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Degree of utilization of primary renewable products in biogas production

For the prediction of gas forming potential, the parameter “content of fermentable organic matter” (FOM) was proposed. The use of this parameter also enables the evaluation of the efficiency of the fermentation process by measuring the degree of utilization of FOM.

Keywords
Biogas, biogas yield, renewable primary products, biogas forming potential, fermentable organic matter, degree of degradation, biogas fermenter

Abstract
Landtechnik 64 (2009), no. 1, pp. 18 - 21, 2 figures, 3 tables, 6 references

Within biogas production, degree of degradation is defined as „reduction in the concentration of organic substance due to anaerobic degradation expressed relative to the original content of the substrate” [3]. Normally, organic matter (OM) or chemical oxygen demand (COD) is the subject of balancing in determining the degradation degree. Those balances only result in information about a partial degradation since OM as well as COD includes the substrate proportion which is non-biodegradable. Therefore, these balances do not indicate as to whether the extent of degradation was limited by the non-degradable fraction of OM or by poor efficiency of the fermentation process. However, by balancing „fermentable organic matter“(FOM) instead of OM or COD, it seems to be possible to determine the degree of utilization of the true gas production potential of substrates. The aim of the present study was to measure this degree of utilization in practical conditions. Additionally, it was the intention to verify the recently proposed biogas yield of renewable primary products (RPP) as 800 litres of biogas and 420 litres of methane, respectively, per kg FOM [6].

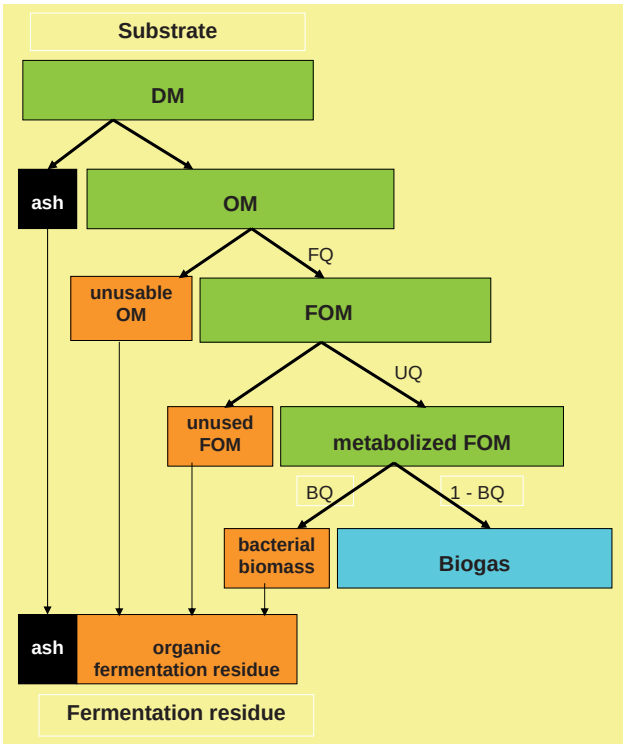
Materials and methods

In the scope of the study, 3 fermenters of an industrial biogas production facility were monitored. These fermenters had a net volume of 2,575 m^3 each and were fed a substrate mixture of identical composition. Fermenters were run with one-phase fermentation process at mesophilic temperature and were fed at a loading rate of approximately 3 kg OM per m^3 and day. Feeding was done almost continuously by administering about 32 portions of substrate per day, which had been mixed with material taken from fermenter prior to feeding. Based on OM, substrate mixture was composed of 2% slurry, 15% milled grain and 83% whole-plant maize silage. Hydraulic retention time was approximately 90 days.

During a period of 3 months, samples of substrates and fermentation residues were taken from each of the 3 fermenters and analyzed on regular intervals. A total of 67 samples of whole-plant maize silage, 36 samples of milled grain, 23 samples of slurry and 126 samples of fermentation residues were analysed for dry matter (DM) and crude ash (XA). In maize silage and milled grain also crude fibre (XF) was determined. DM content of maize silage was corrected for the loss of volatiles during drying [5]. FOM concentration was calculated based on published prediction equations [6]. For slurry, FOM content was calculated by using recommended values published by KTBL [2] for biogas yield from “cattle slurry with feed residues” (370 litres biogas per kg OM divided by 800 litres per kg FOM = 0.46; thus, FOM for slurry equalled to 0.46 • OM).

The method for balancing used in this study did not require measuring the amount of fermentation residues, which would have been impossible to do under practical conditions anyway. The method used is exclusively based on the relation of XA contents in substrate mixture to that in fermentation residue. Due

Fig. 1



Fractions of substrate DM and its fate in the fermenter
FQ = fermentation quotient [FOM / OM]
UQ = utilization quotient [metabolized FOM / FOM input]
BQ = biomass generation quotient [OM in bacterial biomass / metabolized FOM]

to degradation of organic matter during fermentation of RPP, XA content in DM considerably increases. This drastic change can be used for balancing. Measuring the respective amounts of materials is then only required for substrates in order to enable the calculation of weighed arithmetic mean of FOM and XA concentrations in substrate mixtures.

Results on degree of utilization

Figure 1 illustrates the individual fractions of the substrate and their fate in the fermenter. DM consists of XA and OM. OM can be separated into the proportion of organic matter which is undegradable under anaerobic conditions and in FOM. Degree of degradability is described by the parameter fermentation quotient (FQ). Under practical conditions of biogas production, FOM might not be fully exploited due to technological constraints. Therefore, total FOM can be split into non-utilized and bacterially utilized (metabolized) proportions. Degree of utilization can be described by the parameter utilization quotient (UQ).

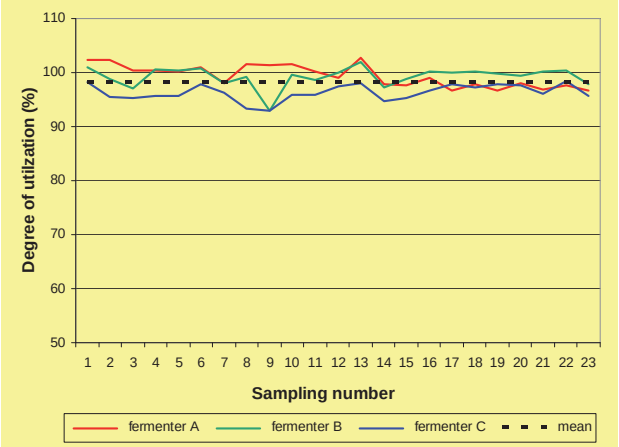
The following equation provides an expected value for the XA content in fermentation residue (XA_R) as affected by XA in substrate (XA_S) and FOM in substrate (as g/kg DM in each case) and the utilization quotient (UQ):

$$XA_R[g/kgDM] = \frac{1000\,XA_S}{1000 - FOM + (1 - UQ)\,FOM} \qquad (1)$$

From this, the following equation can be derived which enables to calculate an expected value for UQ if XA_S, XA_R and FOM are known:

$$UQ = \frac{1000}{FOM}\left(1 - \frac{XA_S}{XA_R}\right) \qquad (2)$$

Fig. 2



Utilization percentage of biogas formation potential at optimal fermenter operation under practical conditions

Table 1

Apparent and true utilization degree (UQ and UQ', respectively) of fermentable organic matter (FOM) depending on degree of incorporation into bacterial biomass

Fermenter	FOM in substrate g/kg DM	XA in substrate g/kg DM	XA in residue g/kg DM	UQ	UQ' at incorporation of metabolized FOM of			
					3%	5%	7%	9%
A	810.2	48.4	206.7	**0.945**	0.974	**0.995**	1.016	1.038
B	816.3	46.4	202.2	**0.944**	0.973	**0.994**	1.015	1.037
C	819.6	48.7	195.2	**0.916**	0.944	**0.964**	0.985	1.007
Mean	815.1	48.0	201.3	**0.934**	0.963	**0.983**	1.004	1.026

Table 2

Biogas yield per kg of fermentable organic matter (FOM) under practical conditions (UQ' = true utilization quotient)

FOM input kg/day	UQ'	Biogas m^3/day		relative %	Biogas measured	
		calculated from FOM	measured (STP volume)	(measured = 100)	m^3/kg FOM input	m^3/kg FOM metabolized
Fermenter A						
6,622	0.995	5,271	5,197	**101.4**	0.785	**0.789**
Fermenter B						
6,182	0.994	4,916	5,032	**97.7**	0.814	**0.819**
Fermenter C						
6,683	0.964	5,154	5,143	**100.2**	0.770	**0.798**
Mean						
6,497	0.983	5,109	5.124	**99.7**	0.789	**0.802**

However, it must be taken into consideration that bacterial activity does not only produce biogas but also that a small proportion of FOM will be incorporated into bacterial biomass [1, 3]. OM of this biomass remains in the fermentation residue. Therefore, the high XA content of fermentation residue which could be expected solely from FOM degradation is reduced to a certain extent. Thus, equation (2) is incomplete. The parameter UQ which is calculated by its use can only reflect the "apparent" degree of utilization. The „true" degree of utilization (UQ') can only be determined if a correction parameter is introduced into the equation. This correction parameter is the biomass formation quotient (BQ). BQ defines the proportion of metabolized FOM which is incorporated into bacterial biomass and, thus, unavailable for biogas formation:

$$UQ' = \frac{1000}{FOM\,(1-BQ)}\left(1-\frac{XA_S}{XA_R}\right) \qquad (3)$$

Table 3

Methane yield per kg of fermentable organic matter (FOM) under practical conditions (UQ' = true utilization quotient)

FOM input kg/day	UQ'	kWh/day	Methane in m^3/day		relative %	Methane calculated from kWh	
			calculated from FOM	calculated from kWh	(calculated from kWh = 100)	m^3/kg FOM input	m^3/kg FOM metabolized
Fermenter A							
6,622	0.995	10,084	2,767	2,669	**103.7**	0.403	**0.405**
Fermenter B							
6,182	0.994	9,619	2,581	2,545	**101.4**	0.412	**0.414**
Fermenter C							
6,683	0.964	10,252	2,706	2,713	**99.7**	0.406	**0.421**
Mean							
6,497	0.983	9,985	2,682	2,642	**101.5**	0.407	**0.414**

Generally valid data on the proportion of metabolized FOM which is utilized for microbial biomass synthesis is not available. In the literature, suggested values vary between 3 and 10 %. In VDI guideline no. 4630 [3], it is recommended to calculate 7% of the metabolized OM as to be used for formation of bacterial biomass. In the same reference, it is assumed that even 10% of the COD is related to formation of bacterial biomass.

Table 1 shows the mean apparent and true utilization quotients calculated using equations (2) and (3), respectively, for each of the fermenters monitored over the entire investigation period. As expected, true utilization degree (UQ') was shown to be strongly affected by the extent of biomass formation. Also based on the consideration of the results on biogas yield given below, the value for biomass formation under practical conditions is likely to be about 5%. Figure 2 demonstrates the course of utilization degree over time based on repeated consecutive analyses of the fermentation residues and assuming 5 % incorporation of used FOM into bacterial biomass.

Results on biogas yield

Data summarized in table 2 compare predicted volumes of biogas formation, as it can be calculated from FOM input with measured volumes of biogas at standard temperature and pressure (STP). Predicted biogas volumes were calculated from metabolized FOM which resulted from multiplication of FOM input by UQ' at the assumption that 5 % of FOM is used for bacterial biomass synthesis. The amount of metabolized FOM is then multiplied by the proposed specific yield of 800 litres biogas per kg FOM [6]. It can be seen that mean values for predicted biogas volume and measured biogas volume corrected for STP compare reasonably well. This might be taken as a confirmation of assumptions which had been made.

In analogy to biogas yield, this comparison was carried out for methane yield (Table 3). Calculation of predicted volumes was also based on the amount of metabolized FOM obtained with an UQ' at the assumption that 5 % of FOM is used for bacterial biomass synthesis. In this case, the amount of metabolized FOM is then multiplied by the proposed specific yield of 420 litres methane per kg FOM [6].

These predicted values were compared with methane yields which were derived from measured data on electric energy production (kWh). For the calculation, a net heating energy content of 35.8 MJ per m^3 methane and an efficiency coefficient of 38% for production of electricity were assumed. Also in this case, the average methane yield predicted from FOM input and true utilization quotient (UQ') compared well with measured values.

Conclusions

The method used in these investigations to determine the degree of utilization of substrates in biogas production obviously led to plausible results. It enabled for the first time to separately evaluate biogas production potential of the substrate and the efficiency of its utilization in the fermentation process. The suggestion provided in a previous publication [6] was fully confirmed that approximately 800 litres of biogas and 420 litres of methane, respectively, can be produced from one kg FOM of the most important types of RPP under practical conditions.

Results of the current investigation proved that a very high degree of utilization of biogas production potential of used substrates can be ensured even in one-phase biogas production facilities, given that these are appropriately configured and adequately operated. Despite the almost full utilization of the substrate, there will always remain a small amount of degradable organic matter in the fermentation residues. If the fermenter is operated efficiently, this remaining degradable organic matter mainly consists of formed new bacterial biomass, but hardly of non-utilized biodegradable compounds from the substrate. Upon subsequent anaerobic incubation of those fermentation residues at 37°C in laboratory batch fermenters as it has been done [4], it can be expected that some degradation of this microbial biomass occurs due to development and succession of new bacterial populations, which in turn leads to production of additional but minor amounts of biogas. The magnitude of this unavoidable „residual gas potential" reported in the above mentioned batch trials with fermentation residues was in good agreement with that of the likely formation of new bacterial biomass in commercial fermenters which was found in the investigations reported on in this paper. The unavoidable remaining gas forming potential of the fermentation residues from appropriately operated fermenters is always much lower than that of unfermented slurry.

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