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Methane production/emission in storages for animal manure

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Abstract

Results of extended research on laboratory scale have shown that relatively high gas productions can occur at digestion of animal manure in fed-batch (=Storage)- systems at ambient temperatures. High gas productions are also reported at on-farm storage of animal manure.

In order to predict the gas production during the storage of animal manure at different conditions, a model is developed based on first order kinetics for the hydrolysis and on Monod kinetics for methanogenesis. Results of anaerobic digestion of manure in both CSTR- and fed-batch systems have been used for the estimation of constants. The model predicts that, when continuously 15% of the storage is filled, no gas production is produced, at a temperature of 15°C and a storage capacity $\leq$ 100 days and at a temperature of 10°C and a storage capacity $\leq$ 150 days. At higher temperatures and longer storage capacities methane gas is always produced.

Introduction

Forced by legal constraints for animal waste spreading, the storage capacity on farm has been extended over the past years in the Netherlands and other European countries. Nowadays the storage capacity should amount to 5 months or longer. The increased storage period could, amongst other things, create favourable conditions for the production of methane gas. The ultimate methane production will also depend on the ambient temperature and the amount of (digested) manure which is retained in the storage as an inoculum. Results of extended research on laboratory scale have shown that relatively high gas productions can occur at digestion of animal manure in fed-batch (=Storage)- systems at ambient temperatures (Zeeman, 1991). High gas productions are also reported at on-farm storage of pig manure in pits below the slatted floors (Zeeman *et al.*, 1985). The estimated global emission of CH_4 by animal waste is 10–18 Tg yr^{-1} (Gibbs and Woodburry, 1993), ± 3.5 % of the annual anthropogenic CH_4 emission. As the global warming potential of CH_4 is importantly higher as compared to CO_2 (Houghton, 1991), the methane emissions from animal wastes should either be minimized or maximized in order to subsequently use the gas. In order to predict the gas production during the storage of animal manure at different conditions, a model is developed (Zeeman and Hamelers, 1992), based on first order kinetics for the hydrolysis and on Monod kinetics for the methanogenesis. This paper presents the predicted methane productions at different process temperatures and storage times both for fresh manure and for digested (in a CSTR) manure. The different figures enable to choose between the above mentioned possibilities, viz. minimize or maximize the methane production.

Methods

The model

The model of Zeeman and Hamelers (1992) is based on first order hydrolysis (formula 1) and Monod kinetics for the methanogenesis (formula 2)

$$r_{sp} = \alpha S_p \qquad (1)$$

where

- r_{sp} = degradation rate biodegradable polymer substrate (g l^{-1}.day^{-1})
- α = first order hydrolysis constant (day^{-1})
- S_p = concentration biodegradable polymer substrate (g l^{-1})
-

$$\mu = \mu_m(S_m/(K_s + S_m)) \qquad (2)$$

where

- μ = growth rate (day^{-1})
- μ_m = maximal growth rate (day^{-1})
- S_m = substrate (=VFA) concentration (g l^{-1})
- K_s = substrate concentration where $\mu=\frac{1}{2}\mu_m$

The model requires the following data for predicting the methane production during digestion in a CSTR or during storage in a fed-batch system.

- α (day^{-1})
- μ_m (day^{-1})
- Y (g g^{-1})
- K_s (g l^{-1})
- S_{p0} (g l^{-1})
- S_{m0} (g l^{-1})
- Q (l day^{-1})
- V_{CSTR} (l)

*– $V_{fed-batch}$ (l)
*– $V_{inoculum}$ (l)
*– X (g l^{-1})

- X_0 (g l^{-1})

*only for fed-batch systems

Y =yield for methanogenic bacteria
S_{p0} =biodegradable polymer concentration of the influent
S_{m0} =(monomer) (=VFA) concentration of the influent
Q =flow rate
V_{CSTR} =volume of the CSTR-system
$V_{fed-batch}$ =volume of the fed-batch (=storage)-system
$V_{inoculum}$ =volume of the digested manure retained in the fed-batch-system
X =concentration methanogenic bacteria of the digested manure
X_0 =concentration methanogenic bacteria of the influent

The results of the research of v. Velsen (1981) and Zeeman (1991) for respectively pig and cow manure, have shown that both hydrolysis and methanogenesis are inhibited at the presence of NH_4^+-N. The values for α and μ_m for the prediction of the methane production and the VFA concentration in CSTR systems are calculated according to the empirical formulas 3, 4, 5 and 6 (Zeeman and Hamelers, 1992).

Pig manure

$$^{1}*\alpha = 0.482 - 0.067\,[NH_4^+ - N] \qquad (3)$$

$$*\alpha = 0.086 - 0.0014\,[NH_4^+ - N] \qquad (3b)$$

Table 1. Values for α en μ_m, used at predicting the polymer-, VFA-concentration and gas production after the digestion of **cow manure** in fed-batch-systems

temperature (°C)	α^1 (day^{-1})	μ_m (day^{-1})
15	0.002	0.02^2
20	0.004	0.071^2
30	0.018	0.12^2

[1] calculated with Formula 7;
[2] calculated with experimental results from fed-batch experiments (Zeeman, 1991).

Table 2. Values for α en μ_m, used at predicting the polymer-VFA-concentration and gas production after the digestion of **pig manure** in fed-batch-systems

temperature (°C)	NH_4^+-N (g l^{-1})	α^1 (day^{-1})	μ_m (day^{-1})
15	4.9	0.0043	0.02^2
20	4.9	0.007	0.025^2
30	4.9	0.016	0.09^2

[1] calculated with formula 3b;
[2] calculated with experimental results in fed-batch systems.

$$\mu_m = 0.39 - 0.059[NH_4^+ - N] \qquad (4)$$

$*$ different types of manure

Cow manure

$$\alpha = 0.099 - 0.019\,[NH_4^+ - N] \qquad (5)$$

$$\mu_m = 0.228 - 0.028[NH_4^+ - N] \qquad (6)$$

From experimental results of batch digestion with cow manure (Zeeman *et al.*, 1988) a relation (7) between the hydrolysis constant α and the process temperature is calculated.

$$\begin{aligned} \alpha &= 0.163t - 8.9 \\ t &= \text{temperature}(^\circ C) \end{aligned} \qquad (7)$$

The values of the required data for the prediction of the methane production in fed-batch-systems are given in Tables 1 and 2.

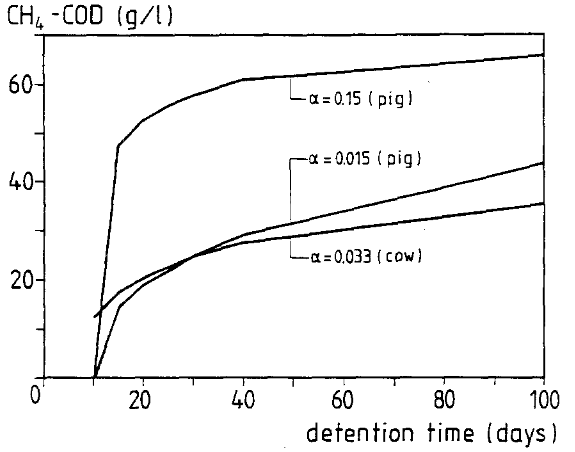

Fig. 1. Predicted methane production as a function of the detention time at digestion of 'fresh' cow manure (S_{pO} = 44 g COD l^{-1}, S_{m0} = 5 g COD l^{-1}, NH_4^+-N =3.5 g l^{-1}) and fresh pig manure (S_{pO} = 65 g COD l^{-1}, S_{m0} = 5 g COD l^{-1}, NH_4^+ -N = 5 g l^{-1}) in CSTR-systems. The total influent COD for both pig and cow manure is 100 g l^{-1}

Substrate

The composition of the manure, as used for the predictions, is given in Table 3.

Results

The predicted methane production as a function of the detention time for the digestion of pig and cow manure in a CSTR-system is given in Figure 1.

Figure 1 illustrates that digestion of fresh manure in a CSTR at a process temperature of 30°C, at the generally applied detention time of 20 days, results in an effluent containing a considerable amount of biodegradable organics. These organics could be degraded to methane gas in the subsequent effluent storage (Table 5).

The results of the prediction of the methane production in fed-batch-systems as a function of the storage time is given in Figures 2 and 3 for respectively pig and cow manure.

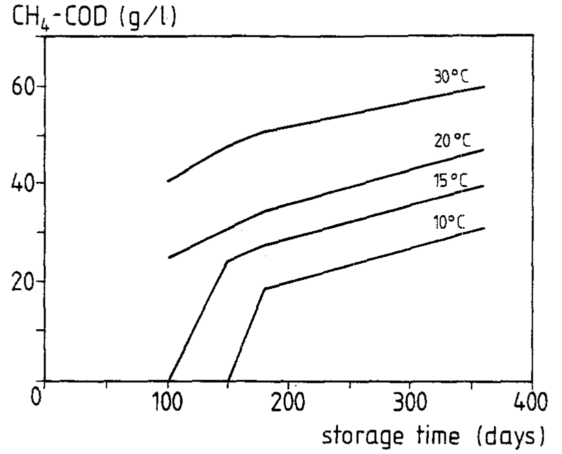

Fig. 2. Predicted total methane production as a function of the storage time at temperatures of 10, 15, 20 en 30° C, for the digestion of 'fresh' pig manure (S_{pO} = 65 g COD l^{-1}, S_{mo} = 5 g COD l^{-1}, NH_4^+-N = 5 g l^{-1}) in a fed-batch-system at 15% inoculation.

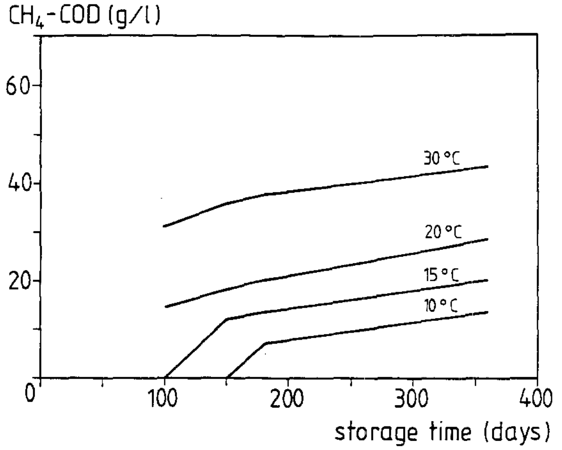

Fig. 3. Predicted total methane production as a function of the storage time at temperatures of 10, 15, 20 en 30° C, for the digestion of 'fresh' cow manure (S_{pO} = 44 g COD l^{-1}, S_{m0} = 5 g COD l^{-1}, NH_4^+-N = 3.5 g l^{-1}) in a fed-batch-system at 15% inoculation.

Discussion

The results in Figures 2 and 3 illustrate a considerable methane production at storage/digestion of manure in fed-batch systems even at low process temperatures of 10 and 15 °C, on condition that continuously 15% of the storage is filled with digested manure and the storage time is respectively >150 and >100 days. When less inoculation is applied, similar results will only be achieved at longer storage periods.

The methane conversion factor (MCF) is defined as the fraction of the biodegradable COD, which is converted to methane gas. Table 4 presents the methane conversion factors at different temperatures and storage capacities as calculated from Figure 2 and 3 and as reported by Gibbs and Woodbury (1993). Gibbs and Woodbury (1993) only distinguish between storage periods > and < 30 days. The results from this

Table 3. Composition of the manure as used for the prediction of the methane production

	Pig manure	Cow Manure
Total-COD (g l^{-1})	100	100
dissolved-non-VFA-COD (gl^{-1})	10	15
VFA-COD (gl^{-1})	5	5
NH_4^+ -N (g l^{-1})	5	3.5
B_0	0.7	0.49

[1] B_0 = biodegradability (g CH_4-COD/g COD).

Table 4. Methane conversion factor (MCF) for the storage of pig and cow manure at different temperatures and storage times.

storage time (days)	process temperature (°C)			
	10	15	20	30
pig manure				
30[2]	0	0	0	0.30
100[2]	0	0	0.36	0.57
180[2]	0.27	0.39	0.45	0.72
<30[1]	0.05	–	0.18	0.33
>30[1]	0.10	–	0.35	0.65
cow manure				
30[2]	0	0	0.02	0.34
100[2]	0	0	0.31	0.63
180[2]	0.15	0.27	0.41	0.77

[1] Gibbs and Woodbury (1993);
[2] This study.

Table 5. [1]Methane production and emission during anaerobic digestion/storage of pig manure

digestion/storage system	CH_4 production (l l^{-1})	CH_4 emission (l l^{-1})
[2]CSTR + [3]open storage	18.4	2.4 (23%)
[2]CSTR + [3]covered storage	20.8	0 (0%)
fed-batch (30° C)	17.7	0 (0%)
fed-batch (20° C)	11.1	0 (0%)
[4]storage under slatted floors	0	10.4 (100%)

[1] The methane emission during field spreading of the manure is not included.
[2] process temperature 30° C, detention time 20 days;
[3] temperature in winter 10° C and in summer 15° C;
[4] temperature in winter 15° C and in summer 20° C;

study clearly shows that besides temperature, the storage capacity will strongly affect the methane conversion factor (MCF) also beyond a storage capacity of 30 days. The difference between the MCF value of Gibbs and Woodbury and from this study could be caused by a different amount of inoculation.

Avoiding methane emission will become very difficult when large storage capacities are compulsory. When a suitable bacterial population has established, the methanogenesis will develop irrevocably unless the storage can be completely emptied. The latter has been shown in practice to be rather difficult (Zeeman, 1991). The application of controlled digestion could however reduce the methane emission from animal manure. Herewith the effect of two digestion systems to the methane emission from animal manure storages will be described.

1. Digestion of fresh manure in a CSTR at mesophillic conditions, followed by storage (either covered or not) of the 'digested' manure.
2. Combined storage/digestion in a covered fed-batch system at ambient or mesophillic conditions.

Table 5 presents the methane production and/or emission from pig manure under the beyond mentioned conditions in comparison with methane emission at the indoors storage under slatted floors.

The results in Table 5 illustrate that the methane emission from animal manure can be reduced considerably by the application of controlled anaerobic digestion in both a CSTR and a fed-batch system. When a CSTR is applied some methane emission (23% of the uncontrolled emission) will occur during storage of the digested manure. The latter can be avoided by the use of a covered storage. The application of an AC-system is however much more suitable for manure digestion on farm-scale than the CSTR-system, for no extra reactor is required.

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