Bernd Linke and Pia Mähnert, Potsdam-Bornim

Biogas Production from Cattle Slurry and Energy Crops

Effect of Fermenter's Load

The organic loading rate (OLR) on the base of volatile solids (VS) is an important parameter for biogas yield. Based on the substrate balance equation in a completely stirred digesters and the substrate decay after a reaction of the first degree an assessment equation is derived, where the VS-biogas yield is computed depending on the VS-loading rate B_R, the maximum possible biogas yield y_m, the VS-concentration in the substrate c_0 and a reaction rate constant k. The equation was proven in systematically organic load increasing experiments at 35 °C.

PD Dr. agr. habil. Dipl.-Ing. Bernd Linke is head of the Department Bioengineering and Dipl.-Ing. agr. Pia Mähnert is scientific employee at the Leibniz-Institute of Agricultural Engineering Bornim e.V. (ATB), Max-Eyth-Allee 100, 14469 Potsdam; e-mail: *blinke@atb-potsdam.de*

Summarized contribution to LANDTECHNIK. You will find the long version under LANDTECHNIK-NET.com

Keywords

Liquid manure, energy crops, biogas yield

Since the amendment of the Renewable Energy Sources Act (Erneuerbare Energien Gesetz) utilisation of energy crops is of interest. Proven technology is the common treatment of animal waste slurry as basic substrate and energy crops at mesophilic temperatures in co-digestion [1, 2]. Besides, digestion of energy crops as single substrate becomes more important. Starting with pilot scale experiments about 10 years ago in Triesdorf (Bavaria) with grass as substrate [3], further lab-scale experiments were conducted to obtain kinetic data for anaerobic digestion of fodder beets silage [4, 5, 6]. However, full-scale experiences with forage maize silage [7], whole crop rye silage [8] and fodder beets silage [9] as single substrate have shown that the biogas process operates stable and generates electric power. However, the organic loading rate (OLR) is recognised as the most important parameter for reactor dimensioning. Hence, long-term lab-scale experiments with forage maize silage, fodder beets silage, whole crop rye silage and cattle slurry were conducted in order to investigate the effect of OLR on the biogas yield. This effect can be described by means of a simple equation that is set up on the base of substrate mass balance in a completely stirred tank reactor (CSTR) and the substrate decay according a first order reaction.

A simple kinetic calculation model

On base of the mass balance equation of substrate in a completely stirred tank reactor (CSTR) with a volume V a simple kinetic model has been developed. The decay of substrate with a mass flow m_0 and a VS-concentration of the input c_0 follows a substrate removal rate r(c) which depends on c at a balanced concentration in the fermenter c_F (1).

$$V\,\frac{dc}{dt} = m_0 \cdot c_0 - m_0 \cdot c_F + V \cdot r(c) \quad (1)$$

There the reactor volume V is equal to the product of mass flow m_0 and the hydraulic retention time HRT. For the steady state of the reactor as dc/dt=0 and assuming that the substrate removal rate r(c) in a CSTR follows a first order reaction with a reaction rate constant k like r(c) = -k•c, HRT can be written as follows (2):

$$t_m = \frac{1}{k} \cdot \left(\frac{c_0}{c_F} - 1 \right) \quad (2)$$

The correlation between biogas yield y, the decayed substrate concentration c_0-c_F, the substrate concentration c_0 which can be converted to biogas and the maximum biogas yield y_m is shown in (3). Therefore, equation (4) results from combining (2) and (3).

$$\frac{c_0 - c_F}{c_0} = \frac{y}{y_m} \quad (3)$$

$$t_m = \frac{1}{k} \cdot \left(\frac{y}{y_m - y} \right) \quad (4)$$

With HRT = c_0/OLR and OLR as organic loading rate of the reactor on the basis of volatile solids, the biogas yield y can be calculated as follows (5):

$$y = y_m \frac{k \cdot c_0}{k \cdot c_0 + B_R} \quad (5)$$

Both, y_m and k can be determined by simple experiments and are substrate specific like c_0. Knowing y at a certain OLR, k can be estimated with equation 6).

$$k = \frac{B_R}{c_0} \cdot \left(\frac{y}{y_m - y} \right) \quad (6)$$

Substrate analysis and experiments

The energy crops investigated are silages from forage maize (variety Lincoln/Cascadas; end of soft dough), rye as whole crop (variety Avanti; end of heading) and fodder beets (variety Kyros; ensiling after cleaning). Co-digestion were carried out on base of cattle slurry from a dairy cattle plant. Samples of all substrates were analysed according to the German standard methods and averaged in *table 1*, compared with literature [10] (means in brackets) concerning total solids (TS), crude protein (XP), crude fat (XL) and crude fibre (XF). In addition to the mono-fermentation two mixtures of each energy crop with cattle slurry were investigated with a percent by VS-weight of about 67% and 33%, respectively.

Semi-continuous experiments were carried out with ten completely stirred tank reactors with a fermenter volume of 8 l at 35 °C. The biogas produced was collected in a gas bag each, measured daily by a multichamber gas meter (Ritter) and analysed by a gas analyser (Pronova) regarding the gas components CH_4, CO_2 and H_2S.

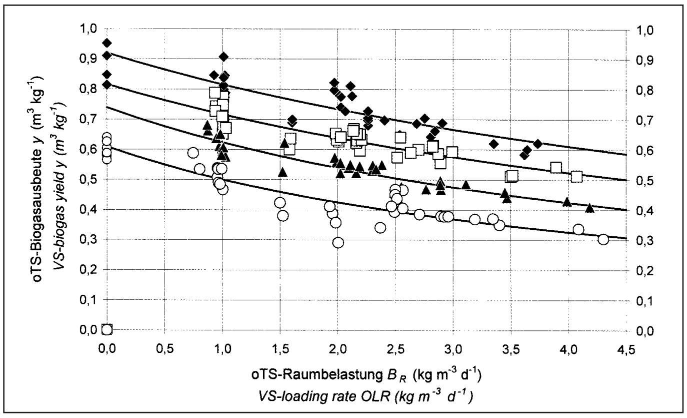

Fig. 1: Effect of VS-loading rate OLR on VS-biogas yield from continuous fermentation with forage maize silage and cattle slurry. (-◆-) Mono-fermentation (R^2=0.72); (-❑-) co-fermentation of 67 % forage maize silage (R^2=0.79); (-▲-) co-fermentation of 33 % forage maize silage (R^2=0.83); (-❍-) fermentation of cattle slurry (R^2=0.64); symbols at OLR=0 result from batch-experiments

Results

The effect of the organic loading rate OLR on the VS-biogas yield is shown exemplary for maize silage as mono-substrate and mixtures of maize silage and cattle slurry (*Fig. 1*). A decrease of VS-biogas yield occurs with an increase of OLR and an increased percentage of slurry in the mixture, respectively.

Curves according to eqution (5)can be fitted to attained VS-biogas yield. By knowing the VS-concentration of the input c_0 and with the fitted hyperbolic curves to measured values for about one year, the maximum biogas yield y_{max} and the reaction rate constant k can be calculated. Alternatively y_{max} can be estimated by a simple batch experiment and the biogas yield y results from semi-continuous experiments at the steady state of a reactor with OLR of about 2 or 3 $kgm^{-3}d^{-1}$. Accordingly, k is given by equation (6).

The influence of OLR on VS-biogas yield from the energy crops investigated have been different. Whereas the mono-fermentation of beet silage at an OLR of 3,0 $kgm^{-3}d^{-1}$ ($y_{BR=3}$) attains nearly maximum biogas yield, the fermentation of cattle slurry attains with 0,38 m^3kg^{-1} only 62 % of the maximum. This feature is substrate-specific and causes also different reaction rate constants k.

Energy crops attain with 55 to 57 % methane in the biogas a lower methane content than cattle slurry. Biogas yield and methane content of mixtures from energy crop and slurry are directly proportional to the amount of VS from substrates in the mixture (*table 2*).

Conclusions

Results from semi-continuous long-term experiments for anaerobic digestion of slurry and energy crops in a CSTR have shown that the effect of OLR on VS-biogas yield can be described by a simple kinetic calculation model. It is based on the VS-concentration of the input, the maximum biogas yield and a reaction rate constant. These parameters are substrate-specific and can be estimated by an analysis of volatile solids, a simple batch test and a long-term experiment at a defined organic loading rate.

Substrate	pH	TS	oTS VS	XP	XL	XF
	[-]	% FM	% TS	% TS	% TS	% TS
Maize silage	3.7	31 (35)	94.6	14.4 (8.1)	2.6 (3.2)	24.1 (20.1)
Beets silage	3.8	13 (15)	91.8	7.5 (7.7)	0.9 (0.7)	8.2 (6.4)
Rye silage [1])	4.7	23 (21)	86.7	9.4 (10.5)	3.3 (3.7)	31.6 (35.1)
Cow slurry	7.1	9.8	81.2	-	-	-

[1]) whole crop

Table 1: Average nutrient composition of the substrates used (-) values from [10]: pH, total solids (TS), volatile solids (VS), crude protein (XP), crude fat (XL) and crude fibre (XF)

Substrate	c_0 g kg^{-1}	y_m $m^3 kg^{-1}$	k d^{-1}	$y_{(BR=3)}$ $m^3 kg^{-1}$	CH_4 Vol-%
100% Maize silage	292	0.92	0.027	0.67	54.6±1.3
67% Maize silage	147	0.82	0.049	0.58	56.2±1.4
33% Maize silage	98	0.74	0.055	0.48	58.1±1.1
100% Beet silage	124	0.93	0.273	0.85	55.5±2.2
67% Beet silage	100	0.80	0.252	0.71	56.4±2.1
33% Beet silage	84	0.73	0.129	0.57	58.4±1.3
100% Rye silage [1])	198	0.91	0.037	0.65	57.2±1.7
67% Rye silage	125	0.81	0.056	0.57	58.3±1.5
33% Rye silage	92	0.72	0.066	0.48	59.9±1.3
Rindergülle	72	0.61	0.064	0.37	61.3±1.9

[1]) whole crop

Table 2: Results of continuous fermentation of energy crops: average VS-concentration of the substrate c_0; maximum VS-biogas yield y_m and reaction rate constant k; VS-biogas yield at OLR of 3 $kgm^{-3}d^{-1}$ (y_{BR}=3) and methane content of the biogas (n = 69 to 74)

Literature

Books are identified by •

[1] *Weiland, P.*: Anaerobic waste digestion in Germany - status and recent developments. Biodegradation (2000), no. 11, pp. 415-421

[2] -: Wissenschaftliches Messprogramm zur Bewertung von Biogasanlagen im landwirtschaftlichen Bereich. Abschlussbericht, Institut für Technologie und Biosystemtechnik, Bundesforschungsanstalt für Landwirtschaft (FAL), FNR-FKZ: 22 01 79 00, (2004)

[3] • *Graf, W.*: Kraftwerk Wiese - Strom und Wärme aus Gras. 1. Auflage, Eigenverlag, 1999, 143 S.

[4] *Hassan, E., und P. Weiland*: Untersuchungen zur Vergärung von Futterrübensilage. FKZ AZ 99UM031, Bundesanstalt für Landwirtschaft und Ernährung Frankfurt/M., 2001

[5] *Linke, B.*: Biogas aus Energiepflanzen - Ergebnisse aus Langzeitversuchen im Labor. Agrartechnische Forschung 9 (2003), S. 78-82

[6] *Abdel-Hadi, M., J. Beck und T. Jungbluth*: Methanerträge bei der Kofermentation flüssig silierter Gehaltsrüben. Landtechnik 57 (2002), H. 2, S. 96-97

[7] *Rugen, A.*: Erfahrungen aus dem Praxisbetrieb einer reinen NawaRo-Anlage. In: Biogas, Nachwachsende Rohsstoffe, Neue Wege für die Landwirtschaft, Tagungsband 14. Jahrestagung des Fachverbandes Biogas e.V., 11.-14. Januar 2005, Nürnberg, S. 47-53

[8] http://www.graskraft.de/beispiele/dolgelin.html

[9] *Scherer, P. A, S. Dobler, S. Rohardt and R. Loock*: Continuous biogas production from fodder beet silage as sole substrate. Water Science and Technology 48 (2003), pp. 229-233

[10] *Kirchgessner, M.*: Tierernährung. 10. Auflage, Verlags Union Agrar, Frankfurt/M. , 1997