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Performance of Temperature-phased Anaerobic Digestion in Sanitising Liquid Dairy Cattle Manure

The efficiency of a multiple-stage biogas plant in sanitizing liquid manure was investigated on a pilot scale. A high methane yield of 0.24 m^3•kg VS^{-1} was achieved, with a comparably low methane performance of 0.34 m^3 • $(m^3$• $d)^{-1}$. Faecal coliforms, coliforms and intestinal enterococci were reduced at a temperature of 54 to 55°C in the thermophilic digester. A mesophilic treatment upstream of the thermophilic stage impaired the methane productivity and did not appear to significantly improve system sanitation efficiency.

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Keywords

Biogas, animal manure, hygiene, pathogens

Literature

Literature references can be called up under LT 05521 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm.

Animal manure applied to farmland is a potential source of pathogenic microorganisms. Upcoming restrictions for agriculture in areas upstream of bathing waters and the enlargement of water protection areas may cause significant problems for livestock farmers. Liquid manure may be subjected to different treatments prior to land spreading in order to reduce the amount of microorganisms of sanitary relevance. Anaerobic digestion offers the peculiar advantage of producing biogas as a versatile, renewable energy source. In order to achieve the reduction of pathogenic and indicator organisms to a large extent, the German "Bioabfallverordnung" (Ordinance on the Utilisation of Bio-Wastes on Land Used for Agricultural, Silvicultural and Horticultural Purposes) specifies a treatment temperature of 55 °C (thermophilic process) and a guaranteed retention time of 24 h. Most agricultural biogas plants treating animal manure and, if so, renewable plant materials feature completely mixed digesters operated at mesophilic temperatures (35 to 42 °C) [1].

Combining mesophilic and thermophilic digestion may increase the biogas yield from manure and improve the inactivation of resistant parasites as indicated by previous investigations [2, 3]. Also, the development and evaluation of biomolecular methods adapted for the detection of various, specific pathogens in liquid manure and digest, as an alternative to conventional cultivation, are still subject to research. In a joint project of Bavarian research institutions and communal water suppliers, these aspects of anaerobic digestion were investigated in a pilot-scale plant treating liquid dairy cattle manure (*Fig. 1*). The central question was whether an appropriate anaerobic digestion process would be capable of sanitizing liquid cattle manure to such a degree that its application to farmland - possibly including sensitive areas - may be acceptable in the future.

Materials and Methods

The pilot biogas plant was designed for treating the manure of 100 livestock units of dairy cattle, and featured three digesters in series: Digester 1, completely mixed tank - Digester 2, horizontal, tubular reactor - Digester 3, completely mixed tank. Digesters 1 to 3 were operated at mesophilic, thermophilic and mesophilic temperature level, respectively. A detailed description of the plant as well as the methods applied have been published previously [4, 5, 6].

Results and Discussion

Results from steady-state operation of the biogas plant are reported in this paper. The plant was fed liquid dairy cattle manure in two different modes, i.e. feeding occurred about every hour and about every four hours, respectively.

Anaerobic digestion process

Mean values of dry matter content and volatile solids (VS) concentration in samples of liquid manure were 7.7 and 6.0 % (m/m) during the first period (feeding every hour), and 8.8 and 6.3 % (m/m) during the second period (feeding every four hours), respectively (*Table 1*). The high ash content of the liquid manure of about 23 % was attributed to fine grit from the concrete surface in the cattle stable.

The biogas produced during the two periods with different feeding modes had a mean methane content of 58.7 and 56.8 % (v/v), respectively. Daily measurements of methane content in the mixed biogas from all three digesters and the storage tank for the digest ranged between 47.2 and 62.6 % (v/v) during the entire period of steady-state operation. This corresponded to methane contents of between 54.6 and 62.9 % (v/v) after correction for the airflow that was added to achieve biological desulphurization of the biogas. Methane contents below 53 % occurred when air was sucked into the biogas collection system due to the withdrawal of digest.

With mean organic loading rates of 1.36 and 1.49 kg VS•(m^3•d)$^{-1}$ with respect to the total usable volume of digesters 1 to 3, identical biogas and methane yields of 0.41 and 0.24 m^3 per kg of VS fed, respectively, were achieved for both feeding modes. This corresponded to a mean biogas yield of 24.9 and 25.8 m^3• m^{-3} liquid manure fed every hour and every four hours, respectively. A methane yield of 14.6 m^3•m^{-3} liquid manure fed was observed for both periods. Methane productivity was calculated to 0.32 and 0.34 m^3•(m^3•d)$^{-1}$, respectively. These data did not indicate an influence of the feeding interval on the performance of the anaerobic digestion process. The methane yield achieved from liquid dairy cattle manure in the pilot biogas plant compares favourably to relevant references from full-scale installations (*Table 3*). The organic loading rate of the system was limited by the first, mesophilic digester in the series which had a relatively small volume (about 1/5 of the total volume of all three digesters).

On average about 34 and 43 % of VS contained in the raw liquid manure were degraded up to Digester 3 and the storage tank, respectively, corresponding to additional 9 % reduction of VS fed or 21 % of the total VS reduction taking place in the storage tank. Consequently, considerable amounts of biogas were produced during storage of the digest. Temperatures in the storage tank which was not heated and hardly insulated reached values of 20 °C and above during the summer months. About 55 % of the VS reduction in the three digesters occurred in Digester 1, whereas only 16 to 20 % of VS were degraded in the thermophilic digester.

Sanitation

Numbers of naturally occurring faecal coliforms, coliforms and intestinal enterococci in samples from Digester 3 were about 5, 4 and 2.5 log units lower than in samples of raw manure. While the change in feeding interval had no perceivable effect on the sanitation performance of the plant, a temperature of 55°C in the thermophilic stage was required to achieve this reduction of indicator organisms. Tracer tests performed in the thermophilic digester showed a guaranteed retention time of eight to nine hours. Spore-forming bacteria were hardly affected by the treatment. The data indicated a slight regrowth of not lethally damaged fractions of the above stated indicator organisms in the storage tank by a maximum of one log unit. Results on the occurrence and fate of other microorganisms, i.e. various viruses and cryptosporidia (protozoae), will be published elsewhere.

The sanitation performance of the pilot biogas plant was determined by the thermophilic stage. No sufficient sanitation was achieved during mesophilic treatment. Under the conditions stated above, the two additional mesophilic digesters exhibited no significant advantages in terms of sanitation efficiency.

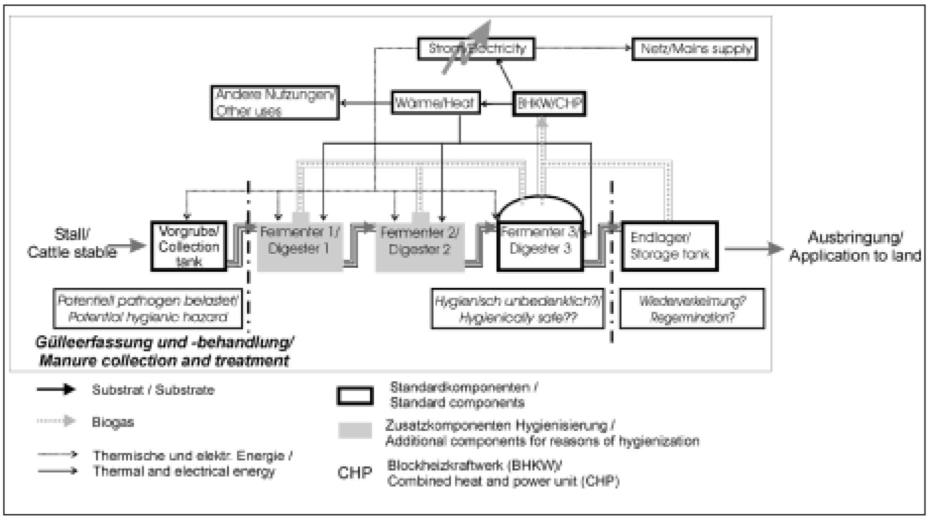

Fig. 1: Overview of the investigated treatment process for dairy cattle liquid manure

Feeding interval		**1 h**	**4 h**
Dry matter content (DM)	% (m/m)	7.7 ± 0.9	8.1 ± 0.3
Volatile solids content	% (m/m)	6.0 ± 0.7	6.3 ± 0.3
Chemical oxygen demand (COD)	mg/l	86.7 ± 8.6	
pH	-	7.4 ± 0.1	7.4 ± 0.1
Volatile fatty acids	mg/l	6844 ± 530	
NH_4-N	mg/l	1963 ± 216	2959 ± 1227
Alkalinity	g $CaCO_3$/l	12.1 ± 0.5	

Table 1: Results of chemical analyses of dairy cattle manure

Feeding interval		**1 h**	**4 h**
Biogas yield	m^3•(kg oVS$_{fed}$)$^{-1}$	0.41	0.41
Methan yield	m^3•(kg oVS$_{fed}$)$^{-1}$	0.24	0.24
Biogas yield FM	m^3•m^{-3}	24.9	25.8
Methan yield FM	m^3•m^{-3}	14.6	14.6
Biogas produktivity	m^3•(m^3•d)$^{-1}$	0.55	0.59
Methan produktivity	m^3•(m^3•d)$^{-1}$	0.32	0.34

Table 2: Biogas and methane yields achieved in the pilot biogas plant

Process / scale [reference]	**Loading rate** kg VS•(m^3•d)$^{-1}$	**Methan yield** m^3•(kg VS$_{fed}$)$^{-1}$
Guideline value for agricultural biogas plants [7]	3.5	0.15
37 °C, single-stage, bench-scale plant [8]	2.9	0.20
Mesophilic, full-scale plants [9]	4.1	0.17

Table 3: Selected parameters for methane yields of liquid cattle manure

Conclusions and Outlook

Anaerobic digestion of liquid dairy cattle manure in the three-stage biogas plant at pilot scale, with additional biogas collection from the storage tank for the digest, produced a relatively high methane yield. The thermophilic stage was required to achieve efficient sanitation. The upstream mesophilic treatment with a comparably short retention time was dispensable in terms of sanitation but impaired the methane productivity of the plant. A two-stage, thermophilic-mesophilic treatment is proposed as a more efficient solution which still has to be investigated.