Effect of zeolite addition on the biogas production from chicken manure leachate

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Abstract: The aim of this study was to investigate the effect of zeolite on the quality and methane potential of leachates obtained from bench-scale leach-bed reactors (LBR) filled with chicken manure (CM). CM with a volatile solid content of 486±36 g/kg ww was loaded into LBRs having been mixed with different bulking agents (zeolite and pebbles) at various ratios (10% and 3.5% v/v). The effect of the water quantity added in the LBRs (3.40 and 6.79 g/g ww), the leachate recirculation rate (2.88 and 5.76 mL/mL CM bed·d) as well as the hydraulic retention time (HRT; 1 and 2 d) were also studied. The optimum medium as bulking agent was found to be the zeolite at a 10% v/v ratio and 2.88 mL/mL CM bed·d, since it produced leachate with the highest organic content (0.26±0.01 gCOD/gVS) and lowest total ammonia concentrations (2.25±0.1 g/L). The biochemical methane potential (BMP) of the leachate from the LBR with the zeolite (10% v/v) was 0.274±0.035 LCH4/gCOD at STP conditions which was 1.3 times higher than that from the LBR with the pebbles.

Keywords: leach bed reactor; zeolite; ammonia, chicken manure

Introduction

Chicken manure (CM) management has attracted the interest of the scientific community, due to its biogas production potential and fertilizing value (Bayrakdar et al., 2018). In this respect, anaerobic digestion (AD) seems to be a suitable method for CM management (Li et al., 2018). Ammonia is produced at high concentrations during CM digestion and is regarded as one of the major inhibitory parameters for methanogens’ growth and efficiency (Fuchs et al., 2018).

In the case of high solid feedstocks, e.g., animal manure, it may be beneficial to apply an ex-situ treatment in leach-bed reactors (LBR) before the AD process; the coupling of LBR and anaerobic digesters enhances hydrolysis and organic matter extraction (Nizami and Murphy 2011). Since LBRs require bulking agents in order to increase the permeability and to avoid channelling problems due to the heterogeneous structure of the waste, it was thought to use zeolite as bulking agent aiming to reduce ammonia and enhance the anaerobic biodegradability of the leachate. The positive effect of zeolite on anaerobic digesters have been demonstrated in several studies (Kotsopoulos et al., 2008). Moreover, it is a promising additive in fertilisers (Ramesh & Reddy 2011) and this aspect could add more value to the solid residue of the LBR which can be composted.
As a first step of proving this concept would be to test the effect of the zeolite on the quality and BMP of leachates produced while adding and recirculating water to the LBR at different quantities and rates. A series of tests with inert pebbles at similar size with zeolite was also conducted as a control test.

Material and Methods

CM containing manure droppings and bedding material, was taken from a poultry farm with an annual manure production of 1000 tons at Xanthi in Greece. The composition of CM used is given in Table 1.1.

Three identical 120 mL bench-scale LBRs with a CM bed volume of 100 mL (internal diameter: 3.4 cm and bed height: 9.5 cm), were used in this study. All three LBRs were operated at the same conditions to test the repeatability of the results. In each experimental run, the LBRs were loaded with CM (14.18±0.66 gTS and 11.46±0.79 gVS) using different bulking agents (BA); zeolite or river pebbles, having similar particle size (mean diameter 1-2 mm). The CM/BA ratios tested were 10% or 3.5% v/v CM bed for the zeolite and 10 % v/v CM bed for the river pebbles. Tap water was added at loadings of 3.40 or 6.79 g/g wet weight of CM. The leachate produced was collected in a flask (Fig. 1.1) and recirculated to the top of the CM bed at different ratios (2.88 or 5.76 mL/mL CM bed/d). All leachate or half of it was removed and replaced with fresh tap water daily to achieve the desired HRT (1 or 2 d respectively). All scenarios tested are presented in Table 1.1.

Table 1.1 Composition of chicken manure and operating conditions of LBRs.

<table>
<thead>
<tr>
<th>Runs</th>
<th>TS (g/kg ww CM)</th>
<th>VS (g/kg ww CM)</th>
<th>Material</th>
<th>Rec/tion</th>
<th>Water loading</th>
<th>HRT (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>645±2</td>
<td>532±1</td>
<td>10 (zeolite)</td>
<td>2.88</td>
<td>3.38</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>620±4</td>
<td>517±48</td>
<td>10 (pebbles*)</td>
<td>2.88</td>
<td>3.44</td>
<td>1</td>
</tr>
<tr>
<td>3.</td>
<td>594±3</td>
<td>459±21</td>
<td>10 (zeolite)</td>
<td>2.88</td>
<td>6.79*</td>
<td>1</td>
</tr>
<tr>
<td>4.</td>
<td>599±0</td>
<td>484±1</td>
<td>10 (zeolite)</td>
<td>5.76*</td>
<td>3.41</td>
<td>1</td>
</tr>
<tr>
<td>5.</td>
<td>553±8</td>
<td>435±6</td>
<td>10 (zeolite)</td>
<td>2.88</td>
<td>3.35</td>
<td>2*</td>
</tr>
<tr>
<td>6.</td>
<td>602±0</td>
<td>491±0</td>
<td>3.5* (zeolite)</td>
<td>2.88</td>
<td>3.40</td>
<td>1</td>
</tr>
</tbody>
</table>

*These values denote the parameter differentiating each experimental run from the rest. Solid loading was attempted to be as similar as possible in all runs.

The BMP tests on the leachates were conducted in (at least three) 100 mL serum bottles run in parallel. Each bottle was inoculated with 85 ml of anaerobic sludge (4.7±0.1 gVS/L), obtained from a full-scale anaerobic digester treating slaughterhouse wastes. For each experimental run, the first portion of the leachates removed from the 3 LBRs was mixed and a certain volume (ca. 6 mL) was added in vials to achieve a loading of 0.5±0.1 gCOD/gVS inoculum. The vials were filled in with water up to 100 mL. No leachate was added in the blank tests. The vials were purged with a N₂/CO₂ mixture (80/20) for 1 min, sealed and incubated at 36⁰ C. The vial headspace was connected with a NaOH (6N) displacement apparatus to trap CO₂. The methane production was expressed at standard conditions for temperature and pressure (STP). TS, VS, COD, ammonia and TKN were analysed according to the standard methods (APHA, 1989).
Results and Conclusions

In all runs, CM volume in LBRs was kept the same, leading to slightly different dry matter loading with respect to wet weight (ww). The LBRs were operated for 6 d and the leachates were removed and replaced with fresh tap water daily. After measurement of COD and NH3-N concentrations in each portion removed, the total quantities of COD and NH3-N mass extracted in the liquid could be estimated. Figure 1.2(a) shows the total VS of CM in g loaded in each run (Table 1.1), as well as the quantity of COD extracted in the leachate, while Figure 1.2(b) shows the ratio of the COD extracted to the initial total VS. It is obvious that similar COD extraction capacities (0.25±0.01gCOD/gVS) were achieved in first 3 runs. It was observed that the two-fold increase of the water loading (run# 3) did not affect the COD extraction efficiency. In addition, lower extraction of ammonia (34±1 % of total TKN) took place in the presence of zeolite (Figure 1.2c), which can be attributed to the adsorption capacity of the zeolite (Li et al., 2018b).

Figure 1.2 (a)Total VS of CM loaded and COD extracted into leachate, (b) COD (gCOD/gVS) extracted into the leachate and (c) % NH3 extracted into the leachate during each scenario tested. (runs: #1- 10% zeolite, #2- 10% pebble, #3: as #1 but double water loading, #4: as #1 but double water recirculation ratio, #5: as #1 but double HRT, #6 – 3.5% zeolite)

Figure 1.3(a) shows a typical methane production profile versus time during a BMP test using the leachate resulted from run#1 (10% v/v zeolite). The BMP tests suggested that the total net (after subtraction of blank) methane potential of the leachate taken from the LBR with zeolite was higher (0.274±0.035 LCH4/gCOD) compared to the leachate from the LBR with the pebbles (runs#1 and #2) (Figure 1.3b). This shows the beneficiary effect of the zeolite on the process. Compared to the maximum theoretical yield (0.35 LCH4/gCOD), the leachate from run#1 shows high biodegradability. The methane yield with respect to the VS of the CM bed of run#1 is 0.071±0.008 LCH4/gVS which is much lower than 0.272 LCH4/gVS reported in literature (Bayrakdar et al., 2018). However, it should be noted that the leachates denote the readily
extractable organic matter and they are not the product of the hydrolysis of CM solids. Therefore, it is expected that the methane yield will be increased in the coupled LBR-anaerobic digester system solid hydrolysis will take place.

Figure 1.3 (a) Accumulated methane yield vs time during a BMP test using the leachate from LBR with zeolite (run#1) and (b) Comparison of net total methane yield of leachates taken from LBRs with zeolite and pebbles under similar conditions (runs #1 and #2).

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