Anaerobic digestion of solid animal waste in an accumulation system at mesophilic and thermophilic conditions, start up

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Abstract The anaerobic digestion of solid animal wastes has been studied in an accumulation system (AC) at a filling time of 60 days followed by about 50 days batch digestion at 40 and 50°C. Poor mixing conditions during anaerobic digestion of solid wastes promote stratification of the substrate and intermediate products along the reactor height. The effect of layers stratification has also been followed in the AC system. The results showed a pronounced stratification of both COD<sub>dis</sub> and VFA concentrations along the AC system height. The temperature had a minor effect on the methane yield. The results also showed that methanogenesis was rate limiting in the AC system while the hydrolysis was the rate-limiting step during batch digestion.

Keywords Accumulation; hydrolysis; mesophilic; solid wastes; stratification; thermophilic

Introduction

On farms anaerobic digestion of animal manure is an attractive technique for both energy and organic fertilizer production. Literature on manure digestion is mainly focused on liquid manure (i.e. TS<100 g/l) digestion (e.g. Velsen, 1981; Zeeman, 1991; Hill and Bolte, 2000). Nevertheless many farms, especially smaller ones, throughout the world, still produce solid manure.

For on-farm application the digestion system should be as simple as possible to operate and in agreement with the on-farm practice. Wellinger and Kaufmann (1982) showed for the first time, the operation of an accumulation system for the digestion of liquid animal manure in practice. According to Zeeman (1991), the AC system is the simplest system for on-farm practice as it combines storage and digestion. As manure cannot be used as a fertilizer during the winter period storage of some months is always necessary in medium and low temperature climates. So far the anaerobic digestion of solid animal wastes, to our knowledge, has not been studied in the AC system. Moreover previous studies on accumulation systems focused on mesophilic and psychrophilic conditions.

The present study focuses on the feasibility of solid manure digestion, making use of the knowledge achieved in liquid manure digestion (e.g. Zeeman, 1991) and in solid digestion of household waste (e.g. Ten Brummeler, 1993). Optimization of energy production is aimed at, by combining digestion with the application of solar energy, resulting in the possibility of application of thermophilic conditions (El-mashad et al., 2001a).

The objectives of the present research are to: first, optimize the performance of an accumulation system for the anaerobic treatment/storage of solid manure and to study the effect of layer stratification on the process performance. Secondly, compare the mesophilic and thermophilic performance. And finally to study, next to the methanogenesis, the hydrolysis step under such conditions.
Materials and methods

**Experimental set up: substrate, inoculum and feeding procedures.** Two AC reactors, each with a working volume of 30 liters were used in this study. The aspect ratio of the reactor (reactor effective height/reactor diameter) is about 2. The filling time was chosen based on the period of the year when no crops are cultivated, due to low temperature conditions. For Mediterranean conditions this will be a maximum of 2 months. After filling, the reactors were operated batch-wise for an extra 50 days. The reactors were incubated at 40°C and 50°C. The outlet gas passed on a 15% NaOH solution to absorb CO₂, then the methane produced was measured by a wet gas meter. The gas volume was re-calculated for standard temperature and pressure.

The cow manure used consisted of feces, urine, and bedding material obtained from fattening animals. The manure was refrigerated (4°C) until used. The chemical characteristics of this substrate are given in Table 1.

As an inoculum, 10% (w/w), thermophilic (50 °C) batch-wise digested horse dung was used. The maximum specific methanogenic activity (SMA) of the inoculum has been measured by VFA depletion as described by Lier (1995). The SMA was 0.098 and 0.106 gCOD/g VS.day at 40°C and 50°C respectively. After inoculation, the reactors were flushed with nitrogen for 15 minutes and incubated at the desired temperatures. Feeding was done weekly. After 60 days, the reactors were opened and sampled from different heights along the AC reactor. After that the reactors were re-flushed with nitrogen for 15 minutes and incubated batch-wise for about 50 days. After that an analysis sequence was done for both batch reactors.

**Sampling and analyses.** Samples were taken from different heights along the AC reactor. For the batch-wise stage, a composite sample was taken from each reactor after about 50 days. The analyses have been done in duplicate after dilution and mixing for 3 minutes using a food mixer. The total COD; Nkj; VFA and COD\textsubscript{dis} measurements are made according to Zeeman (1991) and Lier (1995). Total ammonium (NH\textsubscript{4}⁺-N) was determined by steam distillation method according to *Standard Methods* (APHA, 1992).

**Calculations.** The calculations of the hydrolysis, acidification and methanogenesis percentages were calculated as described by El-mashad *et al.* (2001b).

Results and discussion

Figure 1 shows the methane production rate (MPR) from both studied reactors. A lag phase of about a week at 50°C and about two weeks at 40°C is shown. This might be due to the adaptation of the microflora to the experimental conditions. Such a ‘long’ lag phase was not noticed from an AC system started with inoculum pre-cultured in an AC system treated solid cow manure (data not shown). As can be seen from Figure 1, no noticeable difference between the studied reactors can be recognized. Figure 2 shows the concentration of VFA and COD\textsubscript{dis} over the AC system height. From this figure it can be seen that the bottom layer had the lowest concentration of both VFA and COD\textsubscript{dis}, which should be attributed to a combination of the long period of contact with the inoculum and the higher methanogenic activity in the lower layers compared to the upper layers. It should be mentioned that the gradient of stratification depends strongly on the moisture content of the substrate (data not shown). This evidently is due to the higher transport, between layers, of different components with the higher moisture content. The experiments and simulations of Veeken and Hamelers (2000) on the solid state digestion of biowaste in batch reactors showed that the reactor performance could be improved by applying leachate recirculation. They mentioned that the transport of VFA from the acidogenic pocket (fresh biowaste) to methanogenic pockets (seeding material) can only take place through the liquid phase.
Figure 1 Methane production rate during the experiments

Figure 2 CODdis and VFA concentration over the AC system height

Table 1 Results of concentrations of different parameters after anaerobic digestion of solid cow manure in an accumulation system followed by batch digestion

<table>
<thead>
<tr>
<th></th>
<th>Influent</th>
<th>AC (after 60 days)</th>
<th>Batch (after 110 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$R_{40AC}$</td>
<td>$R_{50AC}$</td>
</tr>
<tr>
<td>TS (g/kg)</td>
<td>250.1 (2.38)</td>
<td>215.4 (64.1)</td>
<td>213.1 (13.2)</td>
</tr>
<tr>
<td>VS (g/kg)</td>
<td>189.4 (1.37)</td>
<td>160.7 (45.5)</td>
<td>156.9 (20.6)</td>
</tr>
<tr>
<td>COD (g/kg)</td>
<td>314.85 (4.9)</td>
<td>n.d*</td>
<td>n.d</td>
</tr>
<tr>
<td>VFA (g/kg)</td>
<td>14.98 (0.34)</td>
<td>14.23 (10.4)</td>
<td>8.59 (5.7)</td>
</tr>
<tr>
<td>Nkj (g/kg)</td>
<td>6.67 (0.12)</td>
<td>6.95 (0.58)</td>
<td>6.87 (0.643)</td>
</tr>
<tr>
<td>NH$_4^+$N (g/kg)</td>
<td>1.83 (0.2)</td>
<td>4.26 (0.75)</td>
<td>3.85 (0.9)</td>
</tr>
<tr>
<td>CODdis (g/kg)</td>
<td>41.7 (2.4)</td>
<td>46.8 (13.3)</td>
<td>43.2 (6.2)</td>
</tr>
<tr>
<td>Accumulated CH$_4$ (l/kg)</td>
<td>–</td>
<td>16.26</td>
<td>18.26</td>
</tr>
<tr>
<td>MPR (l/l day)</td>
<td>–</td>
<td>0.264 (0.13)</td>
<td>0.302 (0.2)</td>
</tr>
<tr>
<td>H (%)</td>
<td>–</td>
<td>29.6</td>
<td>30.25</td>
</tr>
<tr>
<td>A (%)</td>
<td>–</td>
<td>19.24</td>
<td>19.25</td>
</tr>
<tr>
<td>M (%)</td>
<td>–</td>
<td>14.72</td>
<td>16.53</td>
</tr>
</tbody>
</table>

* Not determined; Standard deviations are shown between brackets
It can be seen from Table 1 that the average total VFA concentrations were higher at R\textsubscript{40AC} compared to R\textsubscript{50AC}. After operating the reactors batch-wise (R\textsubscript{50Batc} and R\textsubscript{40Batc}), the VFA concentration decreased sharply.

From Table 1, it can be seen that both reactors have high ammonia concentrations. From these results it can be concluded that it is possible to apply anaerobic digestion for solid animal wastes even at high ammonia concentration at thermophilic conditions. Furthermore the hydrolysis; acidogenesis and methanogenesis percentages were higher at R\textsubscript{50AC} and R\textsubscript{50Batch} compared to R\textsubscript{40AC} and R\textsubscript{40Batch} correspondingly. From this table, it can also be concluded that methanogenesis was the rate-limiting step in the AC system, while the hydrolysis is the rate-limiting step during the batch digestion. The latter can be attributed to the increasing contact with the inoculum in the second step.

Follow-up research has shown that at the researched high solid influent concentration with adapted inoculum the stratification gradient is reduced but is still present to an extent that batch digestion is required. A model adapted from Veeken and Hamelers (2000) is developed in order to predict the amount of liquid recirculation necessary to prevent the period of batch digestion subsequent to the fed-batch process.

**Conclusions**

At an inoculum percentage of 10% (w/w), the contact between the substrate and the inoculum affects the process performance. Stratification of different components like VFA and COD\textsubscript{dis} occurred due to: the long period of contact between the lower layer (s) and the inoculum, and the higher methanogenic activity in the lower layers compared to the upper ones.

During the digestion of solid cow manure in an AC system, at 60 days filling time followed by 50 days batch digestion a total hydrolysis, acidification and methanogenesis of 45, 33 and 32% occurred respectively at 40°C and 50, 35 and 35% occurred at 50°C respectively.

Leachate recirculation should be considered, in order to reduce the need for batch digestion.

**References**


