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Assessment of process stability and biogas yield for the anaerobic digestion of horse dung in lab-scale

Although biogas technology is widely applied in Germany, anaerobic digestion of horse manure for this purpose is limited to only a few applications, despite constant availability of this material. In laboratory scale tests it could be shown that straw-based horse dung is suitable for biogas production in continuous-stirred-tank and plug-flow fermenters, achieving high yields of gas compared with manure from other animals. The material has a heterogeneous composition and gas yield reduces markedly with age. Maintaining process stability with increasing digester loading requires increased levels of control.

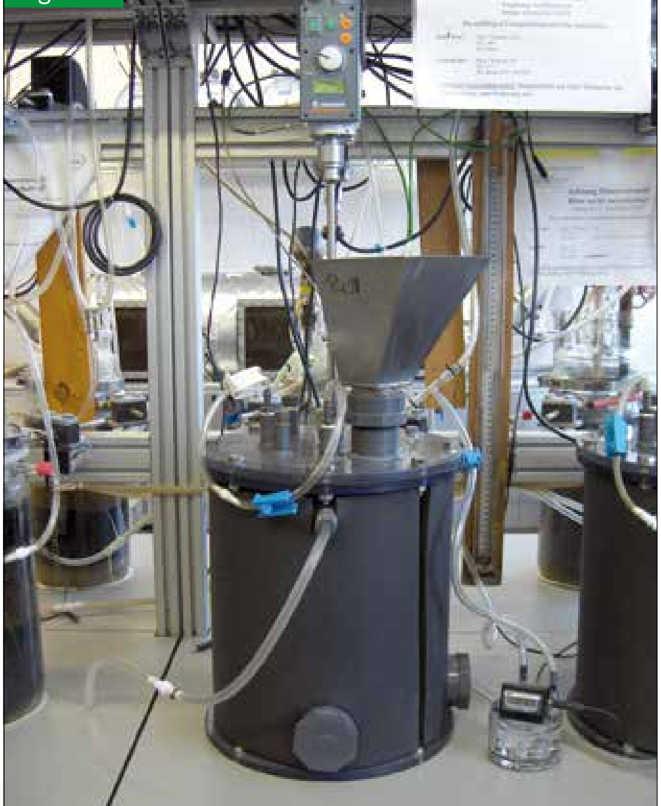
Keywords
Horse dung, biogas yield, process stability, straw

Abstract
Landtechnik 68(4), 2013, pp. 248–251, 2 figures, 2 tables, 12 references

Referring to corn silage the production of alternative biogas crops, such as sugar beets, sorghum or different types of grass, can only diminish the competition on arable land for agriculture and biogas plant operators. For different legal and technical reasons significant potentials from animal husbandry are not used to produce biogas today. As long as horse dung could not be treated in German biogas plants granted by the Renewable Energy Act (EEG) of 2004 [1], utilization was limited to direct spreading as fertiliser or cultivation of mushrooms. Combustion of horse dung was also investigated [2, 3], but could not be established as allowed fuel due to requirements from the federal emission protection ordinance. It took two amendments of the EEG (2009 and 2012) and one adaption of veterinary standards (EC 1069/2009) to improve the legal situation for the digestion of horse dung in agricultural biogas plants. Subject to the material which is used as bedding (e.g. straw), horse dung is a suitable substrate for biogas plants. As the share of straw usually predominates the share of dung, the potential gas yields and technical requirements should be defined by straw. Anaerobic treatment of horse dung has been investigated in several studies using fermenter sizes of 1–125 l, operated as solid-phase digesters with percolation [4–6]. Another study regarded a codigestion with 80 % cow dung with a fermenter size of 2 m³ [7]. Such systems are not common for agricultural biogas production in Germany.

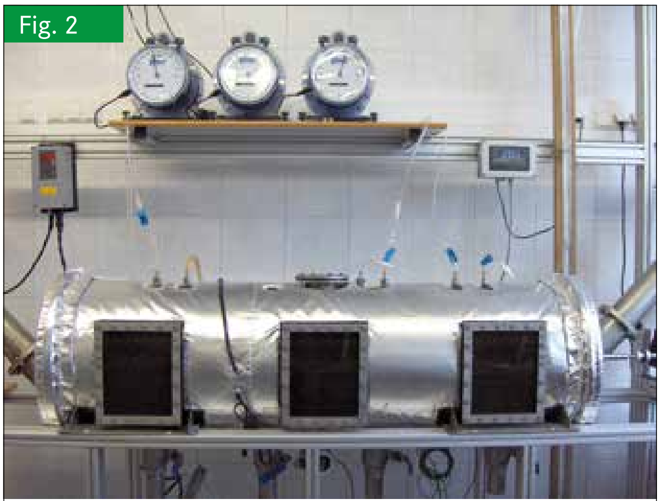
The number of batch-type fermenters, which are generally able to digest horse dung without technical modifications, is still too small to cover an appreciable portion of this biomass potential. At the same time, the number of new constructed

Fig. 1



Continuously-stirred-tank reactor with a net volume of 10 l (photo: C. Beil)

Fig. 2



Plug-flow reactor with a net volume of 180 l (photo: C. Beil)

biogas plants in Germany is declining due to falling remuneration by the EEG and growing environmental requirements. For this reason the construction of new solid-phase biogas plants seems unlikely.

To ensure a nationwide utilisation of horse dung in existing one or two-stage biogas plants, the substrate has to be pretreated. Therefore practical experience with this substrate is low, which is also reflected by the share of horse dung utilised in biogas plants. If the usage of horse dung should be significantly increased, it is not sufficient to carry out batch experiments without determining the biological effects which may occur under continuously operated long term conditions. For this reason continuous experiments have to be conducted.

The aim of the experiment shown here is to achieve stable process conditions by using horse dung as sole substrate at organic loading rates of 3.0 kg VS /(m^3 d). The experiment is carried out in a continuous stirred tank reactor (CSTR) and a plug-flow reactor (PFR) to identify the applicability for both systems. Horse dung is used as sole substrate to characterise the material regarding higher shares in the substrate mixture.

Approach

To evaluate the digestibility the experiment was carried out twice in a semi-continuously fed CSTR with a net-volume of 10 l. The start-up was done with an inoculum from a nearby agricultural biogas plant and rested for one week at 38 °C before substrate was added. The same procedure was applied to start-up the PFR with a net volume of 180 l. The CSTR was successfully restarted for the second experiment with the old digestate after a rest period of several months. Substrate was fed once a day, the digestate was also taken daily. All experimentations started with an OLR of 1.0 kg VS /(m^3 d) and were stepwise increased by 0.5 kg per week to a final OLR of 2.5 kg VS /(m^3 d) in the CSTR and 3.0 kg VS /(m^3 d) in the PFR.

The horse dung used in the first CSTR experiment came from one source for the whole time. In the second experiment horse dung came from six different farms consecutively to determine the influence of different origins and age of the substrate (**Table 1**). All reactors were operated at 38 ± 1 °C, the biogas production of the CSTR was measured using a Milligascounter®. The gas space of the PFR is separated into three compartments, which were individually connected to drum-type gasmeters (Ritter TG 05 and 1). The hydraulic retention time was 30 days in the CSTR and 100 days in the PFR.

Process stability and biogas yield

Only four days after attaining an OLR of 3.0 kg oTS /(m^3 d) in the CSTR, process instabilities became evident. The concentration of volatile fatty acids (VFA) rised within 15 days from < 1.5 to 7.4 g/l, although substrate feed was reduced first and then totally abandoned. The addition of a trace element composition (novoDYN®) and sodium bicarbonate to increase the pH did not show any positive effect. Finally, recirculation of digestate from the post digester stabilised the process. The concentration of VFA then decreased within 20 days below 2.0 g/l. The reason

Table 1

Characterization of horse dung from different sources

Nr. *No.*	TS *DM* [%]	oTS *VS* [% TS/*DM*]	Einsatzdauer *Period of use* [d]	Alter *Age* [d]	Biogasausbeute/*Biogas Yield* CSTR [ml g^{-1} oTS/*VS*]	PFR [ml g^{-1} oTS/*VS*]
1	21.2	64.3	46	>56	52	nB
2	24.6	86.3	9	7 bis 14	202	164
3	29.4	85.4	25	7 bis 14	341	378
4	41.4	84.9	12	1	278	376
5[1)]	33.5/34.1	76.6/69.8	42	3	261	307
6	22.4	79.1	25	3	365	371

[1)] Zweite Bestimmung nach 42 Tagen Lager- und Einsatzdauer/*After 42 days of storage and utilization.*

for the instability could not be resolved. As there was still little gas production during the instability and the increase of VFA affected acetic acid but not propionic acid, a disturbance in the acetoclastic microbial community is probable [8, 9].

In the following an OLR of 2.5 kg VS /(m³ d) was choosen as the process ran stable under this conditions. The weekly stepwise increase of the OLR was replaced by a daily increase with a similar range of additional 0.5 kg VS /(m³ d) per week. During the rest of the experiment no more instabilities were observed. The biogas yield showed average values of 414 ml/g VS at the end of the experiment from day 107 to 119. Older studies claimed biogas yields between 197 to 430 ml/g VS [7, 10], in a recent study methane yields up to 273 ml CH_4/g VS were found [4]. This leads to a biogas yield of 496 ml/g VS assuming a methane content of 55 %. Considering a HRT of 30 days and advancing adaptation of the microbial community the yield has to be marked as high. The methane content showed only few fluctuations and was 54.5 ± 1.1 % in average. According to the results of Mähnert, the compostion of the biogas was not influenced by the OLR [11]. With regard to the relationship between OLR and HRT it has to be mentioned that water had to be added to prevent foaming and to improve mixing. The experiment showed that a dry matter content of 9 % should not be exceeded in the lab-scale CSTR.

The second experiment was aiming towards the effect of different qualities of horse dung. The material showed dry matter contents from 21.2 to 41.4 % and volatile solid contents from 64.3 to 86.3 %. While storing the substrate at temperatures of 5 °C, volatile solids decreased from 76.6 to 69.8 % within 30 days, accompanied by visible moulding. Compared to the first experiment the biogas yield in the CSTR was significantly lower, in average 365 ml/g VS for the whole experiment. If fresh horse dung with storage times below 5 days was used, the yield was 421 ml/g VS, which is almost equal to the first experiment. The biogas yield declined in both fermenters with further storage. After 25 days 13.3 % of the biogas potential in the CSTR and 9.6 % in the PFR was lost regarding the most promising batch of horse dung (**Table 2**). A correlation between gas yield and age of the substrate may also be influenced by presence of pectinolytic enzymes [12].

The average biogas yields of the PFR was 328 ml/g VS. With regard to the quality of the horse dung, the best batch yielded an average of 378 ml/g VS and a maximum yield of 463 ml/g VS when using fresh material. Under the same conditions the PFR showed higher biogas yields (**Table 1**) and could be operated with up to 14 % dry matter content in the effluent. The amount and composition of the gas in the three subdivisions of the gas compartment revealed that the fermenter is only partially mixed. This could be observed with a delay in time e.g. when the substrate batch was changed or regarding the fluctuations in the hydrogensulphide concentrations. The productivity of the compartments was 1.00 l Biogas/(l OV d), 0.84 l Biogas/(l OV d) and 0.70 l Biogas/(l OV d) respectively and therefore shows a constant decline from the intake to the outlet. In contrast to the first two compartments where the amount of hydrogensulphide reached 1,521 ppm after the addition of iron chloride (FerroSorp DG®) on day 52, the third compartment did not show a rising concentration of hydrogensulphide. Obviously the iron repository was sufficient to hold the concentration at a low level when the dosage was kept at 2.35 g/d. Maybe the effect could also result from an advanced moulding of the substrate in the questionable term which led to a reduced gas production rate and rising concentrations of hydrogensulphide until the next batch was used. The methane concentration in the third compartment increased up to 59.7 %. The first and second compartment showed more fluctuating gas compositions without any noticeable pattern.

Table 2

Loss of biogas potential in the CSTR subject to duration of storage

Tage/*Days*	Ausbeute *Yield* [ml g^{-1} oTS/*VS*]	Verlust *Loss* [%]
5	421	0.0
10	384	8.8
15	392	6.9
20	379	10.0
25	365	13.3

Conclusion

Horse dung is suitable for biogas production. Compared to other types of dung the gas yield is partially higher. Both systems, PFR and CSTR, appear as suitable systems for the intended use. Depending on the material the biogas gas yield is determined to be 378 ml/g VS when using a PFR. Treatment of horse dung in a CSTR leads to 414 and 365 ml/g VS respectively. Thus, the results are similar to solid-phase digestion systems. Thereby it has to be mentioned that gas yields may be higher – up to 463 ml/g VS in the PFR - if fresh dung is used. A significant decrease of the biogas yield can be seen after only 8 days of storage. The PFR can be operated stable with a higher dry matter content and lower digester volumes. If the technical preconditons in existing biogas plants for the digestion of straw are given, horse dung can be used as cosubstrate up to an OLR of 2,5 kg VS /(m³ d).

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