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EVALUATION OF CO-FERMENTATION UNDER AGRICULTURAL BIOGAS PLANT CONDITIONS

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Summary. Co-fermentation is an anaerobic processing of specifically different biomass mixtures for purposes of biogas production. Its use began mainly in the last decade. The main advantages of co-fermentation are: a possibility to process various kinds of biomass occurring around biogas plants through the anaerobic digestion, a possibility to promote economical efficiency of such facilities, a possibility to increase the biogas production or the methane volume in the biogas. In the paper the authors deal with a co-fermentation of mixtures consisting of cattle manure and various biomass co-substrates, which were used during a long-term monitoring of the anaerobic digestion process done within the international project AMONCO – *Advanced prediction, monitoring and controlling of anaerobic digestion processes behaviour towards biogas usage in fuel cells* (project N^o NNE5-2001-00067). The following co-substrates were consistently used: corn silage, fresh grass, kitchen waste and grass silage. On the basis of the obtained results corn silage seems to be the most suitable co-substrate: its adding to the manure almost doubled the biogas production.

Key words: co-fermentation, biogas, biomass, silage, kitchen waste

INTRODUCTION

Co-fermentation is a simultaneous digestion of a homogenous mixture of two or more co-substrates. The most common situation is when a major amount of a main basic substrate (e.g. manure or sewage sludge) is mixed and digested together with a minor amount of one or more additional co-substrates. Today, anaerobic digestion is better known and therefore it is easier to control and also the confidence in the related technology has increased. Consequently it has become a multi-purpose process serving at the same time waste upgrading, energy production, improvement of fertilizer quality and other purposes.

Various municipal, agricultural and industrial kinds of waste are frequently treated using anaerobic digestion. Sewage sludge has been digested worldwide for many decades in numerous large and medium sized biological sewage treatment plants. Compared to sewage sludge, only few digesters can be found using agricultural by-products like liquid pig manure, cow manure or chicken manure.

Due to co-fermentation of organic waste and manure from livestock breeding it is possible to increase the biogas production [Andreas 1998, Luthard-Behle 1999, Weiland&Rieger 2000, Langhans 2001, Braun 2003]. It is very important in the co-fermentation process to pay attention to both quantity and quality of the added co-substrates to ensure a continuity of the anaerobic digestion process. Therefore one should know the composition of the added co-substrates as well as the necessary duration of the biomass staying in a digester to reach an adequate digestion of the organic materials contained in it and the maximal allowable load of the digester.

OBJECTIVES OF THE EXPERIMENTS

The main goal of the international project AMONCO (Project N° NNE5-2001-00067) was advanced prediction, monitoring and controlling of anaerobic digestion processes behaviour towards biogas usage in fuel cells. In relation to this goal there were carried out experiments with co-fermentation of animal biomass mixed with energy crops and kitchen waste at the Biogas plant in Kolíňany. These long-term experiments were done from November 2003 up to November 2004. During this period the researchers monitored composition of input substrate samples, composition of substrate samples taken from the digester and composition and quantity of the produced biogas. The observed parameters are presented in Table 1.

Table 1. Parameters observed during the co-fermentation process

	Measured parameters
Input substrate	COD – chemical oxygen demand OLR – organic loading rate TS – total solid SO_4^{2-} – sulphate N_{total} – total nitrogen
Substrate from DIGESTER	TS – total solid VSS – volatile suspended solid NH_4^+ – ammonia nitrogen VFA – volatile fatty acids t – temperature pH
Biogas	CH_4 – methane CO_2 – carbon dioxide H_2S – hydrogen sulphide P_G – biogas production

Within the experiments the cattle manure was mixed with various kinds of co-substrates and these consequently were corn silage, fresh grass, kitchen waste and grass silage. An experiment with pure cattle manure served as a reference one. Duration of the particular cycles of the experiments is given in Table 2.

Table 2. Duration of the particular cycles of the experiments with co-fermentation process

Cycle	Used substrate	Duration
I	100% vol. cattle manure	21.11.2003 – 08.03.2004
II	40% vol. cattle manure, 60% vol. corn silage	23.03.2004 – 23.04.2004
III	60% vol. cattle manure, 40% vol. corn silage	24.04.2004 – 26.05.2004
IV	90% vol. cattle manure, 10% vol. fresh grass	07.06.2004 – 19.07.2004
V	92,3% vol. cattle man., 7,7% vol. kitchen waste	04.08.2004 – 20.09.2004
VI	90% vol. cattle manure, 10% vol. grass silage	27.09.2004 – 18.11.2004

MATERIAL AND METHODS

Experimental facility used for the biogas production at the Biogas plant in Kolíňany consists of a homogenization tank, co-mixture tank for co-fermentation mixture preparation, digester, biogas holder and storage tank of the digested sludge. A scheme of the experimental biogas production facility is shown in Fig.1.

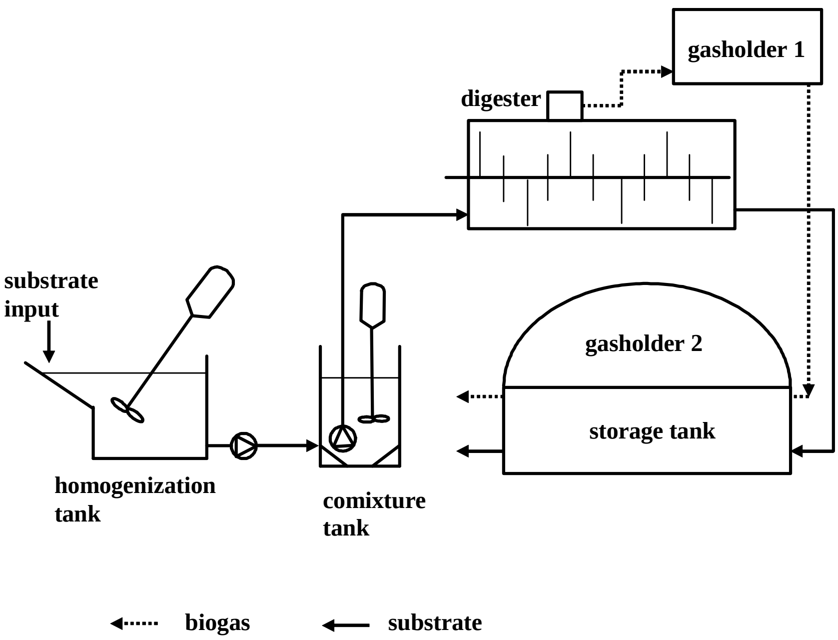

Fig. 1. Scheme of the experimental facility for biogas production

Cattle manure is fed to the substrate input homogenization tank, in which it is adulterated at need and homogenized by means of a propeller mixer. A mixture needed for the co-fermentation process is prepared in the next homogenization tank, where it is treated by means of a vertical mixer. Once a day, the prepared mixture is overdrawn into the digester. The digester is a main technological part of the biogas production facility. It ensures heating and mixing of the biomass substrate during the whole anaerobic digestion process. After an addition of the fresh substrate daily amount, the same amount of the decomposed substrate is removed through a flow-off, situated in the back part of the digester, into a storage tank of the decomposed substrate. The produced biogas is collected in a gasholder in the upper part of the digester and due to its own excess pressure it is treaded out through a distributing pipeline into the gasholder.

RESULTS OF THE EXPERIMENTS WITH CO-FERMENTATION

One of the main characteristics related to the composition of the input substrate is a value of chemical oxygen demand (COD), which is directly proportional to the total amount of organic compounds contained in the substrate which is theoretically possible to convert into the biogas. From the COD value the organic loading rate is calculated according the formula:

$$OZF = \frac{CHSK\left(\mathrm{kg} \times \mathrm{m}^{-3}\right)}{V_F\left(\mathrm{m}^3\right) \times 24}, \quad (\mathrm{kg\ CHSK} \times \mathrm{m}^{-3} \times \mathrm{h}^{-1}) \qquad (1)$$

where:

V_F – digester volume, m^3.

An influence of the organic loading rate on the biogas production is presented in Fig. 2–4, showing the courses of organic loading rate and biogas production during the co-fermentation processes with substrates prepared from the corn silage, kitchen waste and grass silage added into the cattle manure. Excessive load of the digester by organic compounds can lead to an inhibition effect and even to a breakdown of the anaerobic digestion process.

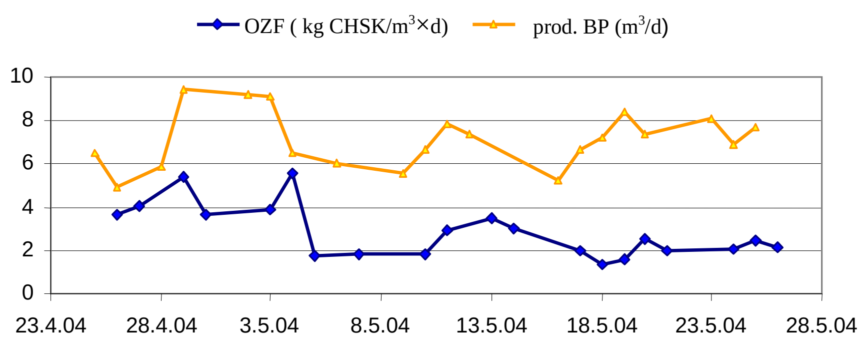

Fig. 2. Record of the digester organic load and biogas production per day during co-fermentation of the mixture consisting of cattle manure and corn silage (40:60)

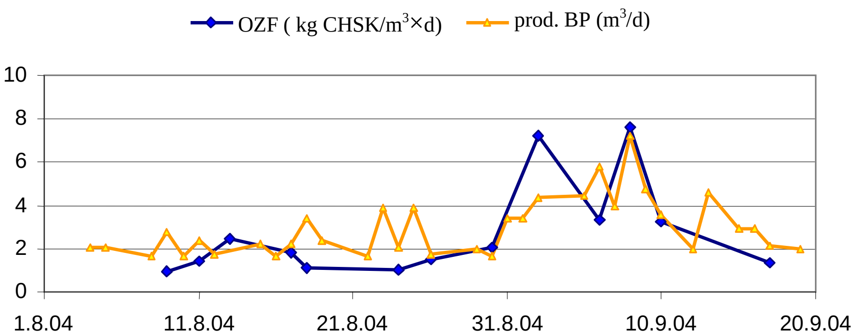

Fig. 3. Record of the digester organic load and biogas production per day during co-fermentation of the mixture consisting of cattle manure and kitchen waste

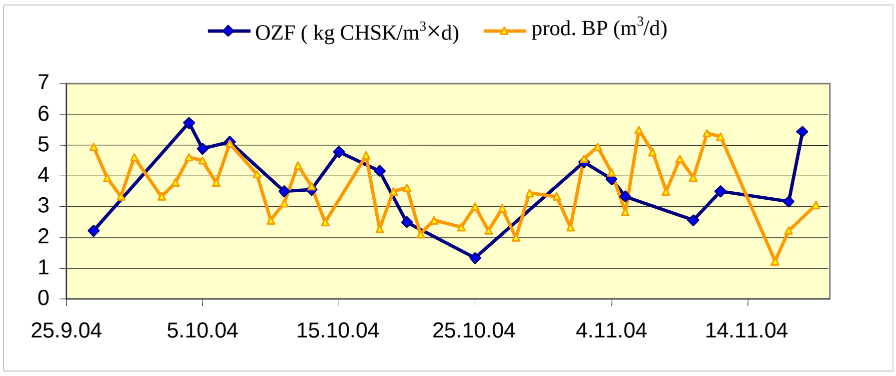

Fig. 4. Record of the digester organic load and biogas production per day during co-fermentation of the mixture consisting of cattle manure and grass silage

All the measured data were processed with the use of the descriptive statistics and the average values of all the observed parameters are presented in Tables 3–5.

Sulphate emissions are not a direct threat to the environment, but high sulphate concentrations can cause an imbalance in the natural sulphur cycle. Sulphide production can present serious operational problems in anaerobic reactors used for the treatment of waste waters containing high sulphate concentrations. Hydrogen sulphide (H_2S) in aqueous and gaseous solution causes chemical (corrosion, odour, increase of the effluent COD) and biological (toxicity, inhibition) problems that can affect the anaerobic digestion process.

A carbon – nitrogen ratio of about 30÷1 is ideal for the raw material fed into a biogas plant. A higher ratio will leave carbon still available after the nitrogen has been consumed, starving some of the bacteria of this element. These will in turn die, returning nitrogen to the mixture, but slowing the process. Too much nitrogen will cause this to be left over at the end of digestion (which stops when the carbon has been consumed) and reduce the quality of the fertiliser produced by the biogas plant.

Table 3. Results of the analyses of the input substrate samples

Cycle	Used substrate	COD $mg \times l^{-1}$	OLR kg $COD \times m^{-3} \times d^{-1}$	TS %	N_{total} $mg \times l^{-1}$	SO_4^{2-} $mg \times l^{-1}$
I	100 % CM	45508	3.19	4.82	93.1	191.3
II	40% CM + 60 % CS	53208	3.12	5.29	91.7	60.3
III	60% CM + 40 % CS	54700	2.86	5.98	114.2	48.6
IV	90% CM + 10 % FG	47750	1.85	4.92	86.5	41.8
V	92.3% CM + 7.7 % KW	41769	2.7	3.59	59.6	61.6
VI	90% CM + 10 % GS	61535	3.77	5.2	105.4	66.0

where:

CM – cattle manure
CS – corn silage
FG – fresh grass
KW – kitchen waste
GS – grass silage

Table 4. Results of the analyses of substrate samples taken from the digester

Cycle	Used substrate	TS %	VSS %	VSS % TS	NH_4^+ $mg \times l^{-1}$	VFA $mg \times l^{-1}$	pH -	t °C
I	100 % CM	-	-	-	808	-	7.05	37.5
II	40% CM + 60% CS	4.87	3.46	70.47	835	1148	7.19	38.68
III	60% CM + 40% CS	4.45	3.37	76.54	551	1150	6.92	37.92
IV	90% CM + 10% FG	4.87	3.46	70.47	835	1148	7.19	38.68
V	92.3% CM + 7.7% KW	8.34	3.50	43.52	627	769	7.50	36.71
VI	90% CM + 10% GS	7.54	3.92	51.87	598	1483	7.43	37.73

Table 5. Results of the biogas samples analyses and biogas daily production

Cycle	Used substrate	CH_4 (% vol.)	CO_2 (% vol.)	H_2S (ppm)	P_G ($m_N^3 \times d^{-1}$)
I	100 % CM	55.77	39.07	158	4.8
II	40% CM + 60% CS	55.6	41	53	8.29
III	60% CM + 40% CS	55.1	44	141	7.126
IV	90% CM + 10% FG	55.4	44.5	81	1.273
V	92.3% CM + 7.7% KW	59	41	319	2.97
VI	90% CM + 10% GS	56.7	43	338	3.6

An increase of the pH value caused by an excessive NH_3 production from proteins is another important inhibition factor. The NH_4^+ inhibition factor makes itself felt accordingly [Andreas 1998] at a volume above 2500 mg×l^{-1} and the toxicity even at the values above 12 000 mg×l^{-1} while the volume of the free ammonia is not higher than 80 mg×l^{-1}. Under certain conditions also volatile fatty acids (VFA), which are an intermediate product of the acidogenous phase of the digestion, can have inhibitory and toxic impacts.

In the biogas methane is the main energy holder. Hydrosulphide combustion generates allied substances SO_x, which in an interaction with water create sulphate acids, and which have corroding effects on metallic elements.

Courses of the biogas production in the particular cycles of the experiments with co-fermentation are represented in Fig 5.

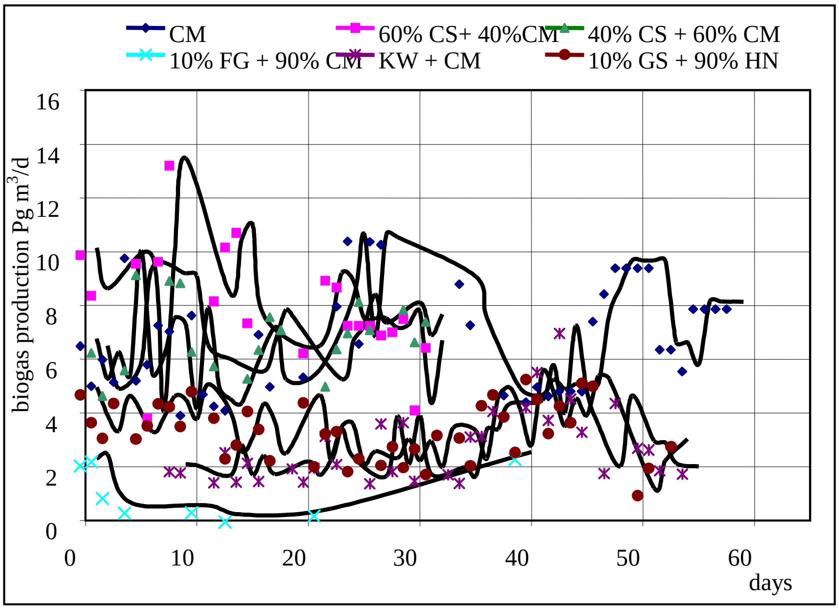

Fig. 5. Biogas production time behaviour

As it results from the graph given in Fig. 5, the biogas production increased only in the case of manure – corn silage co-fermentation. In the other cases a decrease of the biogas production was registered. The fermentation of the manure with fresh grass led almost to a total breakdown of the biogas production. But after some time the biogas production started to rise, what means that at a changeover from pure manure fermentation to co-fermentation necessary adaptation period of methanogenic bacteria is a longer one than the time duration of the particular experimental cycles. Therefore to compare an average biogas production, the Table 3 presents an average biogas production for the case of pure manure fermentation during a period when the anaerobic digestion process in digester was constant.

CONCLUSION

The experiment results show that an average methane volume in the produced biogas did not change significantly in the particular cycles. In the case of co-fermentation of manure with grass silage or kitchen waste its slight increase can be observed. A similar experiment with co-fermentation of manure with kitchen waste was done in laboratory conditions at the Institute for biotechnology in Braunschweig [Weiland&Rieger 2000], who consequently added to the manure 30, 50 and 70% of waste. In their experiments due to the kitchen waste addition to the manure the methane volume was significantly increased by 17%, and at an elongation of the substrate stay in a digester to 65 days even by 50% in comparison with the experiments with pure manure fermentation. In our experiments, the kitchen waste addition led to an increase of the methane volume in the produced biogas, but only less than 2%.

A comparison of the average biogas production shows that the best results were achieved when corn silage was added to the manure for the co-fermentation. Adding 40% of corn silage to the manure increased the average biogas production by 48,5% and adding 60% of corn silage to the manure resulted even in 72,7% increase of the biogas production. In the other cases the average biogas production was decreased: the most remarkable decrease (by 73,5%) was registered at co-fermentation manure with fresh grass.

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