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ANALYSIS OF PRODUCTION TESTS IN PROCESSING THE MIXTURE OF SOLID AND LIQUID BIOLOGICALLY DEGRADABLE WASTES BY ANAEROBIC FERMENTATION

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Abstract

FRYČ, J., LOS, J., LOŠÁK, T.: *Analysis of production tests in processing the mixture of solid and liquid biologically degradable wastes by anaerobic fermentation.* Acta univ. agric. et silvic. Mendel. Brun., 2012, LX, No. 3, pp. 19–24

This study concerns the analysis of operating anaerobic fermentation systems of agricultural biogas station and implementing a suitable system enabling the use of a mixture of solid and liquid biowaste. The tests made use of liquid substrates commercially offered to biogas station operators. The study evaluates practical measurements at an agricultural biogas station in order to evaluate the biogas production from these substrates and the efficiency of transforming input material to usable energy. The use of such treated substrates for the anaerobic fermentation technology may have a substantial influence on the volume of dosed energy crops. The mixture of input substrates consisting of liquid cattle excrements, silage corn, solid and liquid waste from food processing, animal waste and glycerine water was experimentally validated. This mixture was compared with the operation using liquid cattle excrements and silage corn. It was concluded that the proposed composition of input raw materials makes it possible to increase the production of biogas and el. power. On the other hand, it was identified that the energy content of the input raw materials is not optimally transformed into usable energy. This is why the proposed mixture of input materials with biowaste is not recommended for use at the used proportion.

biogas, anaerobic fermentation, biologically degradable waste, biogas station

Input raw material for biogas stations is biomass. Energy contained in it ensues from the transformation of solar energy by means of photosynthesis. In our climatic conditions, the amount of solar energy in the growing period ranges from 3 000–3 600 MJ m^{-2}. Although the energy efficiency of this transformation is very low, the use of biomass still represents a high energy potential (KARAS *et al.*, 2007).

The sources of raw materials for the anaerobic fermentation technologie may be divided into two main groups in terms of their origin– waste and intentionally grown biomass (SCHULZ *et al.*, 2004).

The intentionally grown biomass for biogas generation is represented by energy crops– mainly corn. Waste biomass is formed mainly by plant residues from agricultural production and landscape maintenance, waste from livestock production, biologically degradable municipal waste and organic waste from industrial and food–processing plants. It is usually designated as biologically degradable waste (BDW) or biowaste.

The use of waste substrates as suitable input components results in reducing the volume of intentionally grown biomass entering the process, which also enables more efficient operation of the anaerobic fermentation systems.

Various types of biologically degradable waste show various biogas productions and it is always necessary to define suitable conditions for use in the anaerobic fermentation systems. Beef cattle liquid manure can result in an approximate yield of 0.03 m^3 kg^{-1}. Suitable liquid manure preparation and mixing with waste substrates (vegetable oils, food residues…) can result in the biogas yield of approx. 0.20 $m^3 kg^{-1}$ (LUSK, 1998).

The generated fermentation residues may be utilised as a suitable fertiliser and replace industrial fertilisers which often have adverse characteristics (VEZIROGLU, 1991).

The objective of this study was to provide information concerning the operating use of anaerobic fermentation technologies in relation to the processing of biowaste as a suitable raw material replacing target–grown biomass. This study is a follow–up to the article "Analýza složení a tvorby bioplynu vznikajícího při zpracování bioodpadů technologií anaerobní digesce" (Analysis of the composition and formation of biogas produced during the processing of biological waste by anaerobic digestion technologies) (HNILICA *et al.*, 2010) focused on the monitoring of electric power generation while using different input substrates and it also links up with the paper "Operating tests analysis of liquid biologically degradable waste processing by anaerobic fermentation" (FRYČ *et al.*, 2012) addressing the same issue with another composition of input substrates.

MATERIAL AND METHODS

The validation was based on biogas production equipment designed to process liquid cattle excrements and corn silage adjusted to the biowaste use. The planned weigh ratio was 60% liquid cattle excrements and corn silage and 40% biowaste. In the beginning, the biogas station was operated only at 100% substrate composition using liquid cattle excrements and corn silage. The cogeneration unit with a generator has a nominal electric output of 1063 kW and the plant was put into service in January 2009.

The system is equipped with reinforced concrete tanks, fermentors with a capacity of 2 x 2200 m^3. All input raw materials are mixed in a stainless steel mixing tank with a capacity of 8 m^3 before being fed to the fermentor. The technology also includes two stainless steel tanks receiving liquid biowaste, a glycerine storage tank and a facility for receiving and storing loose biowaste.

Corn silage is dosed to the input storage tank with a volume of 80 m^3. liquid cattle excrements are dosed from a collection pit with a volume of 200 m^3. Substrates requiring hygienic treatment pass through the hygienisation unit installed in the operations building and are then pumped into the mixing tank. The fermentor is equipped with an integrated gas holder with a capacity of 800 m^3. Mixing inside the fermentor is ensured by four propeller mixers. Desulphurisation is ensured by driving a small volume of air to the gas holder. The originated biogas is converted to electricity using a cogeneration unit generator. The emitted waste heat is used to heat up the fermentor, and agricultural and farm buildings.

The plant makes it possible to measure and record the volumes of specific input materials, electricity production and heat production for internal and external use, volume, temperature and pressure of originating biogas.

Two basic input materials – corn silage and liquid cattle excrements – were used for the operation and subsequent measurements. Verified was the effect of adding a mixture of one solid substrate of Biogranmix and three different liquid input Biofrit substrates, glycerine water and animal waste (animal stomach contents). Before being fed, the input materials were mixed with the recirculation substrate. The substrate was extracted from the fermentor and fed back together with the input material. Its volume ranged from 30%–40% of the total volume of input substrates.

Corn silage had an average dry solids content of 32% and organic dry solids contents of 98%. The expected biogas yield totalled 0.20 $m^3 kg^{-1}$.

Liquid cattle excrements had an average dry solids content of 10% and organic dry solids content of 67%. The expected biogas yield was 0.03 $m^3 kg^{-1}$.

Biofrit has a dry solids content of 20%–25% and organic dry solids content over 88%. The indicated biogas yield is 0.16–0.18 $m^3 kg^{-1}$. This is a product coming from a specialised plant collecting waste from the food–processing industry, such as industrial kitchens, bakeries, canneries, milk–processing plants. The specific types of waste are stored separately and are treated, sorted or unpacked during processing resulting in a new type of waste guaranteeing a good biogas yield. The resulting product is in a liquid stage and is transportable by cisterns. On site, it is stored in stainless steel storage pits and undergoes sanitary treatment.

Biogranmix has the dry solids content of 70%–80%; the organic dry solids content exceeds 90%. The indicated biogas yield is 0.45–0.50 $m^3 kg^{-1}$. It is a mixture of oily emulsions from the bio diesel production and crops from processing plants, grain mills and central grain storages. Mixing and storing takes place in the processing plant from where it is sent to the final users. The mixture can be pressed and granulate can be produced. The material can be handled easily. A storage silo is used for storing in the place of consumption.

Glycerine water has a dry solids content of 90%–98% and the organic dry solids content exceeds 90%. The indicated biogas yield is 0.55–0.65 $m^3 kg^{-1}$. Glycerine water (G–stage) is a by–product of bio fuel production. It is formed by esterification, when methanol and catalyst, being potassium or sodium hydroxide, are mixed with preheated rape oil. The reaction results in two phases: rape oil methylester phase and G – phase. The repeated settling in the sedimentation tank results in the separation of the two phases, which are pumped into the storage tanks and dispatched from them.

The stomach contents have the dry solids content 15%–20% and the organic dry solids content exceeds 90%. The indicated biogas yield is 0.40–0.80 $m^3 kg^{-1}$.

I: *Input substrate specification*

Substrate	Daily volume without biowaste	Ratio	Daily volume with biowaste	Ratio
	kg·d^{-1}	%	kg·d^{-1}	%
Liquid excrements	24.1×10^3	35	2.2×10^3	3.2
Corn silage	45.5×10^3	65	20.4×10^3	29.7
Biofrit	0	0	24.5×10^3	35.7
Glycerine	0	0	4.5×10^3	6.6
Solid biowaste	0	0	4.1×10^3	5.9
Animal waste	0	0	12.9×10^3	18.9
TOTAL	**69.6 × 10^3**	**100**	**68.6 × 10^3**	**100**

The stomach contents come from slaughterhouses and butcheries. It is a mixture of excrements, blood and parts of tissues. The transport takes place in closed boxes and storage on site is provided in a covered tank.

The selected anaerobic fermentation operation was first analysed and evaluated using input raw materials without the use of biowaste. The monitoring period was selected as 26 days. Operating data were evaluated and electric power generation was recorded.

The input substrate was then replaced to enable the dosing of input substrates including biowaste. Specification of input substrate volumes is shown in Tab. I.

The values of the total volume of input materials, incoming volume of organic solids, theoretical and actual biogas production, biogas yield utilisation coefficient, el. power generation from 1 m^3 of biogas, organic solids load and substrate retention time in the fermentor were compared.

The calculation of organic dry solids load is as follows:

$$X = \frac{c}{V_f 100} \times m \ \left[\text{kg d}^{-1}\text{m}^{-3}\right], \quad (1)$$

where
X ...... organic dry solids load [kg d^{-1} m^{-3}]
m...... dry solids weight of substrate doses per unit of time [kg d^{-1}]
c........ organic dry solids content [%]
V_f...... fermentor volume [m^3].

The calculation of substrate retention time is determined as follows:

$$T = \frac{V_f}{V_{sub}} \ [\text{ d }], \quad (2)$$

where
T........ retention time [d]
V_{sub}.... volume of dosed substrate per unit of time [m^3 d^{-1}]
V_f....... fermentor volume [m^3].

The calculation of theoretical biogas production is as follows:

$$Q_T = \sum_{i=1}^{n} m_i \times q_i \ \left[\text{ m}^3\text{d}^{-1}\ \right], \quad (3)$$

where
Q_T .... theoretical biogas production [m^3 d^{-1}]
m_i ..... dosed substrate weight per unit of time [kg d^{-1}]
q_i ...... lower limit of the indicated biogas yield [m^3 kg^{-1}].

Biogas yield utilisation coefficient calculation is defined as follows:

$$k_V = \frac{Q_S}{Q_T} \ [-], \quad (4)$$

where
k_v...... biogas yield utilisation coefficient [–]
Q_S..... actual biogas production [m^3 d^{-1}]
Q_T .... theoretical biogas production [m^3 d^{-1}].

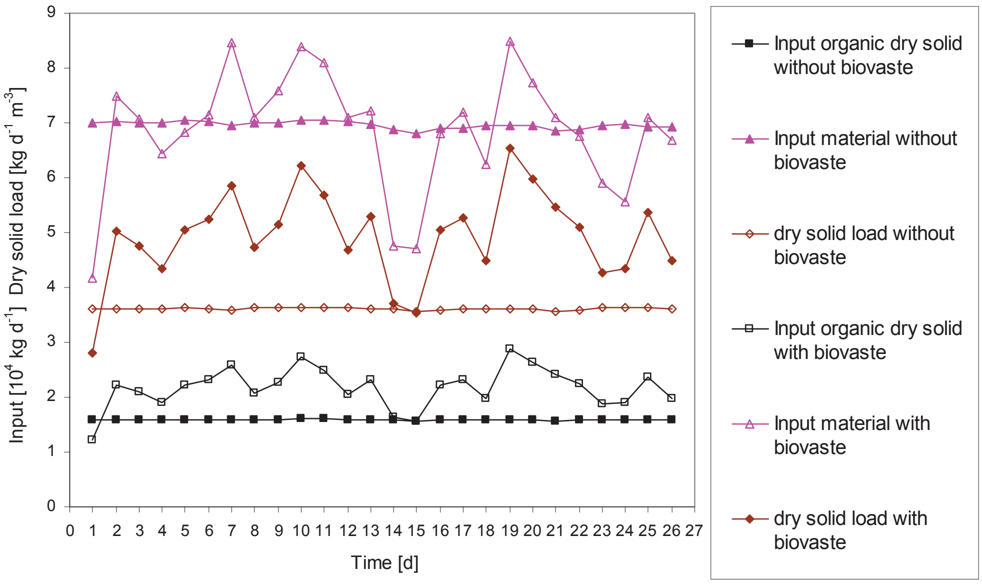
The calculation of electric energy production from 1 m^3 of the fermentor volume per year is as follows:

$$e_m = \frac{E_R}{V_f} \ [\text{kWh m}^{-3}], \quad (5)$$

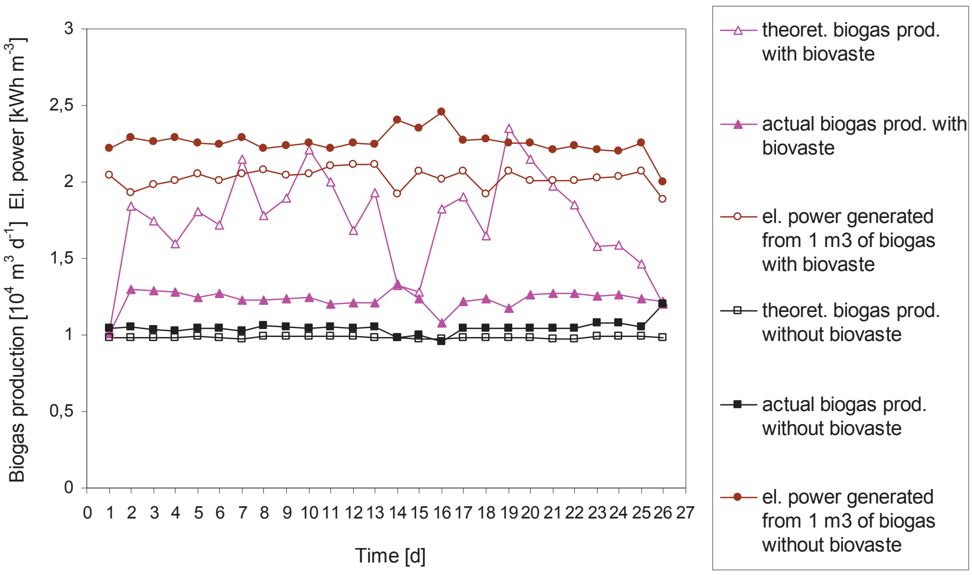
where
e_m........ electric energy production from 1 m^3 of the fermentor volume per year [kWh m^{-3}]
E_R...... electric energy production of biogas station per year [kWh]
V_f....... fermentor volume [m^3].

RESULTS

During the first monitored period, substrates without adding biowaste were fed to the system. The total volume of input material, share of organic dry solids content and the dry solid load during the monitoring are shown in the chart in Fig. 1. The average value of total volume fed into the plant was 69 595 kg d^{-1}. The average volume of input organic dry solids content totalled 15 890 kg d^{-1} and the average organic solids load totalled 3.61 kg d^{-1} m^{-3}.



1: *The total volume of input material, share of organic dry solids content and the dry solid load during the monitoring*



2: *The theoretical and actual biogas production values and el. power generated from 1 m^3 of biogas during the monitoring*

The theoretical and actual biogas production values along with el. power generated from 1 m^3 of biogas are shown in the chart in Fig. 2. The average daily el. power generation amounted to 23 578 kWh. Average biogas production totalled 10 462 m^3 d^{-1}. The average value of theoretical biogas production totalled 9 827 m^3 d^{-1}. The biogas yield utilisation coefficient over the monitored period was 1.06. The average value of generated el. power per 1 m^3 of biogas totalled 2.254 kWh m^{-3} and the average retention time was 55 days.

During the second monitored period, substrates with the addition of biowaste were fed into the system. The input substrate volumes are presented in Tab. I. The total volume of input material, share of organic dry solids content and the dry solid load during the monitoring are shown in the diagram in Fig. 1. The average value of total volume fed into the plant was 68 503 kg d^{-1}. The average volume of input organic dry solids content totalled 21 724 kg d^{-1} and the average organic solids load amounted to 4.94 kg d^{-1} m^{-3}. The theoretical and actual biogas production values along with el. power generated from 1 m^3 of biogas are shown in the diagram in Fig. 2. Average daily generation of electric energy amounted to 24 939 kWh. Average biogas production was 12 309 m^3 d^{-1}. Average theoretical biogas production was 17 513 m^3 d^{-1}. The biogas yield utilisation coefficient over the monitored period was 0.70. The average value of generated el. power per 1 m^3 of biogas totalled 2.027 kWh m^{-3} and the average retention time was 58 days.

The statistical analysis performed by t–test concluded that all measured parameters showed differences between data sets without the use of biowaste as compared with the use of biowaste, which were statistically significant or statistically highly significant – with the exception of the compared total amounts of input materials where the differences were insignificant.

DISCUSSION

It has to be pointed out that the measurements were made on a commercial biogas station where requirements of the plant owner must be respected and the operation may be affected by fallout of supplies as well as by other factors. Therefore, certain changes occurred in the volume and composition of input materials during the monitoring. This was also the reason for the measurements taking a longer time and for selecting time sequences in which the changes were minimal not only over the monitoring period but also during a period preceding the measurement. Notwithstanding the problems, the results are valuable because they come from the actual operation and are not distorted as may be the case of laboratory measurements. During the operation with the mixture of liquid excrements and silage corn, the input volume and component ratio were almost constant. When operating with the added biowaste, this could not be fully ensured and fluctuations occurred in the volume and proportion of components as indicated in the diagrams presented in Fig. 1 and Fig. 2. Given the large fermentor volume (4 400 m^3), small fluctuations in the feed rate have no major impact, which was confirmed by minimum changes in biogas production over the monitored period.

The first measurements made on the biogas station utilising biowaste turned clearly positive (HNILICA *et al.*, 2010). The production of biogas and electric energy increased by 17.7% and by 5.8%, respectively as compared with the operation using the mixture of liquid excrements and silage corn only. However, the fermentor received a nearly identical material volume (differences are not statistically significant) but a larger volume of organic dry solids (by 36.7%). This resulted in the increased average value of organic dry solids load from 3.61 kg $d^{-1} m^{-3}$ to 4.94 kg $d^{-1} m^{-3}$, which is a value that is still lower than as presented by some authors in professional publications (WEILAND, 1992). Likewise, the substrate retention time in the fermentor can be in both cases valuated as adequate. In the first case it amounted to 55 days and in the second case it was 58 days. Comparison with a similar measurement (MORAVEC *et al.*, 2011) carried out on a currently operated biogas station gave positive results, too. The reference parameter is electric energy production from 1 m^3 of the fermentor volume per year. The authors claim that the achieved value was 1417 kWh and consider it to be very good. In our case, the production of electric energy amounted to 1955 kWh and 2068 kWh in the variant without and with biowaste, respectively. It is a value converted from a shorter period and thus the whole–year measurement would certainly show a lower value due to shut–downs. Nevertheless, it can be assumed that even the values gauged over the whole year will exceed the figure given by (MORAVEC *et al.*, 2011).

The analysis of input material composition and the calculation of theoretical production concluded that the biogas yield utilisation coefficient totalled 1.06 with the mixture of liquid excrements and silage corn. Thus, the actual biogas production value was by 6% higher than the theoretical calculated value. However, in the second case with the use of biowaste, the coefficient decreased to 0.70. This means that the biogas production was by 30 % lower than would correspond to the optimum use of input raw materials. Similar results were achieved when assessing the energy transformation of the produced biogas. While the operation using a mixture of liquid excrements and silage corn yielded on average 2.254 kWh of electric power from 1 m^3 of biogas, the addition of biowaste resulted in the decrease of this value to 2.110 kWh. It should be stated therefore that the input material mixture in question is not quite optimal and will have to be modified for a further operation. Similar results were achieved at measuring the effect of liquid biowaste only (FRYČ *et al.*, 2012). However, the opinion that the composition input substrates is not optimal does not have to agree with the consideration of biogas station operators for whom the decisive factors are the amount of produced electric energy and costs of such production. Both parameters were very favourable.

CONCLUSION

The resulting energy content of individual raw materials obtained in laboratory conditions does not have to be fully utilized in actual operation. Therefore, the subject of the study was to compare the operation of a real agricultural biogas station using a mixture of liquid excrements and silage corn with the operation using biowaste. For the biogas station we designed a system enabling co–fermentation of solid and liquid biowaste, which may be applied in most standard agricultural biogas stations. The use of biowaste resulted in the increased biogas and electric power generation. Operators of the biogas station evaluated the experiment with biowaste positively. On the other hand, it was found out that the energy content of the input materials is not optimally transformed to usable energy. Therefore, the proposed mixture of input materials with biowaste is not recommended for practical use. For further operation, we propose changes in the input material composition and making an effort for finding an optimal combination of input materials. The proportion of biowaste should be presumably reduced because the share of this component in the experiments was 67.1%.

SUMMARY

The objective is to analyse anaerobic fermentation that is not carried out under laboratory conditions but directly in an agricultural biogas station. Use was made of equipment with a hygienisation unit enabling the use of liquid biowaste. Solid and liquid substrates commercially available to biogas station operators were used for the tests. The biogas station was designed and operated with a mixture of 35% liquid cattle excrements and 65% silage corn. The mixture of input substrates was validated experimentally, consisting of 3.2% liquid cattle excrements, 29.7% silage corn, 35.7% food–processing liquid waste, 5.9% solid waste from food processing, 18.9% animal waste and 6.6% glycerine water. The input materials were mixed with the recirculation substrate before entering the process. The substrate was extracted from a fermentor and returned together with the input material. The values of the total volume of input materials, incoming organic solids volume, theoretical and actual biogas production, biogas yield utilisation coefficient, el. power generation from 1 m^3 of biogas, organic solids load and substrate retention time in the fermentor were compared.

Upon using the input substrates with biowaste, the production of biogas increased by 17.7% and the production of electric energy increased by 5.8% as compared to the operation with the mixture of liquid cattle excrements and silage corn only. The fermentor received a volume of material lower by 1.4% but a volume of organic dry solids content higher by 36.7%. This resulted in a higher average organic solids load value rising from 3.61 kg $d^{-1} m^{-3}$ to 4.94 kg $d^{-1} m^{-3}$. By changing the composition of the input substrates, the substrate retention time in the fermentor increased from 55 days to 58 days. The analysis of the input material composition and the calculation of theoretical production determined that the biogas production was by 29.7% lower than corresponding to optima use of the input raw materials. Similar results were achieved when assessing the energy transformation of the generated biogas. While the operation using a mixture of liquid cattle excrements and silage corn resulted on average in 2.254 kWh el. power from 1 m^3 of biogas, when using input substrates with biowaste this value decreased to 2.027 kWh. Therefore, it must be concluded that the mixture of raw materials in question is not quite optimal and has to be modified for further use.

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