BIO-METHANE POTENTIAL TEST FOR ANAEROBIC CO-DIGESTION OF FAECAL SLUDGE AND SEWAGE SLUDGE

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ABSTRACT

Faecal sludge (FS) samples taken in Hanoi urban area had COD values ranging from 2.83 g/L to 83.83 g/L, TN values from 0.18 g/L to 3.95 g/L, and VS/TS ratio from 47.5% to 87.7%. Sewage sludge (SS) samples taken from sewage treatment plants in Hanoi had COD values ranging from 2.22 g/L to 24.97 g/L, TN from 0.16 g/L to 1.24 g/L, VS/TS ratio from 53.5% to 69.5%. Bio-methane potential (BMP) tests at mesophilic anaerobic condition (35 °C) provided results of methane production from FS, primary sewage sludge (PSS), waste activated sludge (WAS1 and WAS2) and mixture of primary and secondary sewage sludge at sludge thickener (WAS) as much as 242.3 NmL/gVS, 310.5 NmL/gVS, 294 NmL/gVS, 228.2 NmL/gVS and 282.3 NmL/gVS, respectively. Co-digestion of FS and WAS at different mixing ratios provided from 269.3 NmL to 294.8 NmL CH₄ per gram of fed substrate VS. The values of methane yield have shown promising sludge-to-energy option with FS-SS co-digestion. FS-SS co-digestion in anaerobic digesters built at municipal sewage treatment plants which are often working under capacity provides chance to combat with FS and SS challenges, utilizing infrastructure facilities efficiently.

Keywords: anaerobic digestion, bio-methane potential, fecal sludge, sewage sludge.

1. INTRODUCTION

Sewage treatment plants (STPs) are being built more and more in urban areas in Vietnam. Currently there are 36 centralized STPs in operation, with a total capacity 802,400 m³/day, and 40 centralized STPs are under design or construction, with a total capacity 1,435,000 m³/day [1]. Most of STPs are built in combined sewerage system, applying activated sludge treatment methods. At present, sludge generated at STPs is dewatered (using mechanical methods or drying bed) and dumped at landfills. The study on Hanoi STP suspended solids (SS)
characteristics conducted by the Institute of Environmental Science and Engineering (ISEE) in 2016 has shown the volatile solids/total solids (VS/TS) ratio ranging from 53.5% to 69.5%, chemical oxygen demand (COD) from 2.22 g/L to 24.97 g/L, total nitrogen (TN) from 0.16 g/L to 1.24 g/L [2], proving that SS contains biodegradable substances and nutrients.

Currently in most of urban centers faecal sludge (FS) is often dumped directly into the environment, causing serious environmental problems. It is estimated that FS amount in urban centers will be 9,100 tons per day in 2020, and 13,500 tons per day in 2025 [3]. The study on Hanoi FS characteristics conducted by ISEE in 2016 has shown the FS VS/TS ratio ranging from 47.5% to 87.7%, COD from 2.83 g/L to 83.83 g/L, TN from 0.18 g/L to 3.95 g/L [4], also proving that FS is rich in biodegradable substances and nutrients.

Anaerobic digestion has been widely used as a method to stabilize organic matters in sludge, producing biogas [5]. Anaerobic co-digestion involves simultaneous digestion of a homogenous mixture of two or more substrates and has been promoted very recently in many STPs [5]. Not only does this process accelerate the hydrolysis and biogas yield, it also offers many other benefits, including dilution of potential toxic compounds, supply of missing nutrients, synergistic effects of microorganisms, increased load of biodegradable organic matters, economic advantage of sharing equipment, and better biogas yield. As total nitrogen and ammonium nitrogen (NH₄⁺-N) in FS are usually high, the anaerobic treatment of FS alone is not suitable, due to low C/N ratio [6]. This study was conducted to evaluate the potential of methane recovery from FS when it is mixed with SS from STP at different ratios in laboratory mesophilic condition.

2. MATERIALS AND METHODS

2.1. Substrates, analysis and BMP experiment apparatus

Substrates (S) included FS collected from septic tank emptying trucks and SS from municipal STPs. Substrate samples were stored at 4 °C for utilization over the study time. Inoculum (I) used in the BMP test was taken from the anaerobic digester – incubator operated all year around at ISEE laboratory. This digester is a 40 L continuous stirred reactor operating at a mesophilic temperature 35 ± 0.5 °C. TS, VS and COD were analyzed following the Standard methods (APHA, 2005). The total nitrogen was analyzed following TCVN 6624-1:2000. The biochemical methane potential (BMP) tests of substrates were performed in batch mode using anaerobic digestion at 35 °C. BMP1 experiment was performed to measure the methane potential in batch reactors using single substrates including FS, primary sewage sludge (PSS), waste activated sludge (WAS), WAS1 and WAS2. BMP2 experiment evaluated the methane producing potential in each batch reactor using co-substrate, WAS mixed with FS at ratios FS:WAS =
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BMP apparatus was a temperature controlled water bath with 6 bottles - reactors of 500 mL volume, each equipped with a continuously stirring magnet. A carbon dioxide fixing solution of alkaline (NaOH 3 M) helped to absorb CO₂ and H₂S produced from the anaerobic digestion process. 6 gas volume measuring cylinders were used where collected methane gas was measured through water displacement (see Figure 1 and Figure 2).

2.2. Evaluation formulas

The S/I ratio was calculated based on the initial VS values of the substrate and the inoculum. Instability in the anaerobic process, such as high COD value in the effluent and volatile fatty acids (VFAs) accumulation, occurs with S/I ratio lower than 0.5 [7]. S/I ratio ranging between 0.5 and 2.3 gVS/gVS can prevent acidification phenomena [8]. In this study, S/I ratio of 0.5 was used to ensure the methane potential was achieved. The substrate to inoculum (S/I) ratio (VS basis) is equivalent to the value of the food to microorganism (F/M) ratio. After adding the required volumes of inoculum and substrate, each reactor was added tap water to reach a 500 mL test volume. The reactor was flushed with nitrogen gas for 2-3 min so that anaerobic condition was assured. A control bottle without substrate was also set in BMP1 and BMP2 tests. The experiments were duplicated while the results were expressed as mean values. Experiments were ended when methane was not further produced. The methane produced from the inoculum was subtracted from the sample assays.

CO₂ and H₂S from generated and collected biogas were removed by alkaline solution. Volume of methane was measured daily, and adjusted to the values at standard conditions STP (0 °C, 1 atm). Methane yield η(CH₄) was determined by COD_input / COD_output and measured CH₄ volume as shown in Formula (1). The methane potential of substrates was evaluated based on their specific methane yield, defined here as the total volume of methane produced during the digestion period per gram of VS substrate added in the substrate volume in each reactor (Formula (2)).

\[
\eta_{CH_4} = \frac{COD_{CH_4}}{COD_{removed}} \times 100, \%
\]

where: COD_{CH_4} = V_{CH_4}/350; COD value converted into CH₄ (g); V_{CH_4}: accumulated CH₄ volume produced from reactor at STP (NmL); 350 (NmL CH₄/g): conversion factor, 1 gram COD is theoretically converted into 350NmL CH₄ at STP [4]; COD_{removed} = COD_input - COD_output: value of COD removed in each reactor (g).

\[
\text{Specific methane yield} = \frac{V_1 - V_2}{M_{VS}}, \text{NmL CH}_4/\text{g VS}_{substrate \ added}
\]

where: V₁ is the accumulated methane volume produced from the reactor with both inoculum and substrate mixed (NmL); V₂ is the accumulated methane volume produced by the blank (NmL); M_{VS} is the VS content of the substrate fed to each reactor (g).

3. RESULTS AND DISCUSSIONS

3.1. Characterization of substrates

Table 1 presents the characteristics of the substrates used in BMP1 and BMP2 tests.
Table 1. Characteristics of substrates used in BMP experiments.

<table>
<thead>
<tr>
<th>Experimental parameters (units)</th>
<th>Substrates, BMP1 experiment</th>
<th>Substrates, BMP2 experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>FS</td>
</tr>
<tr>
<td>pH</td>
<td>7.40</td>
<td>7.60</td>
</tr>
<tr>
<td>TS (g/L)</td>
<td>20.8</td>
<td>26.5</td>
</tr>
<tr>
<td>VS (g/L)</td>
<td>12.6</td>
<td>19.0</td>
</tr>
<tr>
<td>VS/TS (%)</td>
<td>60.5</td>
<td>71.7</td>
</tr>
<tr>
<td>COD (g/L)</td>
<td>18.56</td>
<td>24.55</td>
</tr>
<tr>
<td>TN (g/L)</td>
<td>1.09</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Note: I: inoculum; FS: faecal sludge; PSS: primary sludge; WAS1: waste activated sludge, STP#1; WAS2: waste activated sludge, STP#2; WAS: mixture of PSS and WAS1.

The FSTS content was approximately 1.5 - 5.2 times higher than that of the SS, and its VS content was 1.6 - 6.1 times higher. Similarly, the FS had more COD values (approximately 1.4 - 4.8 times) than the SS. The FS VS/TS ratio was 71.7 % - 74.4 %, while ratio of SS was 54.1 % - 68.3 %, indicating that FS contained much digestible organic matters. The VS/TS and COD values of SS in this study were similar to that reported by [9]. The TN concentration in FS was 1.2 - 3.9 times higher than that of SS. The COD/TN ratio of FS (15.8 - 27.4) and SS (14.6 - 23.5) were lower than the optimal ratio range from 400:7 up to 1000:7 for anaerobic digestion [10]. Nitrogen existed in SS in either inorganic forms such as ammonium (NH₄⁺), nitrate (NO₃⁻) or complex organic forms [2]. The concentrations of both inorganic and organic nitrogen were dependent on types of sludge and handling processes. The majority of the FS nitrogen was ammonia [4]. Ammonia helped to maintain alkalinity in the digester, but high ammonia concentration (exceeding 3,000 mg/L) could inhibit methanogens activity [6]. The mixture of FS and SS was expected to improve the efficiency of the anaerobic digestion compared to using FS alone.

3.2. Methane yield

BMP tests were carried out at neutral pH (7.17 to 7.78), reducing possibility of creating toxic conditions [11]. Figures 3 and 4 show methane volume produced per gram of COD removed for all samples were lower than the theoretical value (350 NmL CH₄/g COD removed) [6]. This difference shows loss of COD, probably, due to presence of SO₄²⁻ and NO₃⁻ in the sludge (which may lead to the substrate competition of sulfate-reducing bacteria, nitrate-reducing bacteria and acid-fermented microorganisms), by conversion into volatile fatty acids that have not yet finished the decomposition process. All methane yields have ranged 60÷80 %. Results of BMP1 (Table 2) shown FS anaerobic digestion can produce methane, although FS has been stabilized in the septic tank, and low COD/TN or C/N ratio in substrate. Observed changes in specific CH₄ yield and CH₄ content consistently complied with above mentioned C/N ratio. A high C/N ratio is an indication of rapid consumption of nitrogen by methanogens and results in lower biogas production. On the other hand, a lower C/N ratio causes ammonia accumulation which is toxic to methanogenic bacteria.

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Table 2. Results of BMP1 and BMP2 tests

<table>
<thead>
<tr>
<th>Samples</th>
<th>Inoculum (blank)</th>
<th>S1 = I + FS</th>
<th>S2 = I + PSS</th>
<th>S3 = I + WAS1</th>
<th>S4 = I + WAS2</th>
<th>S5 = I + WAS</th>
<th>S6 = I + 100%WAS</th>
<th>S7 = I + 14%FS + 86%WAS</th>
<th>S8 = I + 25%FS + 75%WAS</th>
<th>S9 = I + 33%FS + 67%WAS</th>
<th>S10 = I + 50%FS + 50%WAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>2</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>pH</td>
<td>7.2 ± 0.03</td>
<td>7.2 ± 0.03</td>
<td>7.1 ± 0.03</td>
<td>7.2 ± 0.18</td>
<td>7.1 ± 0.03</td>
<td>7.2 ± 0.18</td>
<td>7.2 ± 0.03</td>
<td>7.2 ± 0.03</td>
<td>7.2 ± 0.03</td>
<td>7.2 ± 0.18</td>
<td>7.2 ± 0.03</td>
</tr>
<tr>
<td>VS (g/L)</td>
<td>3.77 ± 0.06</td>
<td>5.65 ± 0.18</td>
<td>5.65 ± 0.18</td>
<td>5.65 ± 0.18</td>
<td>5.65 ± 0.18</td>
<td>5.65 ± 0.18</td>
<td>9.92 ± 0.17</td>
<td>9.92 ± 0.17</td>
<td>9.92 ± 0.17</td>
<td>9.92 ± 0.17</td>
<td>9.92 ± 0.17</td>
</tr>
<tr>
<td>COD (g/L)</td>
<td>5.57 ± 0.04</td>
<td>8.00 ± 0.11</td>
<td>8.47 ± 0.08</td>
<td>8.64 ± 0.10</td>
<td>7.97 ± 0.08</td>
<td>8.43 ± 0.10</td>
<td>15.67 ± 0.11</td>
<td>16.07 ± 0.10</td>
<td>16.37 ± 0.18</td>
<td>16.60 ± 0.17</td>
<td>17.07 ± 0.07</td>
</tr>
<tr>
<td>pH</td>
<td>7.57</td>
<td>7.74</td>
<td>7.74</td>
<td>7.73</td>
<td>7.73</td>
<td>7.71</td>
<td>7.60</td>
<td>7.76</td>
<td>7.78</td>
<td>7.78</td>
<td>7.77</td>
</tr>
<tr>
<td>VS (g/L)</td>
<td>2.90 ± 0.07</td>
<td>3.61 ± 0.13</td>
<td>3.39 ± 0.16</td>
<td>3.54 ± 0.08</td>
<td>3.62 ± 0.11</td>
<td>3.50 ± 0.07</td>
<td>5.04 ± 0.08</td>
<td>5.88 ± 0.17</td>
<td>5.76 ± 0.11</td>
<td>5.74 ± 0.21</td>
<td>5.70 ± 0.17</td>
</tr>
<tr>
<td>COD (g/L)</td>
<td>4.30 ± 0.07</td>
<td>5.12 ± 0.11</td>
<td>5.08 ± 0.10</td>
<td>5.42 ± 0.11</td>
<td>5.00 ± 0.10</td>
<td>5.26 ± 0.06</td>
<td>8.12 ± 0.08</td>
<td>9.74 ± 0.13</td>
<td>9.70 ± 0.07</td>
<td>9.66 ± 0.11</td>
<td>9.66 ± 0.18</td>
</tr>
<tr>
<td>Total CH₄ production (Nml)</td>
<td>172.8 ± 3.1</td>
<td>401.1 ± 12.6</td>
<td>465.3 ± 6.6</td>
<td>449.8 ± 7.4</td>
<td>387.8 ± 10.2</td>
<td>438.8 ± 11.6</td>
<td>784.4 ± 14.9</td>
<td>795.9 ± 14.8</td>
<td>799.9 ± 14.2</td>
<td>806.6 ± 11.9</td>
<td>826.5 ± 14.8</td>
</tr>
<tr>
<td>Specific methane yield (NmL CH₄/gVSremoved)</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
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<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>CH₄ prod. from substrate (NmL)</td>
<td>100.00</td>
<td>228.2 ± 9.5</td>
<td>292.5 ± 3.5</td>
<td>277.0 ± 4.2</td>
<td>214.9 ± 7.2</td>
<td>407.8 ± 10.8</td>
<td>329.2 ± 12.3</td>
<td>411.4 ± 5.9</td>
<td>389.7 ± 7.3</td>
<td>385.7 ± 5.7</td>
<td>391.5 ± 7.0</td>
</tr>
<tr>
<td>Specific methane yield (NmL CH₄/gVSsubstrate)</td>
<td>0.00</td>
<td>228.2 ± 9.5</td>
<td>310.5 ± 3.8</td>
<td>277.0 ± 4.2</td>
<td>214.9 ± 7.2</td>
<td>407.8 ± 10.8</td>
<td>329.2 ± 12.3</td>
<td>411.4 ± 5.9</td>
<td>389.7 ± 7.3</td>
<td>385.7 ± 5.7</td>
<td>391.5 ± 7.0</td>
</tr>
</tbody>
</table>

(Note: ¹Values are expressed as mean; and the values followed by “±” are Standard deviation; ²Number of duplicates.)

Compared to the test of SS only (269.3 NmL CH₄/gVSsubstrate), a higher methane volume generated was achieved in mixed SS-FS sample (276 and 294.8 NmL CH₄/gVSsubstrate) in BMP2 experiment. The highest value was from sample with 50% FS (in VS mass).

Figure 3. Specific methane yield NmL CH₄/gCODremoved and methane yield (%) in BMP1.

Figure 4. Specific methane yield NmL CH₄/gCODremoved and methane yield (%) in BMP2.

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4. CONCLUSIONS

BMP batch tests have shown the FS was found to be a potential substrate for co-digestion and methane production with the SS from the municipal STPs with or without primary sedimentation tank. Addition of FS as a co-substrate provided the specific methane yield from 269.3 NmL CH$_4$/gVS$_{sub}$ added when only WAS was digested which increased up to 294.8 NmL CH$_4$/gVS$_{sub}$ added in the case of co-digestion, with a ratio of FS:WAS = 50:50 on VS basis. Co-digestion of FS and SS in anaerobic digesters built at municipal STPs which are often working under capacity provides chance to combat with both FS and SS, utilizing existing infrastructure facilities and retrieve more methane.

REFERENCES