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VERIFICATION OF SUITABILITY OF SUBSTRATE COMPOSITION FOR PRODUCTION AND QUALITY OF BIOGAS

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The paper deals with biogas yield production from two co-substrates – sorghum silage mixture of corn silage and crushed potatoes combined with mixture of livestock manure and swine slurry – in a semi-continuous digester under mesophilic conditions. This paper aims to evaluate the suitability of alternative substrates for biogas production under biogas plant operational conditions. In the first experiment, biogas yield was 0.159 Nm^3 per hour with methane content of 56.96% vol. In the second experiment, biogas yield was 0.18 Nm^3 per hour with methane content of 52.95% vol. Experiments confirmed that both substrates are suitable for biogas production under the given conditions.

Keywords: co-substrate; methane content; biogas plant

Carbohydrate feedstock and waste from animal production, especially livestock excrements, represent perfect type of biomass for biogas production. Feedstock composition is one of the major factors that affect the production of biogas (Kelly and Walker, 2000). Therefore, when designing and operating an anaerobic digester, the quantity and characteristics of the feedstock are important and need to be assessed (Sebola et al., 2014). The process of digestion of crop residues requires inclusion of other components, such as liquid excrements, for its initiation. Furthermore, it is highly recommended to add a certain amount of crop residue to livestock excrement in the digestion process. Materials such as manure and slurry are appropriate for biogas production thanks to their homogeneity and the presence of high amount of methanogenic bacteria. These materials do not require the provision of booster vaccination; however, they do show a lower yield of biogas in comparison to alternative substrates.

Co-digestion represents a procedure for an anaerobic processing of multiple different types of biological materials that are jointly added to the basic, major substrate. Anaerobic co-digestion of different organic wastes together can improve nutrient balance, dilute potentially toxic compounds, and subsequently increase the processing capacity and biogas yield (Mahanty et al., 2014). One of the major benefits resulting from co-digestion is the possibility of digestion of several different biomass types, which can be found in the vicinity of the biogas plant, thereby improving the economic efficiency of the plant. Another benefit is the potential for increase in biogas production, or for obtaining biogas with higher methane content (Košík and Gaduš, 2008). Before the substrates are used in plant, it is necessary to perform their assessment in order to determine the suitability of individual biomass materials for co-digestion.

The aim of this paper is to assess alternative substrate suitability for biogas production under biogas plant operational conditions.

Material and methods

Experimental method

The experiments were performed in a horizontal reactor with a volume of 5 m^3 at the experimental biogas plant facility of the Slovak University of Agriculture in Nitra, locality of Kolíňany. The experiments were performed under operational conditions of the biogas plant. The semi-continuous digester was working under the mesophilic conditions at 40 ±1 °C.

A homogenisation tank with substrate liquid component is positioned as preceding the reactor. The reactor has automatic dosing of the liquid and solid substrate components. Digester content is fluctuated automatically and at regular intervals, by means of slow-moving stirrer blades. Raw biogas from the digester is accumulated in a small gasholder, from where it is pumped through the gas volume meter into a large gasholder located above the final storage tank. Fig. 1 shows the scheme of the experimental device.

The observed input substrates were selected with their availability in the given region being taken into account. The investigation was performed on two alternative substrates, results of which were consequently compared with reference substrate. This substrate, used also as inoculum to which the alternative substrates were added, comprised a mixture of livestock manure and swine slurry in a volume ratio 1 : 4. After homogenization, a daily dose of 250 L of substrate was pumped into the experimental digester, with hydraulic retention time in digester of 20 days.

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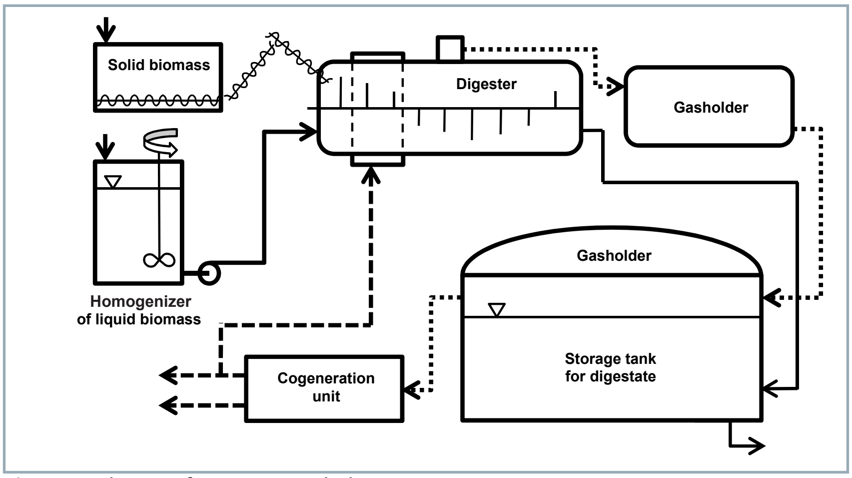

Fig. 1 Scheme of experimental plant

Table 1 Composition of co-substrates

Experiment	Co-substrate	Quantity of co-substrate per day (kg)
1st	sorghum silage	15
2nd	corn silage crushed potatoes	10 10

In experiments, the same daily substrate dose was utilized, resulting in the identical retention time as for the reference biological material. Volume of the original biomass within digester was decreasing by gradual adding of the daily dose of the observed substrate. Co-substrate in the first experiment consisted of sorghum silage; co-substrate in the second experiment was a mixture of corn silage and ground potatoes, which were unsuitable for food production due to low quality. Composition of the co-substrates is shown in Table 1. Duration of the experiments was 30 days per experiment.

Analytical methods

The co-substrate composition before digestion process and substrate composition during the digestion process were subjected to analyses in substrate suitability test for anaerobic digestion. Samples for analyses were prepared by means of dispersant device WTW Disper D8 (Mikro+Polo d.o.o., Slovenia). During the analyses, the content of total solids (TS), chemical oxygen demand (COD), total nitrogen (TN), and sulphate anions (SO_4^{2-}) was measured.

Samples from digester were tested for the content of total solids (TS), volatile solids (VS), loss on ignition (LOI), ammonium ions (NH_4^+) and volatile fatty acids. The pH values and temperature of substrate in digester were observed during the entire digesting process. Furthermore, the total volume of the produced biogas and amount of individual components were also measured. Other observed parameters included specific biogas production – volume of biogas per volume of digester and per day, methane content (CH_4), and other biogas components (CO_2, O_2 and H_2S).

TS test was carried out by constant weight drying method. TS were measured by moisture analyser Kern MLB 50-3 (Kern & Sohn GmbH, Germany). COD, total N, SO_4^{2-}, NH_4^+ were measured photometrically by means of the standard methods by PhotoLab S12 (Xylem Analytics Germany Sales GmbH & Co. KG, WTW, Germany). Gas analyser Schmack SSM 6000 (Schmack Biogas AG, Germany) was utilized for gas composition assessment; for measurement of H_2S and O_2, electrochemical sensor was utilized and values of CH_4 and CO_2. Biogas yield was measured by means of membrane gas meter BK-G2.5M (Elster GmbH, Germany). Biogas yield was converted to units of Nm^3 in accordance with the standards given by ISO 6979:2016.

Table 2 Mean values of the observed substrate parameters

Parameter	Co-substrate (solid biomass)	Parameter	Digester
TS (%)	30.94	TS (%)	3.13
COD (g L^{-1})	153.4	LOI (%)	1.87
TN (mg L^{-1})	706	VS (% of TS)	82.52
SO_4 (mg L^{-1})	595.6	NH_4 (mg L^{-1})	10.2
OLR (kg COD m^{-3} d^{-1})	3.2	VFA (mg L^{-1})	640

TS – total solids; VS – volatile solids; LOI – loss on ignition; COD – chemical oxygen demand; TN – total nitrogen; NH_4^+ – ammonia; SO_4^{2-} – sulphate; OLR – organic loading rate; VFA – volatile fatty acids

Results and discussion

1st experiment

The results of the analyses are given in Table 2.

Content of dry matter in sorghum silage is 30.94%. For bacteria to be able to degrade the material, the dry matter content must not be higher than around 50%. In a biogas plant, however, it should only be around 8–10%, if it is to remain liquid enough to be pumped (Jørgensen, 2009). Due to this, the silage was dosed by means of a direct line. The mean COD of sorghum silage was 153.4 g L^{-1} and total nitrogen amount was 706 mg L^{-1}. Organic loading rate was 3.19 kg COD m^{-3} d^{-1}.

The substrate composed of manure, slurry and sorghum silage showed dry mass content in digester at 3.13% and value of organically decomposable dry matter at 82.52% of TS.

Fig. 2 shows the measured content of biogas components on individual days. The oxygen content within each biogas sample was zero throughout the entire experiment.

Throughout the test cycle, the methane content of the biogas was highly stable and reached an average of 56.96% vol. Very positive values were also achieved with hydrogen sulphide – 83.3 ppm on average – resulting in unnecessity of further biogas treatment before application to the cogeneration unit. Average CO_2 content was 41.6% vol.

Fig. 3 shows biogas yield, temperature and pH values measured on each day of experiment.

Biogas yield was not stable during the experiment period. It was decreasing at the beginning of the experiment, with minimum biogas yield value observed on the 8th day; followed by subsequent increase and maximum biogas yield value observed on the 26th day. The average of biogas yield was 0.159 Nm^3 per hour, the average temperature in digester was 38.11 °C and the average pH was 7.18. Temperature and pH of substrate were constant during the entire experiment.

2nd experiment

The mean values of the observed parameters are given in Table 3.

These values demonstrate that the substrate in the digester has shown a satisfactory VS value – 73.72% of TS. The samples of solid biomass before feeding to digester showed mean COD value of 21.74 g L^{-1}.

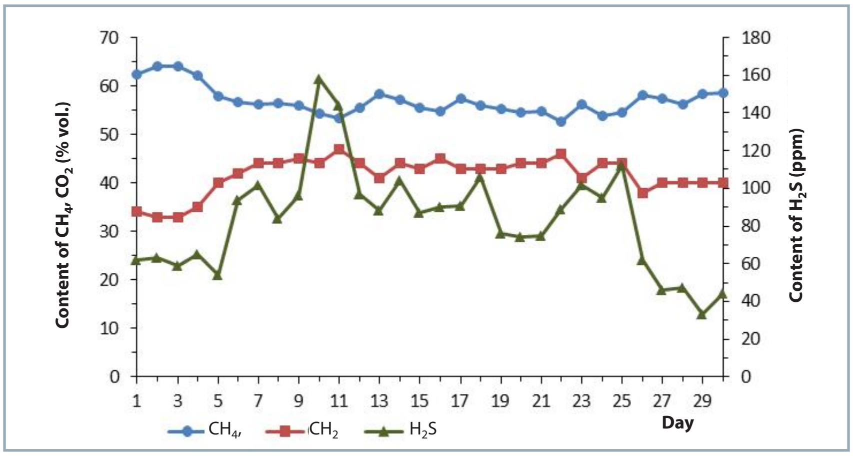

Fig. 2 Content of CH_4, CO_2 and H_2S in biogas

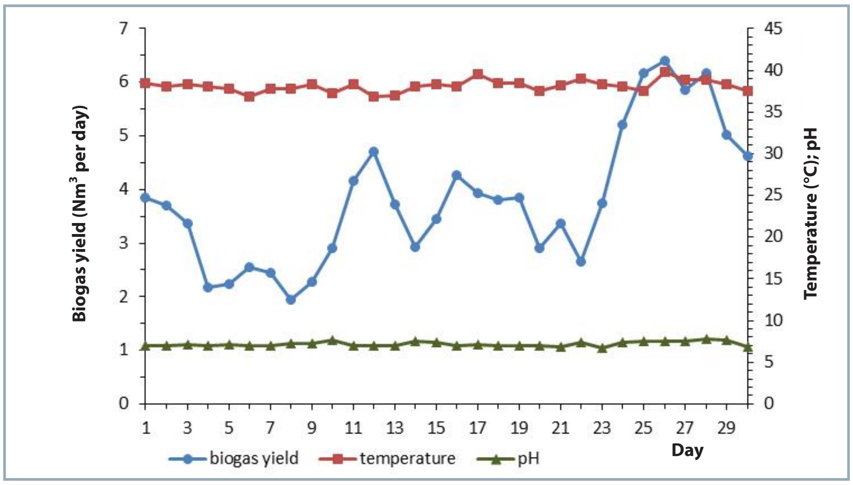

Fig. 3 Biogas yield, temperature and pH values

Table 3 Mean values of the observed substrate parameters

Parameter	Co-substrate (solid biomass)	Parameter	Digester
TS (%)	25.6	**TS (%)**	2.7
COD (g L^{-1})	21.74	**LOI (%)**	1.74
TN (mg L^{-1})	32.2	**VS (% of TS)**	73.72
SO_4 (mg L^{-1})	39.2	**NH_4 (mg L^{-1})**	6.7
OLR (kg COD m^{-3} d^{-1})	0.45	**VFA (mg L^{-1})**	414

TS – total solids; VS – volatile solids; LOI – loss on ignition; COD – chemical oxygen demand; TN – total nitrogen; NH_4^+ – ammonia; SO_4^{2-} – sulphate; OLR – organic loading rate; VFA – volatile fatty acids

TS content in substrate was very low during the experiment – 2.7% on average; therefore, it would be possible to increase the daily dose of the investigated substrate fourfold in order to achieve more efficient digester utilisation. Furthermore, the low value of OLR indicates the possibility of increasing the co-substrate dose; however, higher production of biogas is not always achieved at a large OLR.

Fig. 4 shows the measured content of biogas components on individual days. The oxygen content of the biogas was zero throughout the entire experiment.

In the second investigated co-substrate, the average methane content in the biogas was 52.95% vol.; however, hydrogen sulphide value was higher – 210.1 ppm on average, meaning that this biogas would require desulphurization in order to decrease the value below 100 ppm before usage in the cogeneration unit. The average CO_2 content in biogas was 47% vol.

Fig. 5 shows biogas yield, temperature and pH values measured on each day of experiment.

Average of biogas yield was 0.18 Nm^3 per hour. Value of pH was stable, average pH of substrate in digester was 6.93, which is slightly lower than values recommended by Jørgensen (2009), who reports that the most suitable pH for methane production is 7.2. The temperature in the digester was stable, with an average of 38.39 °C.

The comparison of the obtained mean content values of methane, hydrogen sulphide, CO_2, and biogas yield in both experiments with the reference substrate is given in Table 4.

The specific biogas production was 5.37 times higher in the first experiment and 5.82 times higher in the second experiment in comparison to reference substrate, which represents a significant result. The differences in the amount of the produced biogas are significant despite the lower methane content. Similarly to research performed by Alvarez and Lidén (2008), Dubrovskis and Plume (2017), Luna-del Risco et al. (2011), our results also confirm that the increase in biogas production can be achieved by means of an appropriate combination of materials.

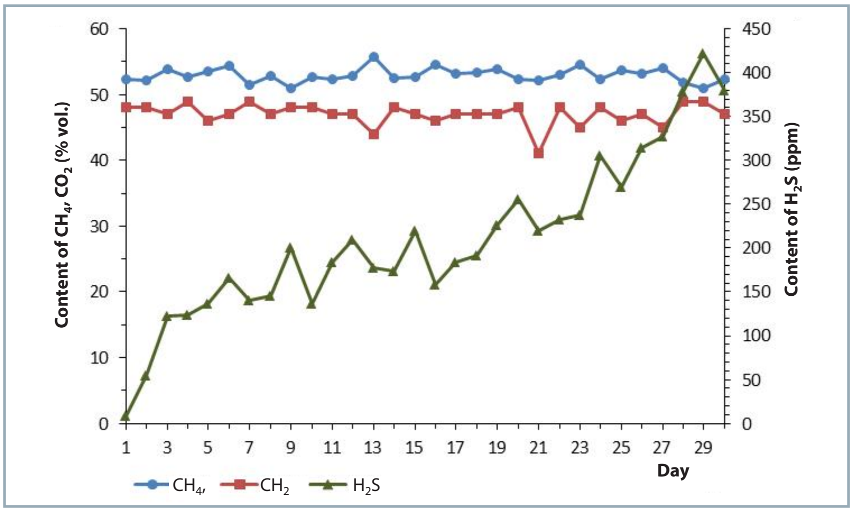

Fig. 4 Content of CH_4, CO_2 and H_2S in biogas

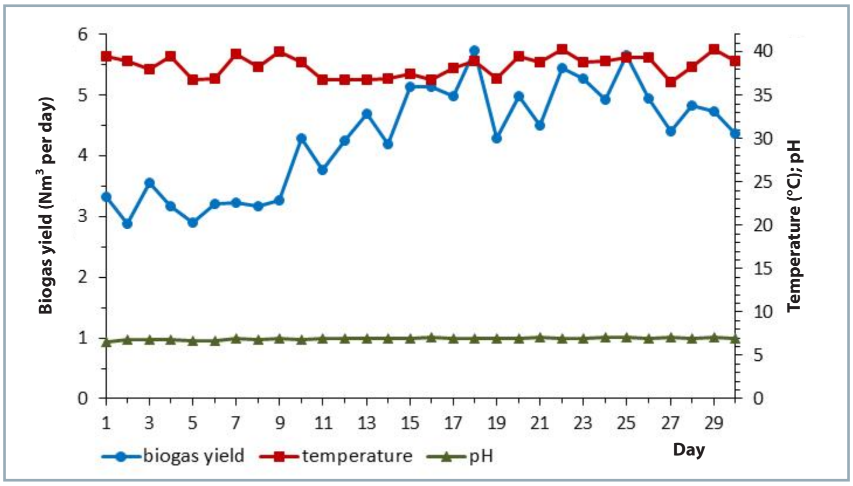

Fig. 5 Biogas yield, temperature and pH values

Table 4 The comparison of mean parameters of biogas production

Substrate	CH_4 (% vol.)	H_2S (ppm)	CO_2 (% vol.)	Biogas yield ($Nm^3\ h^{-1}$)	Biogas specific yield ($m^3\ m^{-3}\ d^{-1}$)
1st experiment	56.96	83.3	41.6	0.159	0.859
2nd experiment	52.95	210.1	47	0.18	0.931
Reference/ comparative substrate	60.8	1,343	31.2	0.032	0.16

CH_4 – methane, H_2S – hydrogen sulphide, CO_2 – carbon dioxide; Nm^3 – normal cubic meter

The mean hydrogen sulphide content, which is considered an undesirable component of biogas, is significantly lower than in case of reference substrate.

Conclusion

The obtained results have confirmed the suitability of usage of sorghum silage, potatoes and corn silage as a co-substrate in biogas devices. The values of biogas production and specific biogas production were significantly higher in both observed substrate mixtures than in digesting of only liquid manure and slurry. Daily doses of co-substrates could be improved, since the total solids content was low in both experiments, and by such measure the increase in biogas production could be ensured.

The reduced production of hydrogen sulphide content in the first experiment is a phenomenon that cannot be neglected, since hydrogen sulphide is undesirable due to its corrosive impacts, especially when using biogas in cogeneration units.

The experimental results confirm that it is essential to pay adequate attention to suitability verification of substrates before practical utilization in biogas stations, as well as efforts to seek biodegradable materials for digestion that are available in sufficient quantities at a reasonable cost.

References

ALVAREZ, R. – LIDÉN, G. 2008. Semi-continuous co-digestion of solid slaughterhouse waste, manure, and fruit and vegetable waste. In Renewable Energy, vol. 33, no. 4, pp. 726–734.

DUBROVSKIS, V. – PLUME, I. 2017. Biogas from wastes of pumpkin, marrow and apple. In Agronomy Research, vol. 15, no. 1, pp. 69–78.

JØRGENSEN, P. J. – PlanEnergi. 2009. Biogas – Green Energy. Aarhus : Aarhus University 36 pp. ISBN 978-87-992243-2-1.

KELLY, T. – WALKER, P. 2000. Bacterial concentration reduction in swine waste amended livestock feed using a single-screw dry-extrusion process, In Bioresource Technology, vol. 75, no. 3, pp. 189–195.

KOŠÍK, L. – GADUŠ, J. 2008. Biogas from anaerobic co-fermentation of cattle slurry and maize silage after mechanical pre-treatment of substrate. In Acta Technologica Agriculturae, vol. 11, no. 4, pp. 105–109. (in Slovak: Bioplyn z anaeróbnej kofermentácie hnojovice s kukuričnou silážou po mechanickom predspracovaní substrátu).

LUNA-DEL RISCO, M. – NORMAK, A. – ORUPÕLD, K. 2011. Biochemical methane potential of different organic wastes and energy crops from Estonia. In Agronomy Research, vol. 9, no. 1–2, pp. 331–342.

MAHANTY, B. – ZAFAR, M. – HAN, M. J. – PARK, H. S. 2014. Optimization of co-digestion of various industrial sludges for biogas production and sludge treatment: Methane production potential experiments and modelling. In Waste Management, vol. 34, no. 6, pp. 1018–1024.

SEBOLA, R. – TESFAGIORGIS, H. B. – MUZENDA, E. 2014. Production of biogas trough anaerobic digestion of various waste: review. In Internatinal Conference on Chemical, Integrated Waste Management & Environmental Engineering. Johannesburg : University of Johannesburg, pp. 196–201.