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Effects of the gas-tight cover of digestate storage tanks in biogas production

Two facilities, one with and one without gas-tight closure of the digestate storage tank, were monitored. By inclusion of the digestate storage tank in the digester system, the hydraulic retention time increased from 40 to about 110 days. As a consequence, the utilization degree of gas forming potential of the substrates and, in this way, the energy production could be improved by about 3 %, respectively. The thereby avoided methane emission from an unheated storage tank, however, is much lower. It amounted to 1.5 % of the total gas forming potential of the substrate during summer and to less than 1 % if calculated for the whole year.

Keywords
Biogas, gas forming potential, substrate utilization, methane yield, methane emission

Abstract
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If the gas forming potential of substrates in biogas production is incompletely utilized, then there is a risk of emissions of the climate-damaging gas methane into the atmosphere during the subsequent storage of the digestate [1]. Therefore, recently implemented legal obligations require the general gas-tight cover of all digestate storage facilities and their inclusion in the gas utilization system. The validity of this far reaching claim has been questioned [2]. However, the full utilization of the gas forming potential of substrates also is in the economic interest of the operator of the biogas plant. This article reports on a study on the economic and ecological effects of the gas-tight cover of the digestate storage tank of a biogas plant under practical conditions with professional management.

Material and Methods

Two identical 500 kW biogas plants were monitored for 12 weeks – one without and one with gas-tight cover of the digestate storage tank. The substrate mixture was identical and contained maize silage (35 % of FM) and cattle slurry (65 % of FM). The hydraulic retention time of the digester (biogas plant 1) was 40 days and the volumetric loading 4 kg organic matter (OM) per m^3 and day. Due to the inclusion of the digestate storage tank in the gas-tight system (biogas plant 2), hydraulic retention time increased to 107 days, and the volumetric loading decreased to 1.5 kg OM per m^3 and day. The study was started in spring 2010 after cleanout of the digestate storage tanks and continued during the following summer months at high ambient temperatures.

The gas forming potential of the input substrates was determined by chemical analyses of a total of 24 maize silage samples and 12 slurry samples and subsequent calculation of the fermentable organic matter (FOM) [3]. The output of non-utilized substrate was analyzed based on 24 digestate samples for each of the two biogas plants.

The DM content of maize silages was corrected for the loss of volatile organic compounds during oven drying according to the equation [4]:

$$DM_c\ [g/kg] = DM + 0.95\ VFA + 0.08\ LA + 0.77\ PD + 1.00\ AA, \quad \text{(eq. 1)}$$

where is VFA = volatile fatty acids (C_2-C_6),
LA = lactic acid,
PD = 1,2-Propanediol and
AA = sum of other alcohols.

All values in the equation are used in the dimension g/kg fresh matter (FM).

The calculation of FOM contents [3] was done by employing the following equations:

- Maize silage

$$FOM\ [g/kg\ DM_c] = 984 - (XA) - 0.47\ (XF) - 0.00104\ (XF)^2 \quad \text{(eq. 2)}$$

- Cattle slurry

$$FOM\ [g/kg\ DM] = 0.50\ (1000 - XA) \quad \text{(eq. 3)}$$

Table 1

Gas and energy production during the experiment

		Anlage 1/*Biogas plant 1* (n = 84)		Anlage 2/*Biogas plant 2* (n = 84)		Relativ/*Relative* (Anlage 1 = 100)
		Mittel/*Mean*	SD	Mittel/*Mean*	SD	
Gaserzeugung/*Gas production*						
Biogas *Biogas*	m^3 (N)/Tag	6 098	358	6 300	254	103,3
Methan *Methane*	m^3 (N)/Tag	3 232	190	3 339	135	103,3
Nutzung des Methans/*Methane use*						
Stromproduktion *Production of electricity*	m^3 (N)/Tag	3 217	178	3 251	84	101,1
Heizung & Fackel *Heating & torch*	m^3 (N)/Tag	15	59	88	91	
Stromerzeugung/*Electricity production*						
Gemessen *Measured*	kWh	12 329	903	12 429	385	100,8
Berechnet[1)] *Calculated*[1)]	kWh	12 226	677	12 354	321	101,1

[1)] kWh_{el} = verstromtes Methan • 3,8 kWh/m^3 / *kWh_{el} = for electricity production used methane • 3,8 kWh/m^3.*

Where XA is crude ash and XF is crude fibre (all values used in the dimension g/kg DM_c and DM, respectively).

The degree of utilization of the gas forming potential was calculated by using a marker-method in which the concentration of crude ash in DM was used as an internal marker [5].

Furthermore, every two weeks large samples of digestate were taken from each biogas plant, filled into 30 L drums under nitrogen atmosphere and brought to the laboratory. Subsequently, batch fermentation testes were carried out, using these drums, at two different temperature levels for 30 days. Incubation temperature was either constantly 38 °C or ambient, whereat the latter fluctuated between 21 and 27 °C (mean: 24 °C).

Energy production

Gas and energy production as well as the use of the produced methane were recorded for 84 days. Produced methane volumes (m^3 (N) = m^3 volume under standard temperature and pressure) are given in **Table 2**. During the initial phase of the study, small volumes of methane from biogas plant 2 were used for heating of a greenhouse.

Both biogas plants practically produced the same amount of electricity. The measured number of kWh is almost identical to that which can be calculated based on the methane used for electricity production (volume produced minus volume consumed for heating and torch) under the assumptions that methane has a caloric value of 10 MJ/m^3 (N) and the efficiency of the cogeneration units is 38 %.

The higher methane consumption for the torch in biogas plant 2 was supposedly caused by the higher amplitude in temperature-related volume variations in the vastly empty digestate storage tank, which was included in the gas-tight system. Taking into consideration the additional methane consumption for heating and torch in biogas plant 2, this plant produced 3.3 % more energy.

Gas forming potential and degree of utilization

The degree of utilization of the gas forming potential of the substrate mix can be calculated by using the follwing equations [5]:

$$UQ = \frac{1000}{FOM}\left(1 - \frac{XA_S}{XA_R}\right) \quad \text{respectively} \quad UQ' = \frac{1000}{FOM(1-BQ)}\left(1 - \frac{XA_S}{XA_R}\right) \qquad \text{(eq. 4)}$$

XA_S and XA_R are the crude ash contents of the substrate and the digestate, respectively. All values are given in the dimension g/kg DM. The apparent utilization coefficient (UQ) does not consider that a certain proportion of FOM is incorporated into the bacterial biomass of the microflora. The calculation of the true utilization coefficient (UQ') accounts for this incorporation which is quantified by BQ (biomass forming quotient).

Table 2 contains all analytical values for the substrate mixture and for the digestate. The concentrations of FOM and XA in the substrates refer to mean values for the whole experimental period. It is important to note that all input substrates, including mineral additives (trace mineral mixes and desulphurization products), must be accounted for. This is only possible by using the mean values for XA_S for the whole experimental period. However, the XA contents of the digestate samples are used as individual values in the calculation of the respective utilization coefficient. In addition to reporting the mean values

Table 2

Contents of „fermentable organic matter“ (FOM) and of ash and utilization of the substrate mixture

	Anlage 1/*Biogas plant 1*		Anlage 2/*Biogas plant 2*		Relativ/*Relative* (Anlage 1 = 100)
	Mittel/*Mean*	SD	Mittel/*Mean*	SD	
FoTS-Gehalt der Substratmischung (n = 12) FoTS [g/kg TS] *FOM content of substrate mixture (n = 12) FOM [g/kg DM]*	709,4		708,1		
Rohaschegehalt der Substratmischung (n = 12) XA_S [g/kg TS] *Ash content of substrate mixture (n = 12) XA_S [g/kg DM]*	71,3		70,8		
Rohaschegehalt der Gärreste (n = 24) XA_R [g/kg TS] *Ash content of the digestate (n = 24) XA_R [g/kg DM]*	229,5	13,0	240,8	19,6	
Scheinbare Substratausnutzung NQ *Apparent utilization of the substrates NQ*	0,970	0,025	0,994	0,033	102,5
Wahre Substratausnutzung[1)] NQ‘ *True utilization of the substrates[1)] NQ‘*	0,990	0,025	1,015	0,033	102,5

[1)] Bei Annahme von BQ = 0,02/*Presumed BQ = 0.02.*

also the standard deviations for XA_R and NQ and NQ’, respectively, are given.

The degradation of organic matter in the fermenter results in an increase in crude ash content per kg DM. Based on this increase, it can be concluded that FOM was almost fully utilized in both biogas plants. However, biogas plant 2 showed an improved utilization of the substrates by 2.5 % in comparison with biogas plant 1. This observation was not affected by the presumed rate of bacterial incorporation (BQ). The somewhat higher efficiency of the biogas plant with the air-tight cover of digestate storage cover, as established regarding the energy production, is hereby confirmed.

Residual gas potential

In this study, the methane forming potential (MFP) of the substrate mixture was used as the basis to evaluate the residual gas formation potential of the digestate. This parameter was not available in previous studies on the residual biogas formation from digestate as measured in fermentation tests by other authors [1, 2]. The use of this parameter as basis of evaluation has the advantage that it is independent of other efficiency characteristics of the respective biogas plant.

For this purpose, the methane volume measured in the fermentation tests and commonly expressed as volume per kg oDM of the digestate (oDM_R) was re-calculated to the methane volume per kg DM of the substrate (DM_S). This was done by using the figure “content of organic dry residue” (oDR) per kg DM of the substrate. This parameter is defined as:

$$oDR\ [g/kg\ DM_S] = 1000 - XA_S\ [g/kg\ DM_S] - FOM\ [g/kg\ DM_S] \quad \text{(eq. 5)}$$

The oDR means the oDM of digestate if FOM of substrate is fully (100 %) utilized. Consequently, the methane formed from the digestate and expressed on DM basis of the substrate can be calculated using the following equation:

$$\text{methane}\ [L/kg\ DM_S] = \text{methane}\ [L/kg\ oDM_R] \bullet oDR\ [g/kg\ DM_S]/1000 \quad \text{(eq. 6)}$$

The methane production figures obtained by this calculation, can then be expressed as percent of the methane forming potential of the substrate (kg FOM • 420 L) and, thus, can be evaluated, independently of other characteristics of the respective biogas plant. Results are summarized in **Table 3**.

The digestate of biogas plant 2 had a markedly lower residual methane forming potential than that of plant 1. Related to the methane forming potential of the substrate, it is declined from 8.1 % to 5.5 %. Both values still appear to be rather high and should be motivation to effords for more efficient substrate utilization. However, for the evaluation of the effect which can be ascribed to gas-tight cover of the digestate storage tank, only the difference between the two biogas plants is of importance. This difference is 2.6 % and confirms very well the effects which were found regarding substrate utilization (2.5 %) and energy production (3.3 %).

The decrease of the methane emission potential achievable by the gas-tight cover of an unheated digestate storage tank is even lower. The avoidable prevention of methane emission amounted to 1.5 % of the total gas forming potential of the substrate during summer and less than 1 % if calculated for the whole year.

Conclusions

In general, it should be concluded that the gas-tight cover of digestate storage tanks and its inclusion in the gas-utilizing system in professional managed biogas plants can improve the utilization of the gas forming potential by about 3 %. This applies to the operation under summer temperatures. On account of the fact that the stored digestate in unheated tanks during winter cools down more and faster than in summer, the economic benefit is likely to be fairly less than 3 % if calculated for the whole year.

Table 3

Results of intermittent fermentation tests with the digestate from biogas production (n = 7 tests with 3 replicates each)

	Anlage 1/*Biogas plant 1*		Anlage 2/*Biogas plant 2*		Differenz	
	Mittel/*Mean*	SD	Mittel/*Mean*	SD	Mittel/*Mean*	SD
Methanbildung aus dem Gärrest bei 38 °C (Rest-Methanertragspotenzial) ***Methane forming from the digestate at 38 °C (residual methane yield potential)***						
L(N)/kg $oTS_{Gärrest}$ *L(N)/kg $OM_{digestate}$*	119,7	3,5	78,6	11,8		
L(N)/kg $TS_{Substrat}$ *L(N)/kg $DM_{Substrate}$*	26,3	0,8	17,4	2,6	8,9	2,7
% des MBP des Substrats *% of MFP of substrate*	8,1	0,2	5,5	0,8	2,6	0,8
Methanbildung aus dem Gärrest bei 24 °C (Rest-Methanemissionspotenzial) ***Methane forming from the digestate at 24 °C (residual methane emission potential)***						
L(N)/kg $oTS_{Gärrest}$ *L(N)/kg $OM_{digestate}$*	41,4	7,8	20,1	8,2		
L(N)/kg $TS_{Substrat}$ *L(N)/kg $DM_{Substrate}$*	9,1	1,7	4,4	1,8	4,6	0,9
% des MBP des Substrats *% of MFP of substrate*	3,0	0,5	1,5	0,6	1,5	0,3

MBP = Methanbildungspotenzial/*MFP = methane forming potential*

The amount of methane, whose emission into the atmosphere can be avoided from an unheated storage tank by a gas-tight cover, is even lower. During the summer period it amounts to approximately 1.5 %, and during whole year it will be less than 1 % of the total gas forming potential of the used substrates. Therefore, it is questionable whether the general request of digestate storage under air-tight cover is justified [2].

Literature

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