Modeling process border conditions for swine manure anaerobic digestion with ADM1

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Introduction

Anaerobic digestion of wastes containing a high concentration of organic and ammonium nitrogen is difficult due to the high risk of process collapse caused by ammonia inhibition(Yenigün and Demirel, 2013). On the other hand, anaerobic digestion seems to be a reasonable step in manure treatment and nitrogen recovery. The development of process conditions ensuring stable and efficient anaerobic digestion of wastes such as swine or poultry manure would be a considerable improvement in the waste management chain. Agricultural biogas plants usually operate at high hydraulic retention time (HRT), thus facility cost is high. Development of process conditions ensuring stable fermentation at lower HRT would improve the profitability of nitrogen-rich wastes anaerobic digestion.

Anaerobic digestion process may be simulated *in silico* since an appropriate model called Anaerobic Digestion Model No.1 (ADM1) is available (Batstone *et al.*, 2002). This tool is very useful in the planning and development of new digestion technologies since it may help eliminate wrong conceptions before experimental work starts. We decided to find the border retention time for stable anaerobic digestion of swine manure by simulating the process with ADM1.

Methods

The simulation was done with ADM1 implemented in Octave environment used previously in modeling VFA digestion simulation(Jabłoński and Łukaszewicz, 2014). Substrate characterization was based on the data from the article written by Moller et al.(Møller, Sommer and Ahring, 2002). The following assumptions were used:

- Swine manure is the only substrate used,
- The simulated reactor operates as CSTR type reactor,
- Dissolved CO_2 in the substrate is in the equilibrium with air,
- Nitrogen present in the substrate is ammonium or is bound in the proteins.

Results

Process parameters during collapse are presented in the figure 1. Continuous fermentation of manure as a pure substrate at 37 °C and HRT above 11 days is a stable process (the period from 0 to 10th day in presented graph). When HRT is reduced to 10 days, process collapse takes place. However, it is not the result of reaching the inhibiting concentration of free ammonia - the concentration of ammonia drops during collapse (figure 1A).

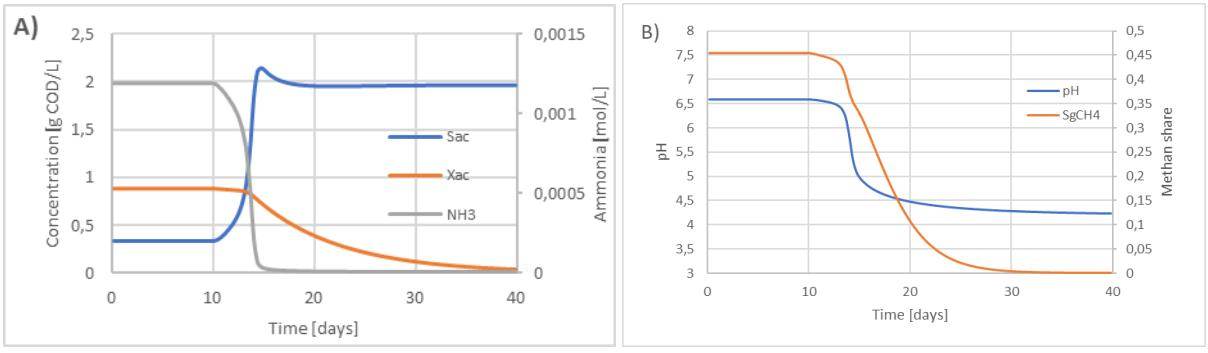

Figure 1. Digestion process parameters during the collapse. Sac – concentration of acetate, Xac -concentration of acetoclastic archaea biomass, NH3 – concentration of ammonia, SgCH4 – concentration of methane in the gas phase.

To test the influence of ammonium nitrogen on the process collapse, various nitrogen concentration were tested. Alternative nitrogen concentrations corresponded values used in work by I. Angelidaki and B. Ahring(Angelidaki and Ahring, 1994). Selected parameters observed for the process collapse are presented in table 1.

Table 1. Process parameters obtained for manure with different ammonia concentrations.			
Total nitrogen [g/L] / ammonium nitrogen [g/L]	2.4/1.8	4.2/3.6	5.4/6.0
Parameters at last stable tested HRT			
HRT [days]	10.00	11.11	12.50
Acetate [g COD/L]	0.26	0.35	0.43
pH	6.58	6.59	6.61
Acetoctastic archaea biomass [g COD/L]	0.89	0.88	0.87

When a substrate with the increased amount of nitrogen is used (Total nitrogen 6 g/L and ammonium 5.4 g/L) the process collapses when HRT is reduced to 11 days. Fermentation of substrate with a reduced concentration of ammonium nitrogen was stable at HRT equal to 10 days. The higher the ammonium concentration, the lower the concentration of acetoclastic archaea biomass, and the higher the concentration of acetate at stable fermentation conditions. Other process parameters showed negligible differences.
To reduce the inhibitory effect of ammonia, we tried to simulate the anaerobic digestion process at an elevated pressure of biogas, however the process showed reduced stability in comparison to standard digestion procedure. Elevated pressure resulted in increased carbon dioxide concentration in liquid and lower process pH. Anaerobic digestion at 1.5 bar was stable only at HRT equal to 20 days.

Discussion and conclusions

Our results indicate that the anaerobic digestion of swine manure may be realized at HRT much shorter than the one used in agricultural biogas plants (usually 30 to 50 days). Even when concentration of nitrogen was increased up to 6 g/L, the process was stable at HRT equal 12.5 days. Simulated process collapse shows a correlation with ammonium nitrogen concentration, however it is not the direct result of reaching the inhibitory concentration of ammonia. The difference in acetoclastic biomass and acetate concentration at stable fermentation conditions indicates that the increase in ammonium concentration slightly reduces the acetoclastic archaea growth rate, thus biomass washout is the deciding factor during the digestion process collapse. The results of our simulations may be useful in the design of new digestion process conditions used in high rate biogas facilities.

Literature

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