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Methane Generation from the Recirculated Liquid Phase in Batch Operated Anaerobic Dry Digestion

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Abstract. Batch anaerobic dry digestion promises further application in agriculture and for treatment of municipal solid waste, especially with smaller substrate throughputs. As in other anaerobic systems, bacteriological activity is inhibited by lack of moisture and in batch dry digestion liquid is sprinkled over the substrate to encourage biomass degradation and biogas production throughout the process. Laboratory-scale experiments were carried out to investigate individual methane generation from the recirculated liquid phase and from the stacked solid material. Results clearly indicate that methane formation within the recirculated liquid significantly adds to the total methane production of the process. Up to 21% of the total methane generation originated from the recirculated liquid. This suggests that methane generation from the liquid phase is not to be neglected and needs to be recuperated. The process water tank should be equipped with gas collection facilities. Experimental results further indicate that higher ratios of easily hydrolysable substrates increase the proportion of methane from the liquid phase while slowly hydrolysable material encourages biogas generation in the decomposing biomass bed itself. While the amount of easily hydrolysable biomass in the system and the ratio of methane produced in the liquid phase could be positively correlated, no correlation was possible between the volume of liquid in the process water tank and the methane proportion originating from the liquid phase.

Keywords: biogas, solid-phase digestion, process water, percolation, batch process, dry fermentation.

INTRODUCTION

Methane obtained from anaerobic digestion of organic materials such as agricultural residues, energy crops and residual biosolids is an important renewable energy carrier. Although being already widely used to process agricultural materials, municipal substrates and industrial wastewaters, anaerobic digestion has significant potential for further application. In particular in countries with strong agricultural character, anaerobic digestion is especially advantageous choice not only to treat organic residues but to simultaneously generate renewable energy, thus displacing other energy sources such as fossil energy. This reduces greenhouse gas emissions and contributes towards a more sustainable energy concept.

A variety of anaerobic methanogenic bioreactors are to be found and have proven reliability in practical application. In agriculture, continuously operated reactors processing materials with high water contents are most common. This is to be explained by the fact that slurry was the predominant substrate for agricultural biogas plants throughout many decades. However, the use of solid substrates such as yard manure and especially energy crops is becoming more attractive (Amon et al., 2007; Weiland, 2006). In full scale, digestion of solid biomass is limited in conventional slurry-plants, due to technical restrictions in particular related to mixing and feeding devices, and technologies appropriate for operation with elevated content of total solids (TS) are imperative. To treat municipal solid waste, so-called dry digestion processes with > 20% TS are implemented to at least a similar extent than wet digestion processes with wastes generally being slurred to < 12% TS (Bolzonella et al., 2003; Forster-Carneiro et al., 2008). However, direct transfer of sophisticated and expensive municipal system into agriculture is difficult, in particular if smaller throughputs are sought as normally is the case on farm.

Batch-wise digestion of stacked biomass represents a particularly simple system. More and more box type fermenters with percolation (sprinkling of process water over the stacked biomass) are to be found. Currently at least 30 agricultural box type reactors are in operation in Germany, and some more facilities digest municipal biowaste. Degradation begins anew with each filling of the reactor. The addition of an appropriate ratio of solid inoculum accelerates methanisation and prevents digester failure (Ten Brummeler and Koster, 1989). The sprinkled liquid assures favourable biomass moisture content. It has been demonstrated that during process initiation discontinuous leachate recirculation is more favourable than continuous watering (Kusch et al., 2009; Martin, 1999; Vavilin et al., 2002, 2003; Veeken and Hamelers, 2000), which is assumed to be the result of encouraging methanogenic areas to expand throughout the whole digester, while continuous watering bears the risk to spread acidification. In addition, it was demonstrated that for the process type discussed in the present paper there is no beneficial effect of continuous water circulation compared to discontinuous watering throughout the whole digestion process (Kusch et al., 2009).

In order to equalise gas production at least three batch-operated dry digestion reactors need to be run offset. In general all digesters are functionally coupled through the recirculated liquid: leachate of all reactors is collected in a common process water tank and reused for percolation. It is not possible to operate the system without a separate process water tank, since the total volume of liquid varies in time and depends on water content, water holding capacity and degradation kinetics of the solid materials (Kusch et al., 2006). Due to the water movement through the stack of solids, organic material is partly washed out from the substrate stack and is metabolised either in the liquid tank or in other solid-phase digesters, while only part of the total methane production actually occurs in the substrate itself.

This paper researches the necessity of catching biogas generated in the process water tank. In order to keep the system as simple and cheap as possible it is one common approach to reduce technical equipment. This however should not be at the expense of overall process efficiency and environmental protection.

MATERIALS AND METHODS

Experiments were carried out in the solid-phase digestion laboratory of the University of Hohenheim (Figure 1; cylindrical stainless steal reactors, holding capacity around 50 L biomass), described in detail in previous publications (Kusch, 2007; Kusch et al. 2005, 2009). Ensiled maize (TS 26.3%, volatile solids VS/TS 96.8%) was mixed with solid inoculum (pre-digested biomass from full-scale plant consisting mainly of grass and horse dung, TS 20.1%, VS/TS 75.2%) and structure material (chopped and composted green cut with woody components, TS 61.9%, VS/TS 80.9%; mass ratio solid inoculum to structure material 1.66:1 based on kg TS). Mixtures of readily degradable biomass (e.g. grass or maize), solid inoculum and structure material (e.g. green cut or straw) are favourable in this reactor type, since they limit compaction while still enabling satisfactory gas yields. Leachate from the digesters was pumped into a separate process water tank (stainless steal, holding capacity around 60 L). 5 L of liquid inoculum was added to all batches, and up to two hours after starting a batch, potable water was added until the desired volume of free liquid was reached in the process water tank.

The experiment was run over a period of 104 days. The proportion of maize was increased during the experiment and the volumetric ratio of liquid in the process water tank to solid material processed in the solid-phase digesters was varied. For this, up to four solid-phase digesters were coupled to the process water tank and liquid was recirculated to all reactors. Details on the experimental set-up are given with Tab. 1.

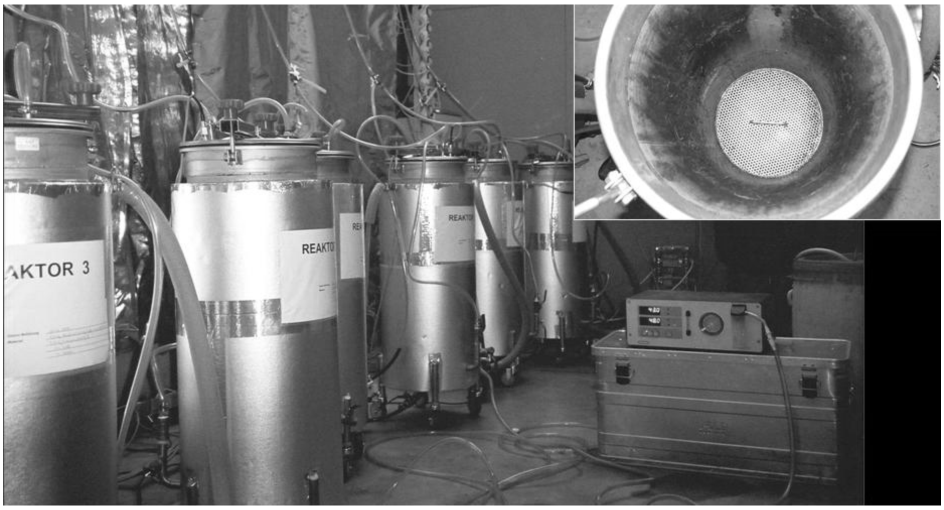

Fig. 1 Solid-phase digestion laboratory at University of Hohenheim

Tab. 1

Experimental set-up (SD: solid-phase digester/s)

Days	Set-up	Percentage maize silage of total solids added to the system	Volume liquid in process water tank (2 h after start of batch) to initial volume of solids in SD digesters
0–9	1 SD with mixture containing 19.6% (w/w on TS-basis) maize silage	19.6% w/w TS	1 : 10.0
9–18	2 SD containing mixtures with 19.6% maize silage, started in 9 days interval	19.6% w/w TS	1 : 3.4
18–27	3 SD containing mixtures with 19.6% maize silage, started in 9 days interval	19.6% w/w TS	1 : 2.9
27–38	3 SD containing mixtures with 19.6% maize silage and 1 SD with 100% maize silage, all SD started in 9 days interval	36.3% w/w TS	1 : 3.3
38–104	2 SD with mixtures with 19.6% silage (SD started on day 0 taken out of group) and 2 SD with 100% maize silage, 4th SD started 10 days after the 3rd	55.0% w/w TS	1 : 3.2
0–104	Total run (SD taken out of group on day 38 taken into account as well): 3 SD with mixture containing 19.6% maize silage and 2 SD with 100% maize silage	47.3% w/w TS	1 : 3.9

Note: with more than 1 SD being operated, common percolation was applied

All reactors and the process water tank were thermostatted at 35°C. Liquid was recirculated 4 x 15 min per day (average liquid flow 4.7 L/min). Biogas generation was determined individually for all reactors. Biogas was collected in aluminium-coated PE/PTFE-gas bags. It was analysed for CH_4 and CO_2 content (infrared spectroscopy, Siemens Ultramat). Gas quantity was determined with a bellows-type gas flow meter (GMT, reading accuracy 0.1 L), calibrated to the flow of the vacuum pump (45 L/min). All gas volumes were corrected to norm litres (L_N, 1.013 bar, 0°C).

RESULTS AND DISCUSSION

Between 10 and 21% of the total methane generation occurred in the process water tank. The volume of the liquid phase was not a distinct factor to influence the result (Figure 2). When digesting substrate which contained 20% maize, 10 to 11% of the methane was produced in the liquid, regardless of whether the ratio of solid material to liquid in the process water tank in the system was 1:2.9, 1:3.4 or 1:10.0. It can be noted that the lowest value occurred when operating the system with the largest volume of liquid (ratio liquid to solids 1:2.9), but the level of differences does not support identification of a tendency. Results suggests that due to the discontinuous recirculation of liquid, organic material having been washed out from the solid biomass was successfully metabolised in the process water tank, thus allowing for a liquid which could enrich itself again with hydrolysed organic components during the next process water recirculation interval.

The amount of easily hydrolysable organic material in the system clearly influenced the proportion of methane generated in the process water tank. The higher the amount of maize silage, the higher was the methane generation in the process water tank. Fig. 3 indicates the correlation.

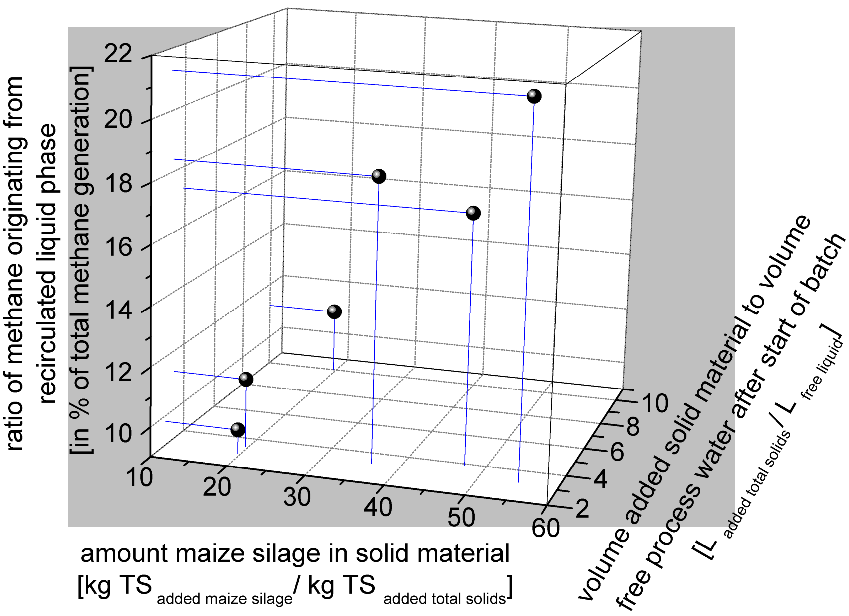

Fig. 2 Percentage of methane attributed to generation in the process water tank in dependency of the level of easily hydrolysable substrate (maize silage) and of the volumetric ratio of added solids to liquid in the process water tank

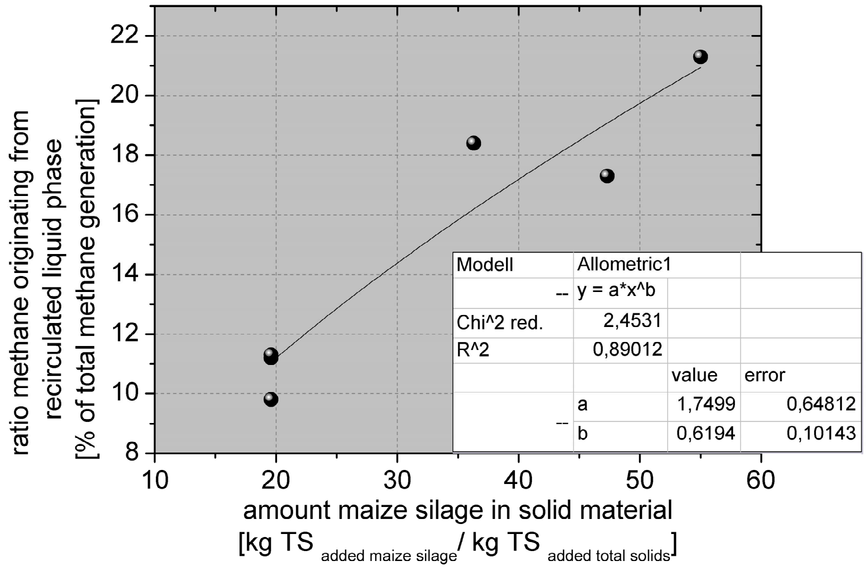

Fig. 3 Correlation percentage of methane generation in liquid phase and level of easily hydrolysable substrate (maize silage) in the solid-phase digesters

Total methane generation from the component maize silage was determined with 361 to 382 L_N/kg VS, for determination methodology please see Kusch (2007). This is in the normal to upper range of methane yields reported for maize silage in wet digestion systems and indicates that dry digestion processes can be highly efficient. Successful digestion in batch-operated dry digestion was shown with horse dung with straw, solid cow dung, mixtures with grass and grass silage, mixtures with maize silage, and green cut (Kusch, 2007).

CONCLUSIONS

Results of this study demonstrate that in batch-operated dry digestion with percolation significant amounts of biogas can originate from methanogenic activity in the process water tank. This gas volume is not to be neglected and represents a valuable energy source. If not valorised, the negative effect lies not only in the fact that the energy content is not utilised but also in the fact that any methane released to the atmosphere will function as greenhouse gas.

In full scale, biogas generation from the process water tank can hardly be assessed with precision. Operation of the process water recirculation pump causes pressure fluctuations, liquid leaving the process water tank can result in a backflow of biogas from the gas holder into the process water tank due to pressure equalisation, and any liquid being poured into the tank will displace the equivalent volume of biogas from the tank without biogas actually having been produced in this step. No measuring device exists to record precise data, especially highly fluctuating biogas flows and possibly occurring gas backflows are problematic. There is a general tendency to keep this plant type as simple as possible. Results of this study suggest that gas capture not only from the digesters but also from the process water tank should be considered as a standard.

Dimensioning of the process water tank is not of decisive influence on methane generation in the liquid phase. Even when deciding in favour of a small process water tank, equipment for catching generated biogas from the tank needs to be foreseen. Especially when digesting easily hydrolysable biomass, special attention needs to be given to biogas generated in the liquid phase.

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