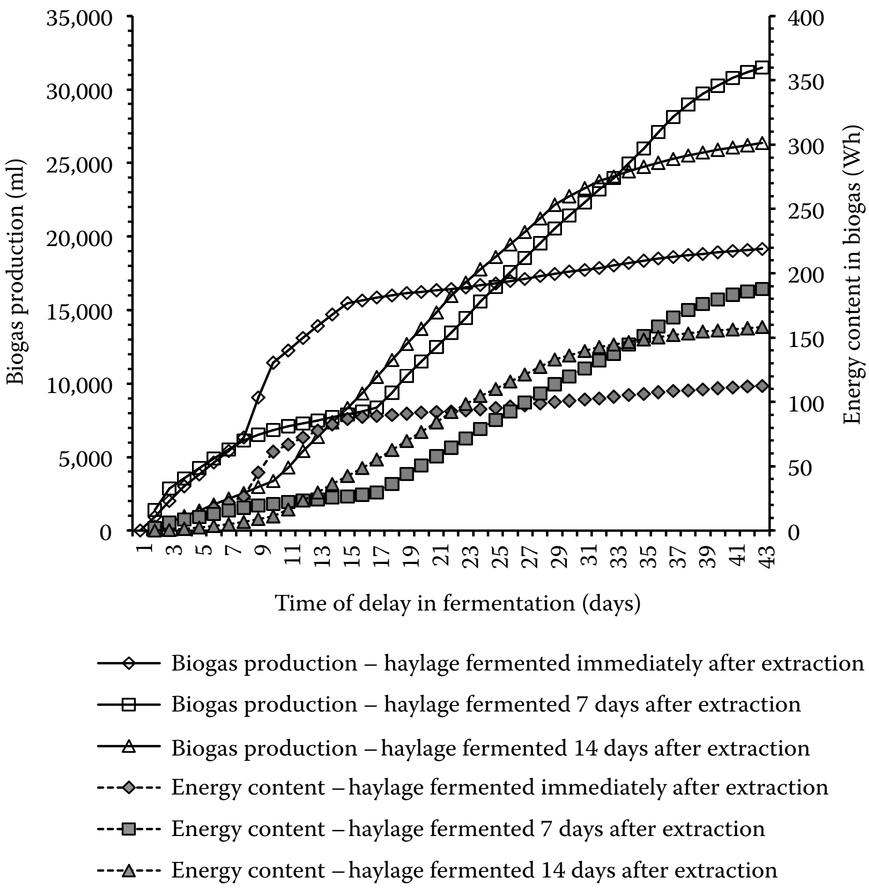

Fig. 4. Cumulative amount of biogas and energy content of biogas at verified duration times of contact of grass silage with air oxygen

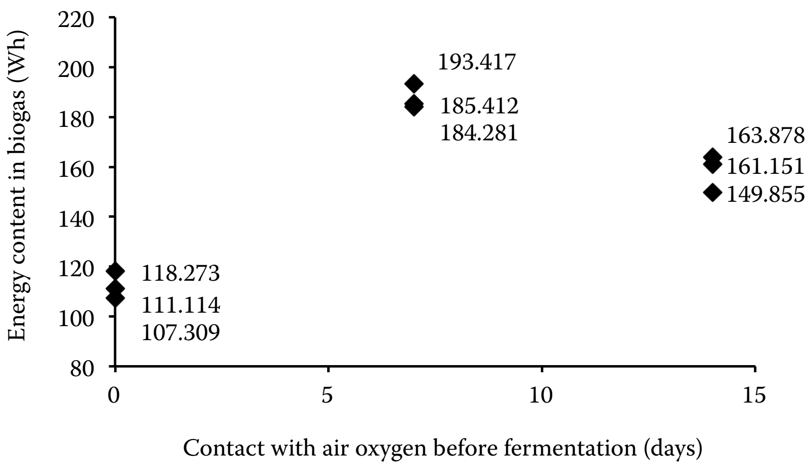

Fig. 5. Dependence of the energy content of biogas on the duration time of grass silage contact with air oxygen (always 3 identical samples for each duration time)

in the sample, in the form of aerobic bacteria, moulds and fungi. Another factor may be partial decomposition of biomass by aerobic organisms and subsequent improved accessibility for anaerobic methanogenous bacteria. These facts probably surpassed the negative effects of mycotoxins and inhibitory substances produced by fungi and moulds, whose negative effects began to surpass during longer delay in air oxygen. For this reason, the total energy obtained in the sample of 14 days began to decline again.

The above-mentioned findings also support the recently discussed biomass processing by using so-called AAA procedure that looks as beneficial in the empirical point of view. In this process, this is a case of aerobic preparation of biomass, anaerobic processing in BP and aerobic stabilization of the digestate.

Fig 5. shows that the time of grass silage contact with oxygen has a significant impact on the energy content of biogas.

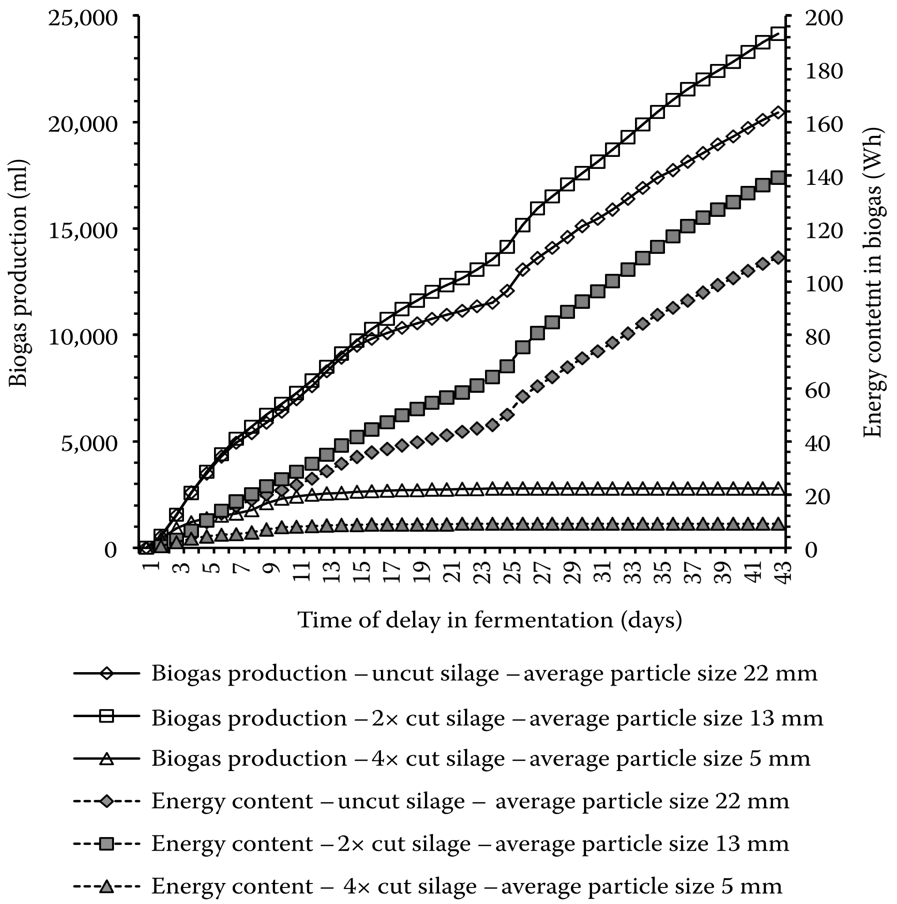

Fig. 6. Cumulative amount of biogas and energy content of biogas at different lengths of chaff of the maize silage

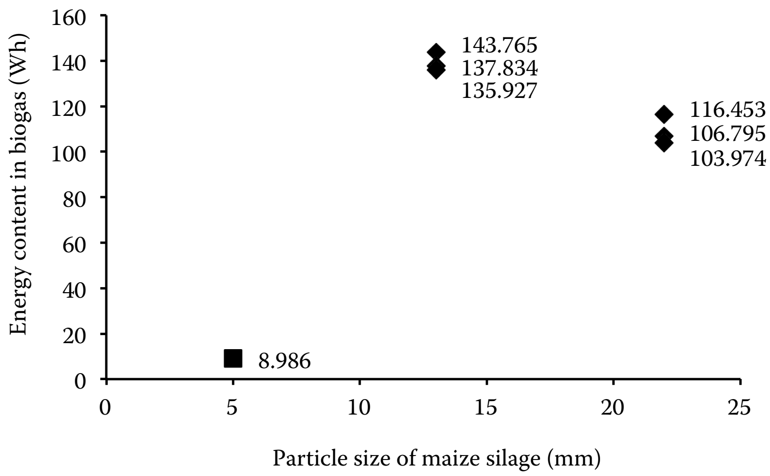

Fig. 7. Dependence of the biogas energy content on the length of chaff in maize silage (always 3 identical samples for each size of chaff)

Maize silage

Results of monitoring the cumulative biogas production from maize silage and energy content of the biogas at the levels of verified lengths are shown in Fig. 6.

The measurement results show that the size of chaff affects production of biogas and total energy content of the biogas from maize silage which can be extracted from the silage within a limited residence time in BP. It can be generally said that we confirmed the hypothesis saying that the increasing specific surface of chaff causes increasing of efficiency of anaerobic fermentation process. This fact is caused by disclosure of chaff biomass for methanogenous bacteria over a larger area. The same results were reached when monitoring the impact of the size and porosity of the silage materials on

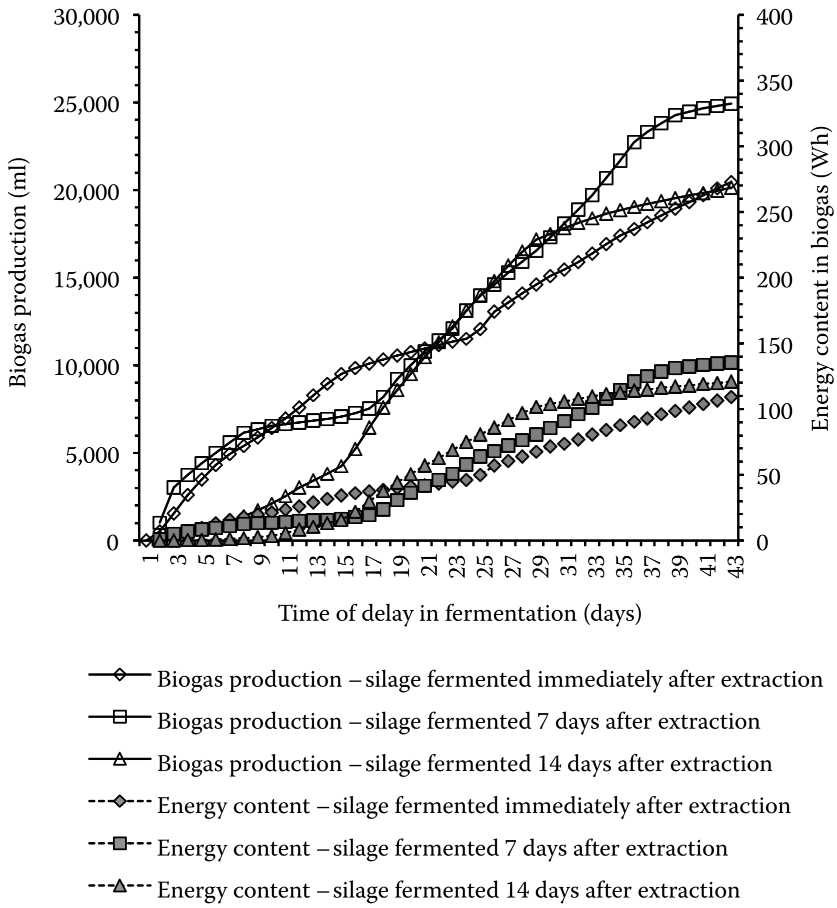

Fig. 8. Cumulative amount of biogas and energy content of biogas at verified duration times of contact of maize silage with air oxygen

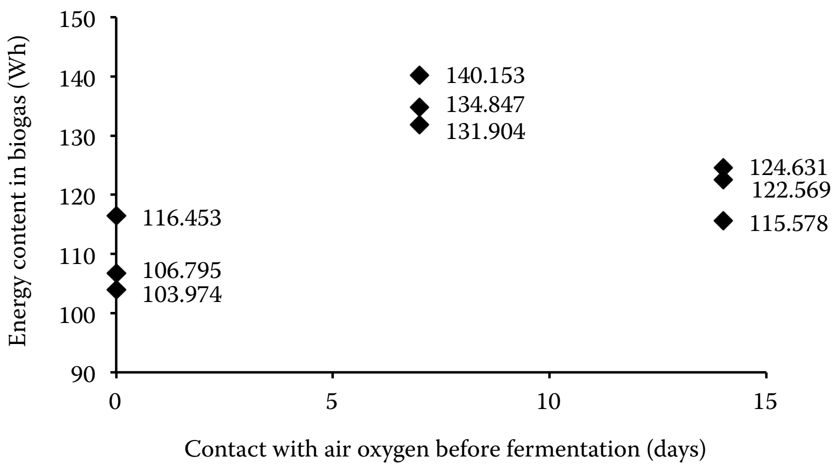

Fig. 9. Dependence of the energy content of biogas on the duration time of maize silage contact with air oxygen (always 3 identical samples for each duration time)

production of methane by Masahiko and Kengo (2012).

The low value of biogas production and its energy value in samples with an average size of chaff of 5 mm are probably caused by too rapid start of anaerobic fermentation process. It most likely happened that the rapid increase of acidogenous phase of fermentation and over-acidity of the whole process appeared due to high accessibility of biomass for anaerobic bacteria. Low pH value subsequently prevented the development of methanogenous bacteria. This fact appeared due to small content of individual experimental fermenters and also due to correspondingly low buffering capacity of their content. It can be assumed that such case of hyperacidity could not appear in a normal BP environment which relates to large and well-stirred volumes of biomass. This claim is also supported by the relatively low pH values, measured on these samples after the test. We did not find a similar conclusion while studying related literature.

When considering the trend of dependence of the energy content of biogas on the length of chaff of maize silage, the value of the energy content for the chaff of 5 mm size was represented by only one point (square), as represented on Fig. 7. Due to the irrelevant results, it was excluded from further consideration of the trend.

As with grass silage (Fig. 3), linear trend of dependence of energy content of biogas on the length of chaff of maize silage may be also assumed, even though we only have 2 points of dependence available. Any polynomial trend should have decreasing tendency starting in a certain min. size of the chaff, which contradicts the basic assumption of increasing energy efficiency of biogas production with increasing specific surface of particles in biomass used. Assuming a linear trend, then its analytical equation shows that reduction in the average size of the chaff by every 1 mm means the increase of the total energy yield by about 3%. The above-mentioned consideration shows the fact saying that the lower the average size of the chaff is, the more efficient the production of biogas will be. This statement has obviously some limits, such as technical ones (you cannot again and again reduce the size of the chaff to infinity) and economic limits too. Reducing the size of chaff is energetically and therefore also economically very demanding.

The research works (Lammers et al. 1996) show that increasing the size of chaff in self-propelled forage harvesters for maize silage only from 15 to 17 mm means 22% increase in harvesting efficiency, measured in quantity of harvested green matter per unit of fuel consumed by the harvester. It is therefore apparent that size of the chaff decrease by every 1 mm causes the increase of the total energy yield during anaerobic fermentation by 3%. And at the same time, there is the decrease in the amount of cut green mass of maize per unit of fuel consumed by the harvester by 11%. The rate of harvesting efficiency reduction is almost 4 times higher compared to the rate of increase of biogas yield. For this reason, there is a given size of the chaff of maize, used for the production of biogas. It is settled to the value of about 15 to 17 mm. To make further disclosure of chaff for anaerobic bacteria, it is more appropriate to use different types of mechanical or pressure extruders, or certain types of hydrolysis which further crush and split the material, consequently increasing the specific surface value and accessibility for methanogenous bacteria.

The results of monitoring the cumulative biogas production from maize silage and energy content of the biogas at verified duration times of contact with air oxygen are shown in Fig. 8

The measurement results show that the cumulative biogas production and biogas energy content increased in prolonged contact of silage with air oxygen, compared to expectations. The total energy obtained in the sample with 7-day delay was increased by 23%, compared to the sample without delay. In case of delaying the material by one more week, there was the reduction by 11%, the reduction of the total energy was extracted from the sample. Explanation of this result of verification is similar to grass silage. The effect of contact of the maize silage on production and energy content of the biogas is not as significant as it is in grass silage.

Fig. 9 shows that the time of maize silage contact with air oxygen has a significant impact on the energy content of biogas.

CONCLUSION

Results of the verification showed the effect of chaff length in the fermented material on production and energy content of the biogas at processing grass silage with high content of dry-matter and especially maize silage. There was consistent production and energy content of biogas at the chaff length of the grass silage of 69 and 112 mm. With longer chaff, the production rate and energy content of biogas went down. When processing maize silage, optimal length of chaff in terms of production and energy content of the biogas was 13 mm. With longer chaff, the production rate and energy content of biogas went down again. The analysis of research related to the impact of chaff length on fuel consumption of a harvesting machine however shows the recommended length of chaff at the level of 15–17 mm. Further verification and deeper analyses would significantly increase the total energetic efficiency of biogas production.

Verification of the influence of time of grass silage and maize silage contact with air oxygen before dosing into the fermenter did not confirm our hypothesis. It was demonstrated that production and energy content of the biogas increased together with the length of duration time of 7 days compared to fermentation of material after max. 3 h of contact with air oxygen. For grass silage, the increase rate of the total energy obtained was 67 % and the increase rate for maize silage was 23%. This fact was observed despite significant mould occurrence. Moulds appeared in the material after 7 days when coming into contact. In contact with air oxygen lasting 14 days, production and energy content of the biogas decreased down. Further measurements would optimize the duration time of different materials contact with air oxygen before dosing into the fermenter.

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