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Determining Biogas Yields from Co-substrates in Semi-continuously Operated Laboratory-Scale Digesters

Gas yields are usually derived from batch experiments. To approximate full-scale conditions, fermentation tests were carried out in semi-continuously fed digesters. The biogas yields obtained from forage maize and from grass silage were 617 LN (kg VS)$^{-1}$ and 493 LN (kg VS)$^{-1}$ with a methane content of 53.6% and 54.0 % respectively.

Designers and clients of biogas-plants typically resort to the many different gas-yields given in literature, which in some cases show a significant variation [1, 2, 3]. Almost all biogas- and methane-yields of diverse usable (co-) substrates given in literature are derived from batch-tests [4]. In practice however, except for some fermentations of solid substrates, there are just a few plants run in batch operation.

Agricultural biogas-plants are run in flow-through-operation. They are charged semi-continuously, one to several times per day. Thereby, significant differences to batch-operation exist, such as an even loading-rate and a constant hydraulic retention time, (that is a theoretical value anyway). In reality, the substrates are never completely decomposed within a definite time period as it is accomplished in batch-experiments.

Experimental setup

The pilot-scale-fermenters (36 L) consist of nine cylindrical, double wall containers with heating-water-circuit, agitator, gas-volume-measurement, gas-collector and gas-analysis. *Figure 1* shows one of those fermenters with a net volume of 28 L. The six glass-fermenters of this plant were operated semi-continuously while batch-tests were conducted in three stainless steel fermenters.

Substrates

The renewable raw materials forage maize - and grass-silage, and as a third substrate rape seed oil, have been selected for the test. Forage maize silage is characterised by a high starch content, while grass silage contains a lot of fibres (*Tab. 1*). In comparison, rape seed oil is a completely degradable substrate, free of fibres (Tab. 1) and was chosen therefore, although its usage as fuel is much more reasonable in practice.

Proceeding

The three substrates were collectively digested with an actively fermenting basis-substrate as inoculum. The inoculum was obtained from a digester charged semi-continuously with liquid manure and total mixed ration (TMR). Set-up and characteristics of this basis-substrate are described in [5]. To start the experiments, the six 36 L-digesters to be charged semi-continuously were filled up with 28 L of water. Afterwards three of

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Keywords

Biogas, co-substrates, continuous flow, laboratory-scale-digester

Literature

Literature references can be called up under LT 05613 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm.

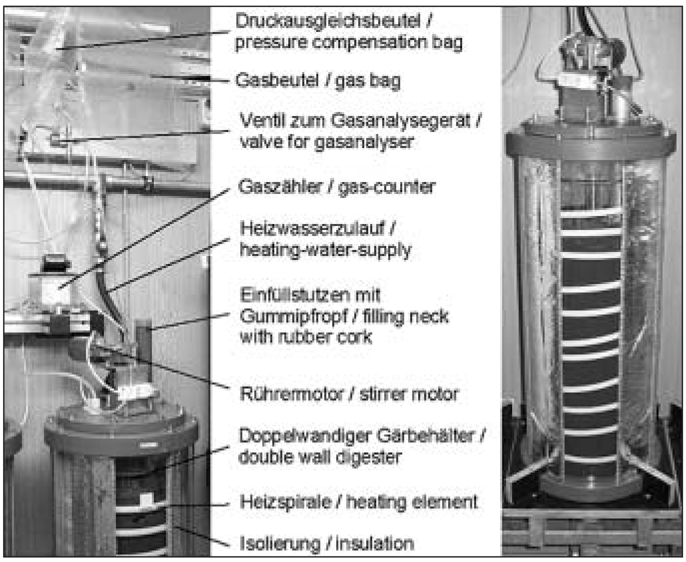

Fig. 1: Laboratory-scale digester

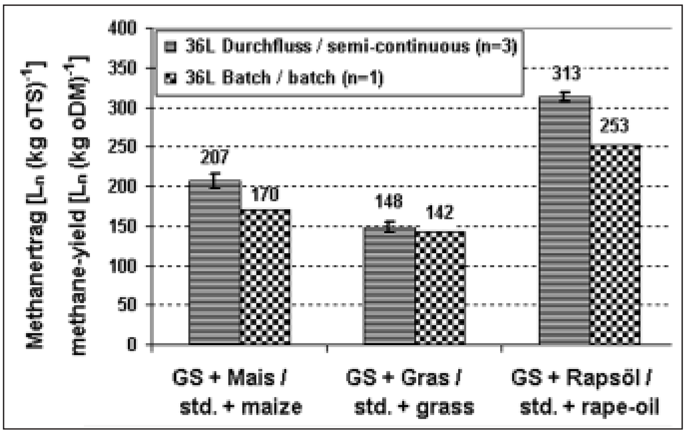

Fig. 2: Methane yields related to volatile solids supplied to the digesters (std = standardized substrate)

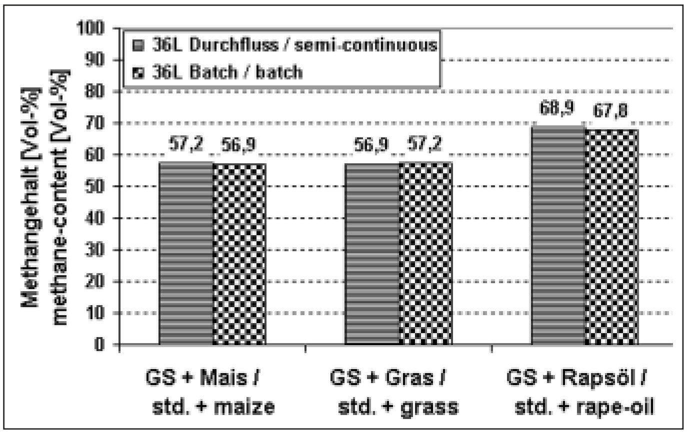

Fig. 3: Average methane-content of the biogas produced (std = standardized substrate)

them were charged with a mixture of inoculum and one of the test-substrates on six days per week. The three remaining digesters were used to obtain a blank value. Therefore the substrate-dosage was replaced by an equivalent mass of water in order to get the same hydraulic retention time as for the other digesters.

The dosage of the substrates to be tested was calculated to 1.7 kg VS m^{-3} d^{-1}.

The digesters operated in batch-mode were charged with an equal mass of inoculum and water and in the following charged with test-substrate. The reference was charged with water instead of substrate.

Results

The results of the batch-tests are adapted to the same hydraulic retention-time of 32.7 days as used for the semi-continuous fed digesters. The three accomplished substrate-tests resulted in lower specific methane-yields in batch operation than in semi-continuous operation (*Fig. 2*). With regard to the gained methane-yields, no significant differences between both digesting-methods were noticeable (*Fig. 3*).

In *Table 2* the biogas- and methane-yields related to the added organic dry matter of the test-substrates are shown in comparison to theoretically calculated values. The latter were determined on basis of the „Weender-Analysis“ (*Table 1*) [6, 7] by using the corresponding digestibility values of ruminants.

Discussion

The fact of lower specific methane-yields of batch-tests compared to semi-continuous charged fermenters may be due to synergistic effects. It is possible, that the activity and specialization of the biocenosis is better in flow-through than in batch-tests. This fact is also affirmed in [8]. The obtained gas yields of grass silage and of rape seed oil are less than 10% lower than the theoretical calculated values. In case of the forage maize silage the value obtained from the experiments is even somewhat higher than the theoretical one. An explanation for this is that metabolism does not take place in the same way in the rumen as inside of a digester. Maize silage contains a lot of starch (Fig.1) which will be degraded in a digester as easily as in a ruminant. In comparison grass silage has a high content of fibres that will be degraded faster by the complex intestinal micro-organisms of a ruminant than by the bacteria in a digester. Grease is a very easily degradable material and should be digested with the same velocity by a ruminant as in vitro. The noted difference nevertheless may have been caused by secretions of enzymes and emulsifiers that are able to accelerate the degradation inside the rumen as opposed to a digester.

Concerning occurring synergy effects there are quite contradictory statements to be found in literature [9], hence it seems very reasonable to investigate this phenomenon by a systematic study.

Co-substrate analytic parameters	corn-silage	grass-silage	rapeseed oil
DM [%]	39.3 ± 6.7	49.2 ± 7.8	100.0
VS [% DM]	95.8 ± 3.1	90.2 ± 3.3	99.95
COD [gO_2/kg]	481.8 ± 49.9	623.7 ± 91.7	2415.6
free volatile fatty acids [mg/L]	5092 ±(1929	5329 ± 4524	25.71
raw protein [% DM]	8.6 ± 0.5	15.1 ± 1.2	n.d.
raw fiber [% DM]	17.7 ± 2.1	31.9 ± 0.9	n.d.
raw fat [% DM]	2.4 ± 0,5	1.5 ± 0.4	98.6
starch [% DM]	38,3 ± 2.7	1.8 ± 0.7	n.d.
sugar [% DM]	n.d.°	0.7	n.d.
N-free extractable solids [% DM]	67.2*	41.8*	n.d.
NDF [% DM]	43.7 ± 2.5	62.9 ± 2.9	n.d.
ADF [% DM]	20.2 ± 1.4	38.0 ± 1.9	n.d.
ADL [% DM]	18.6 ± 1.4	34.2 ± 1.6	n.d.
hemi-cellulose[% DM]	23.5*	24.8*	n.d.
cellulose [% DM]	1.6*	3.8*	n.d.

* calculated value ° not detectable

Tab. 1: Durchschnittliche Analysenwerte mit Standardabweichung der Co-Substrate; Analysen nach [10, 11]

Tab. 1: Mean values of the analysed parameters of the co-substrates; analyses according to [10, 11]

Tab. 2: Comparing biogas and methane yields obtained from the tested co-substrates in semi-continuous run digesters versus the equivalent values calculated on the basis of theoretical degradability

Co-substrate	Biogas yield experim. [LN (kg VS)$^{-1}$]	Methan yield experim. [LN (kg VS)$^{-1}$]	Biogas yield theor. [LN (kg VS)$^{-1}$]	Methan yield theor. [LN (kg VS)$^{-1}$]
Maize silage	617 ± 39	331 ± 23	594	309
Gras silage	494 ± 34	266 ± 19	545	291
Rape oil	1053 ± 32	745 ± 21	1200	816