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Residual biogas yield of digestate from agricultural biogas plants

To evaluate the residual biogas yield during storage, biogas tests at a temperature of 22 °C were performed with samples of liquid digested residue from 15 agricultural biogas plants (BGP). Values of residual biogas yield between 0.3 and 1.3 % with respect to the biogas yield from the raw input materials were measured. For the two one-stage BGP, the value was about 1.2 %. For the two-stage plants, a residual biogas yield (RBY) of 0.9 % was determined as opposed to 0.4 % for the three-stage plants. With a single exception, the RBY was clearly below 1.0 % if the overall hydraulic retention time in the BGP was equal to or larger than 100 days. For the majority of samples, the residual biogas yield showed a positive correlation with the level of volatile fatty acids in the digestate. Since the real conditions in storage tanks cannot be simulated with a simple batch-test, the results are not representative for the actual biogas production and potential methane emissions from the digestate during open storage.

Keywords
Biogas, greenhouse gases, energy crops, animal manure

Abstract
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For biogas production from renewable raw materials (RRM) the main expense factor is the supply of these materials. Besides minimizing losses during harvest and storage, it is therefore necessary to maximize the biogas yield from the input material in order to reach economic operation of a biogas plant. Also, from the point of view of environmental economics, the input materials should be degraded as far as possible to improve the overall energy balance of the biogas production process and reduce potential methane emissions from the digested residue during storage in open tanks. To evaluate the degree of degradation of the input, a test for residual biogas yield can be performed. Such a test involves the anaerobic degradation of a sample of digested residue in a batch test at laboratory scale. This paper discusses the results of such tests for 15 agricultural biogas plants (BGP).

Materials and Methods

The 15 BGP from which the samples of liquid digested residue were taken were commissioned in the years 2001 to 2006. All of the plants treat RRM, partly in mixture with liquid or solid manure (**table 1**). Eleven of the 15 plants were operated at mesophilic and four plants at thermophilic temperature level.

The biogas tests were performed at the experimental facilities of the Institute for Agricultural Engineering and Animal Husbandry. Samples of digested residues from the biogas plants were taken from the last digester upstream of the storage tank.

The tests for residual biogas yield were performed in three replicates at two different temperature levels and over a period of 60 days. To evaluate the degree of degradation, tests were done at a temperature of 38°C. To estimate the potential biogas yield during storage in a tank without external heating, tests were done at a temperature of 22°C. The digestate samples were incubated in flasks with a usable volume of 2 L without adding any inoculum.

The (relative) residual biogas yield (RBY) was calculated as the ratio of the biogas yield measured in the batch-test and the actual biogas yield determined for the biogas plant. For the calculation of the biogas yield in the batch-test, the value of organic dry matter (ODM) content was adjusted according to the degradation of ODM in the biogas plant.

Results and Discussion

The results from the biogas tests with samples from 15 different BGP showed a large variation. At a temperature of 38°C, residual biogas yields varied from 1.3 to 6.1 %. As expected, at a temperature of 22°C, the values were significantly lower. In this case, the residual biogas yields varied from 0.3 to 1.3 %. For the individual plants, this was between 12 and 47 % of the residual biogas yield determined in the „warm“ tests (24 % on average). There was a tendency of a larger difference between

Table 1

Characteristics of investigated biogas plants

Characteristics		from	to
Year of commissioning		2001	2006
Digesters in series		1	3
Total usable digester volume[1)]	m^3	1 080	4 200
Total storage capacity	m^3	739	5 000
Average temperature in primary digester	°C	40	53
Average temperature in last digester	°C	19	53
Hydraulic retention time	d	35	144
Organic loading rate	kg oDM • $(m^3 • d)^{-1}$	1,8	6,2
Specific methane productivity	$Nm^3 • (m^3 • d)^{-1}$	0,34	2,4

[1)] Sum of the usable volume of all digesters (excluding covered storage tanks)

„cold" and „warm" tests for thermophilic compared to mesophilic BGP. This can be explained by the larger temperature drop in the thermophilic plants affecting the methanogenic organisms. For the individual plants, the curves of cumulated biogas production during the biogas tests showed considerable differences. In some cases, variable gas production rates reflected several phases of degradation of different components. **Figure 1** gives an example of the biogas production during tests with samples of digested residue from a two-stage, mesophilic BGP. In this case, biogas production in the „warm" test started instantaneously and then declined during the first day. Presumably, the digestate sample from this plant still contained a small amount of easily degradable organics. From the third day up to the eighth day of the test, the biogas production rate increased again and then slowly faded toward the end of the test period. In the „cold" test, the gas production commenced only after a lag-phase of about ten and a half days.

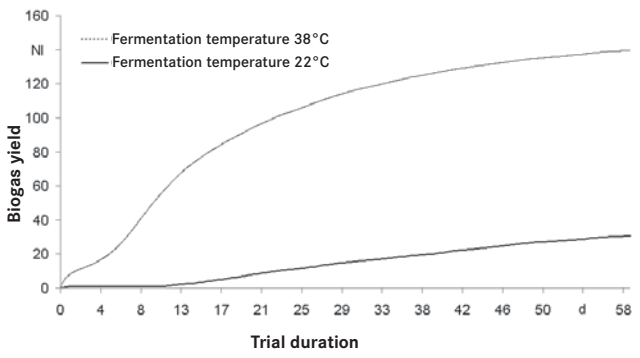
The further discussion of the results refers only to the „cold" biogas tests at 22 °C. The correlation between residual biogas yield and overall hydraulic retention time (HRT) in the biogas plants is not entirely clear (**figure 2**). If the data from one-, two- and three-stage plants are evaluated separately, the values of RBY for the latter three plants with similar HRT around 130 days are on a similar low level. Compared to these, the two single-stage plants with a large difference in HRT showed more than double the RBY (about 1.2 %). For the two-stage plants, both the values of HRT and RBY were highly variable.

The highest value of RBY of 1.7 % was determined for a BGP with a pre-acidification stage and a HRT of 131 days. Apart from this exception, the RBY was always significantly below 1.0 % given a HRT of equal to or more than 100 days. On average, the RBY for the two-stage plants was 0.9 % as opposed to 0.4 % for the three-stage plants. For a sample of 60 biogas plants across the country, the average RBY was 3.7 % for one-stage and 1.4 % for two- and more-stage plants [1]. In this case, the RBY was below 2 % for a HRT larger than 100 days (one exception).

If the values of RBY are plotted against specific methane productivity (SMP) of the individual biogas plants, then the two one-stage plants with values of SMP of 1.8 and 2.4 $m^3 • (m^3 • d)^{-1}$ exhibited clearly higher-than-average values of RBY (diagram not shown). With values of SMP of 1.0 to 1.2 $Nm^3 • (m^3 • d)^{-1}$ and RBY of 1.4 to 1.7 % three of the two-stage plants showed the lowest efficiency.

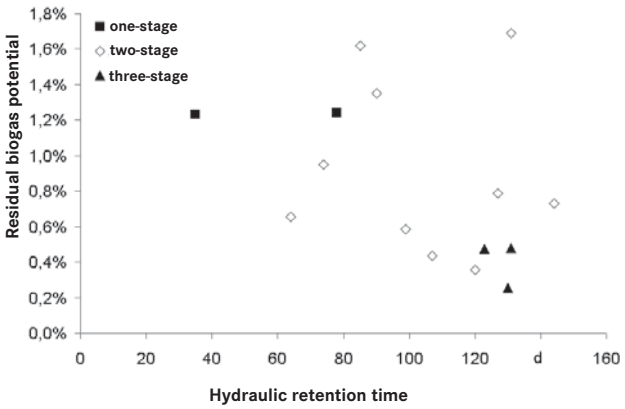
The concentration of volatile fatty acids (VFA) in a sample of the digested residue can be used as an indicator for the remaining digestion activity and thus for the residual potential biogas yield. **Figure 3** shows this interrelationship for the results at hand. No detectable levels of VFA were found in samples from five two-stage BGP. With one exception, these samples also showed a very low RBY (≤ 0.65 %). For the remaining samples, the RBY positively correlated with VFA content, and pairs of values for one-stage and two-stage plants each were situated close together. The highest VFA concentrations were found in samples from two biogas plants of the same type with a pre-acidification stage.

Fig. 1



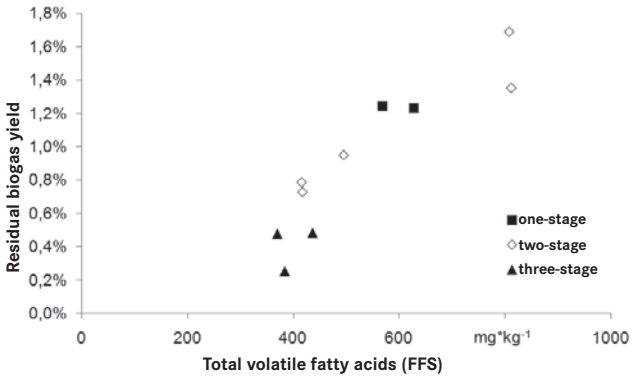
Development of cumulated biogas production during „warm" and „cold" biogas tests for a two-stage biogas plant (mean temperature in 2nd stage: 43 °C; total hydraulic retention time: 99 days; input: 58 % (m/m) energy crops, 42 % liquid pig manure)

Fig. 2



Overall hydraulic retention time (d) and residual biogas yield (%)

Fig. 3



Volatile fatty acid concent (FFS total; mg • kg$^{-1)}$ in samples of plant effluent and residual biogas yield (%)

Conclusions

The values of the residual biogas yield of the digested residues from 15 full-scale agricultural biogas plants that were determined in batch-tests show a large variation. This is the result of different biogas plant configurations in combination with a large variety of input materials. The curves of cumulative biogas production over time indicate that the digested residue still contained various organic compounds with different anaerobic degradability. Given a HRT below 100 days, an increased RBY of larger than 1 % is to be expected, even for biogas plants with two or more digesters in series. Single-stage plants with high specific methane productivity and a HRT that is typically significantly lower than 100 days clearly exceed this value. As a rule of thumb, the level of RBY may be estimated based on the level of VFA in the digestate: For a RBY smaller than 1 %, the total VFA concentration should be below 500 mg • kg^{-1}. It is important to note that the actual biogas production and the resulting methane emissions during storage of the digested residue in open tanks cannot be quantified with a batch-test. Such a test is not suitable to simulate the real-world conditions during digestate storage.

Literature

Books are signed with ●

[1] ● Johann Heinrich von Thünen-Institut: Bundesmessprogramm zur Bewertung neuartiger Biomasse-Biogasanlagen: Abschlussbericht, FNR-FKZ: 22003405. Braunschweig, Januar 2009

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