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Biogas from Renewable Resources through Dry Anaerobic Digestion

The functionality, performance and operational safety of anaerobic digestion using the dry-wet simultaneous technique of Loock Consultants were investigated at the biogas pilot plant in Pirow. In addition to determining process parameters and the input and output balance of the digester, chemical characterisation of the substrates and their biogas production potential were determined in laboratory. The results reveal that a substrate mixture of 60% maize silage, 13% poultry manure and 27% digested material on a mass basis deliver a methane yield of 90 m^3 t^{-1} fresh matter, if conducted as a three-week batch process. A specific methane yield performance of 0.34 m^3 kg^{-1} VS is attained, as with dry anaerobic digestion of maize silage with the standard wet process.

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Keywords

Dry fermentation, percolation system, biogas, methane

A number of process technologies are available for the anaerobic digestion of renewable resources. In addition to the standard wet technology biogas can be produced from manure, crops and other bulk solid biomasses using solid matter produce biogas by dry anaerobic digestion. Several discontinuous, batch technologies have currently been developed for dry anaerobic digestion in agriculture, which are appropriate to digest bulk solid biomasses in garage container reactors. The substrate is mixed with solid already digested material (inoculum), before it is charged to a gastight container. During digestion, the mixture is regularly percolated i.e. sprinkled with process liquid in order to enhance anaerobic digestion.

The biogas pilot plant of the dry wet simultaneous technique of Loock Consultants was established in Pirow (State of Brandenburg). It was designed to use the liquid digested output from the wet system in the dry process in a combined system [1]. The one-year scientific project focused on the process step of dry digestion and was conducted by the Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB), supported by the Agency of Renewable Resources (FNR). The measuring programme started in March 2005. In this contribution we present results of a test series using a substrate mixture of maize silage and poultry manure.

Design of pilot plant

The biogas pilot plant of the dry wet simultaneous technique is composed of 4 garage container reactors with a net volume of 150 m^3 each. Every box is equipped with a gastight door, with an aeration technique to blow in air, a facility for percolation of process liquid and on-line devices for process controlling. Next to the dry digestion plant a conventional wet digestion plant exists, consisting of two reactors with a volume of 1500 m^3 each, digesting pig slurry and renewable resources. The biogas is combusted and electricity generated in a combined heat and power facility (CHP), consisting of 2 units of 250 kW_{el}.

General conditions

In practice the original concept to establish a process water cycle for percolating the substrate in the container reactors (TF) of the dry process via the post digester of the wet system, could not be maintained. The entrained suspended matter in the liquid of the post digester forms a film on the surface of the substrate heap. This film significantly disturbs the percolation through the substrate. Hence, one container reactor (TF2) was converted into a percolate tank (F2).

After charging and a period of 12 hours pre-aeration the container reactors were successively sprinkled (interval: 4 minutes percolation; 30 minutes break) with 15 m^3h^{-1} percolate from F2 (volume ~ 80 m^3).

Results

During the monitored period from 18. 5. 2005 till 4. 7. 2005 container reactors TF 1, 3 and 4 were charged with a substrate mixture of maize silage, poultry manure and digested material from the previous turn. Digestion period was restricted to three weeks. Next the digested material was removed from the containers and partly used for the following turn. Data presented in *Table 1* characterize applied maize silage and poultry manure as representative input substrates.

Table 1: Characterisation of input substrates as pH, total solids (TS), volatile solids (oTS), ammonium-N (NH_4-N), nitrogen (Nges.) and volatile fatty acids (Flüchtige Carbonsäuren)

parameter	unit	poultry manure	maize silage
pH-value	-	8.50	4.10
TS (105 °C)	g kg^{-1} FM	403	306
oTS	g kg^{-1} FM	334	293
NH_4-N	g kg^{-1} FM	2.70	0.54
$N_{tot.}$	g kg^{-1} FM	11.08	3.28
volatile fatty acids	g kg^{-1} FM	0.91	4.38

FM = fresh matter

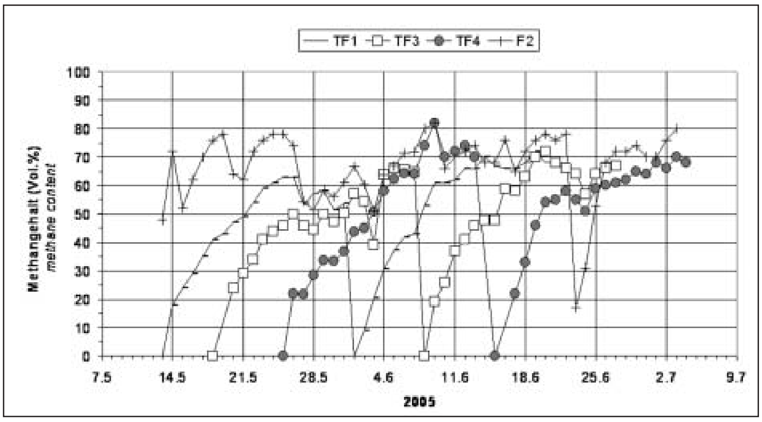

Fig. 1: Course of methane content in biogas during monitored period

Biogas production and methane yields of each reactor were balanced, related to the input (*Table 2*). In the total of all charges the mixtures balanced to mass percentages of 60%, 13% and 27% for maize silage, poultry manure and digested material, respectively.

A few hours after feeding, biogas production started and showed the expected progress. While methane production in reactor TF3 and TF4 showed maximum values of 200 to 300 m^3d^{-1}, production in reactor TF1 did not exceed values of approx. 100 m^3d^{-1}. It was supposed that there was a leakage and part of the total methane yield was not recorded, as all reactors have been charged with almost identical substrate mixtures. This suspicion was confirmed by a revision on 21. 6. 2005.

In all reactors monitored, methane content of biogas was similar with an average value of 50%, with peak values of 70% in some cases (*Fig. 1*). Methane content of the percolate tank averaged at a relatively high level of 69% during the period investigated. Regarding that the leakage in TF1 led to an incomplete record of biogas production and methane yield, but organic compounds from reactor TF1 were converted to biogas in F2 the following balance method was applied: Biogas production and methane yield were integrated from total biogas yield originated from percolate tank, TF3 and TF4 and assuming identical substrate charges of any reactors, the average from TF3 and TF4 were used for TF1.

The total methane yield of 26407 m^3 relates to a specific methane yield of 90 m^3 t^{-1} fresh matter regarding the substrate mixture of 240.5 t maize silage und 53 t poultry manure. This value results in a volatile solid (VS) based methane yield of 0.3 m^3 kg^{-1}. Methane yield from poultry manure is estimated 2400 m^3 from results of lab-scale batch experiment (45 m^3 CH_4 t^{-1} poultry manure) so that for the maize silage a specific methane yield of 0.34 m^3 kg^{-1} VS remains. Hence, dry anaerobic digestion is comparable to the standard wet process [2].

Data presented in *Table 3* characterize discharged digested material. Values differ despite uniform charges. Volatile solids range at 15% of fresh matter with the exception of reactor 1. Low concentrations of volatile fatty acids correlate with the marginal biogas production potential of the digested material determined at 35°C in the laboratory at ATB after discharging.

Conclusion

It could be demonstrated that liquid digested residue from the wet process used as inoculum is not suitable for sprinkling (percolation) in the dry process, because the liquid insufficiently percolates the biomass provided for digestion. Hence, it is necessary to establish a separate process water cycle with a low concentration of solids facilitating an autonomous operation of wet and dry anaerobic digestion plant. Adding solid digested matter to substrates like silages leads to an enhanced methane production. The allotment of inoculum should be restricted to 30% of mass in the substrate mixture. The process control has to take into account the fast degradation of highly concentrated organic acids (e.g. lactic acid, acetic acid) being present in the beginning of the digestion process. In detail, a so-called cross over switching transfers process liquid of a reactor in starting phase to a reactor already in satisfying methane production.

Table 3: Characterisation of digested material and its potential as pH, total solids (TS), volatile solids (oTS), ammonium-N (NH_4-N), nitrogen (Nges.) and volatile fatty acids (Flüchtige Carbonsäuren)

Parameter	unit	TF3	TF4	TF1	TF3
		18.5.	25.5.	1.6	8.6
pH-Wert	-	9.04	9.14	9.14	8.83
TS (105°C)	g kg^{-1} FM	202	193	262	204
oTS	g kg^{-1} FM	157	148	209	150
NH_4-N	g kg^{-1} FM	2.09	3.20	1.16	3.41
$N_{tot.}$	g kg^{-1} FM	6.83	5.96	9.09	6.27
volatile fatty acids	g kg^{-1} FM	1.69	1.62	0.79	4.00
potential of digested material (35°C)					
after 20 d	m^3t^{-1} FM	18	22	11	12
after 40 d	m^3t^{-1} FM	36	33	21	22
FM = fresh matter					

Literature

[1] *Loock, R.*: Anbau und Nutzung landwirtschaftlicher Biomasse zur Vergärung. VDI-Berichter Nr. 1751 (2003), S. 67-89

[2] *Linke, B., und P. Mähnert*: Biogasgewinnung aus Rindergülle und nachwachsenden Rohstoffen. LANDTECHNIK 60 (2005), H. 5, S. 276 - 277 und Agrartechnische Forschung 11 (2005), H. 5, S. 125-132

Table 2: Biogas and methane production from dry anaerobic biogas plant Pirow with two charges for reactor TF1, 3, 4 each within the period 18. 5. 2005 to 4. 7. 2005

reactor	maize silage	poultry manure	digested material	biogas yield	CH_4 yield	CH_4 content
	t	t	t	m^3	m^3	Vol.%
TF1	79.0	17.5	36.0	8916 ¹)	4779 ¹)	56
TF3	80.5	18.0	36.5	10129	5370	53
TF4	81.0	17.5	35.5	7703	4188	54
F2	-	-	-	17562	12070	69
Total	240.5	53	108	44310	26407	59

¹) mean of TF3 and TF4