Anaerobic digestion of residual municipal solid waste using biological–mechanical pre-treatment: the plant of Varennes Jarcy
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ABSTRACT

Residual municipal solid waste can be treated by anaerobic digestion after a sorting process in order to remove the unwanted materials. After a mechanical sorting the quality of the final compost can hardly cope with requirements for agriculture use. In this way, a more efficient sorting process using a specific equipment that provides a combined biological and mechanical effect, has been implemented on the plant of Varennes Jarcy prior to anaerobic digestion. This paper presents the main results obtained on this plant. The reduction of biodegradable organics in particle lower than 10 mm allows a very efficient separation by screening. An additional ballistic sorting removes the remaining glass. The composition of the resulting sorted waste was close to a source-sorted organic fraction. The sorted waste exhibit methane yields comparable with raw biodegradable organics, showing that the pre-treatment had little impact on anaerobic digestion performance.

Key words | anaerobic digestion, compost, full scale plant, pretreatment, residual waste

INTRODUCTION

Anaerobic digestion of solid waste was up to now considered with two different strategies: (i) digestion of bio-waste, source-sorted and separately collected, to produce a high quality compost or (ii) digestion of municipal solid waste (MSW) mechanically sorted to produce a low quality compost or a stabilized end-product for landfill. On the other hand, a specific device called a “rotating tube” has been used for years as a first step for composting MSW. These tubes provide a combined biological and mechanical effect. The implementation of a high performance sorting line after a rotating tube fed with MSW has allowed the production of a compost that copes with the new French regulation (NFU 44-051)(Morvan & Briand 2007).

The pre-treatment consisting of a rotating tube followed by a high performance sorting line prior to anaerobic digestion has been applied at the plant of Varennes Jarcy. The aim of this paper was to characterize the biological mechanical pre-treatment on waste composition and the impact on anaerobic digestion.

PRESENTATION OF THE VARENNES JARCY PLANT

General presentation

The plant of Varennes Jarcy, located south east of Paris, was initially treating municipal solid waste by composting. In 1997, a study was initiated to elaborate a project which aimed to cope with the new regulation for waste management and with the requirement for compost quality. The schedule of conditions included i) absence of fume emission ii) absence of odors iii) no negative impact on atmosphere and iv) energy saving. The trade association for valorization of household waste in charge of the waste management in the area, SIVOM de la Vallée de l’Hyère et des Sénarts,
decided to implement an anaerobic digestion plant using the Valorga process.

The industrial operation of the plant started in 2003. In 2005 it was decided to change into a delegation of public utility, which was entrusted to Urbaser Environnement and Valorga International, who created for this purpose the company Urbasys.

The main characteristics of the plant are the following:

(i) a global treatment capacity of 100,000 tons per year
(ii) the conservation of the 2 rotating tubes (bioreactors) for the pre-treatment
(iii) a digestion unit with 2 digesters of 4,200 m³ and one of 4,500 m³
(iv) a post-composting and compost storage hall of 6,400 m²
(v) an air treatment unit with acid washing and bio-filter
(vi) an excess process water treatment unit in membrane bioreactor (MBR)
(vii) a biogas valorization unit with 3 power generating units of 900 kWel each.

**The biological–mechanical pre-treatment**

The municipal solid waste (MSW) are delivered in a pit and taken with a crane to the feeder of to the two rotating tubes with 48 and 42 m long and 4 m diameter. These tubes were originally used as a first step in the composting process. They are fed at one side, are turning at 1 rotation per minute, and are emptied at the other side after a retention time of about 2 to 3 days. Inside the tubes, the first steps of an aerobic degradation set up and the biodegradable part of waste begin to split up. The rotation of the tube allows a progression of the waste and provides a mechanical effect of homogenization and crushing. Going out from the tubes the waste is transported to a sorting line including a rotating screen with 30 mm round mesh, a magnetic separator to remove iron metals, a “flip-flow” screen with 12 mm square mesh, and a ballistic separator to remove the remaining small particles of glass.

**The anaerobic digestion**

The digestion is carried out with the Valorga process. The scheme of the digester is illustrated on Figure 1. It is a one-step, dry process, with a plug-flow type of processing. The digesters are vertical cylindrical tanks made of pre-stressed concrete, with an internal wall on 2/3 of the diameter. They do not contain any mechanical device. The mixing is provided by injection of biogas under pressure at the bottom of the digester. The waste is fed with a piston pump in one side of the wall and extracted by gravity on the other side.

After digestion, the material is dewatered in vibrating screens and centrifuges. The solid phase undergoes an aerobic post-treatment for maturation. The liquid phase is partly re-used in the process and the excess is sent to a membrane bioreactor before discharge in municipal sewer.

**MATERIAL AND METHODS**

**Waste sampling**

The waste was sampled by taking primary samples from the conveyor belts each 15 minutes during 2 to 4 hours, which seemed more efficient to get representative samples than to take into a heap. The quantities of waste sampled depend on the size particle: about 100 kg for the waste after the tubes and about 10 kg for the final sorted waste.
Waste composition

Hand sorting

The waste was first screened manually with a plane sieve with round mesh (5 mm, 10 mm, 15 mm, 20 mm, 30 mm, 50 mm), and each size category higher than 10 mm was sorted by hand to separate the following fractions: plastics, textile, wood, glass and stones, metals, biodegradable organics (included paper). The composition of fraction lower than 10 mm was determined by analysis.

Waste analysis

The total solid (TS) content was measured by drying at 105°C and the volatile solid (VS) content by calcinations at 550°C. The residue after calcinations was sieved at 1 mm, and the mineral material higher than 1 mm was added to the fraction glass and stone. The synthetic organics were measured after biodegradable organic dissolution into sodium hypochlorite, according to the French norm NFU44-164.

Contaminants analysis

For the determination of contaminants as defined in the French regulation NFU44-051, the samples were sent to an approved laboratory.

Methane potential

The methane potential was determined using 1 litre batches reactors at 37°C. The inoculum used was digested sludge from a wastewater treatment plant. The tests were carried out in triplicate and corrected with a blank. The gas production and composition was measured each day during at least 21 days. The results are expressed as SPT litres of methane per g VS.

CHARACTERIZATION OF THE ROTATING TUBES
OPERATION

Operating parameters during the study

The study was carried out on the 48 m tube, with a rotation speed of 1 rpm. Two operating conditions were tested: the first one with a flow of 90 tons per day, and the second one with a flow of 130 tons per days. The resulting retention times, owing a working volume of 70% of the total volume and an average waste density of 0.7, were 3.6 days and 2.5 days respectively.

Composition of the waste

The waste at the outlet of the tubes was hand sorted to separate the different components with regard to the further biological treatment. The results are shown on Table 1. The content of organics, including fermentable, paper and cardboard, was 52% and 48% for RT 2.5 d and 3.6 d respectively. Although the error on the result was not estimated, it was not considered as significant, owing to the expected variation on raw waste composition. It was thus stated that MSW was containing an average 50% of biodegradable organics, 13% inert minerals (metals, glass and stones) and 37% synthetic and woody organics.

Size distribution of the waste

The size distribution of the waste was examined by hand screening. The results are shown on Figure 2. In both cases 53% of the raw waste was smaller than 30 mm. The longer stay in the tube provided a small increase of about 5% in the...
size reduction of the fractions less than 30 mm. For instance, 26% of the waste was less than 10 mm for 2.5 days RT, whereas 31% was lower than 10 mm at 3.6 days RT.

**Size distribution of separated components**

**Biodegradable organics**

It was the total of fermentable, paper and cardboard. The results are shown in Figure 3a). The biological mechanical effect provided by the rotating tubes leads to a dramatic size reduction of the biodegradable organic included paper: 50% were lower than 5 mm and 66% to 80% were lower than 10 mm for 2.5 days and 3.6 days respectively.

**Synthetic organics**

It was the total of plastics and textiles. The results are shown in Figure 3b). Synthetic organics were in the range higher than 30 mm for more than 94%. As expected, they do not have been reduced to a small size by the rotating tubes.

**Inert minerals**

It is the total of glass and stones. The results are shown in Figure 3c). Inert minerals were more evenly distributed, although less than 15% and 18% were in the fraction lower than 10 mm for RT 3.6 d and 2.5 d respectively. The mechanical effect of the tubes was significant on this fraction.

**Conclusion**

From these results it could be confirmed that a screening around 10 mm was a good compromise to separate unwanted materials while recovering biodegradable organics. It was highlighted that the retention time inside the tube had an impact on the splitting and thus on recovery of organics. The operating parameters of the rotating tubes must be adjusted according to the objective of the pre-treatment. It was also confirmed that the implementation of an additional step is necessary to remove the whole glass and stone fraction.

**Figure 3** | Size distribution of (a) biodegradable organics, (b) synthetic organics and (c) inert minerals for 2.5 days and 3.6 days retention time.
GLOBAL PERFORMANCE OF THE TREATMENT

Separation yield

During the reference period the biological mechanical sorting line has been operated with a mean retention time of 3.6 days in the rotating tubes. In these conditions, the yield was in average 48% sorted organics and 52% refuse, including the metals to be recycled. These figures had to be compared with the 50% initial content of non-biodegradable organics.

Composition of the sorted waste

The sorted waste was analyzed regarding the new regulation on compost. The results presented in Tables 2 and 3 for the sorted waste were the average of samples taken on four different weeks. In order to estimate the adequacy of the sorting line with the objective, the required values for agriculture use of compost are also reported (French norm NFU44-051). The sorted waste contained about 2% (on TS) of macroscopic contaminants – plastics and glass. The heavy metals contents were well below the requirement for agriculture use of compost. The sorted MSW could compete with source-sorted bio-waste described in the literature (Bolzonella et al. 2006; Morvan & Briand 2007).

Methane potentials of the sorted waste

The sorted waste was also characterized regarding his ability for anaerobic digestion. The methane potential has been determined as described in material and methods. Three samples have been taken on three different weeks, with a retention time in the tubes of 3.6 days. The results are reported in Table 4. The average methane potential amounted to 0.27 l STP methane/ g VS fed. This is in the upper range of the yields usually observed with organic fraction of municipal solid waste (Hartmann & Ahring 2006). It can be concluded that no significant negative effect of the pre-treatment is expected for the digestion performance.

Performance of the digestion unit

Owing the quantity of sorted waste produced during the reference period, only one digester of 4,500 m³ was in operation. The figures for the digestion are based on the results of a 6 months period. They are shown in Table 5. The gas production was in average 140 m³ STP/ton fresh weight, i.e. a methane yield of 0.24 m³ STP/kgVS. That represented

Table 2 | Composition and contaminants content in the sorted waste compared to French regulation on compost NFU44-051

<table>
<thead>
<tr>
<th>TS (% FW)</th>
<th>VS (% TS)</th>
<th>Plastic film &gt; 5 mm (% TS)</th>
<th>Other plastics &gt; 5 mm (% TS)</th>
<th>Glass and metals &gt; 2 mm (% TS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorted waste</td>
<td>49</td>
<td>66</td>
<td>0.03</td>
<td>0.13</td>
</tr>
<tr>
<td>NFU44-051</td>
<td></td>
<td></td>
<td>0.3</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Table 3 | Heavy metals content in mg/kg TS, in the sorted waste compared to the French regulation on compost NFU44-051

<table>
<thead>
<tr>
<th>Cd</th>
<th>Cr</th>
<th>Hg</th>
<th>Ni</th>
<th>Pb</th>
<th>Se</th>
<th>Cu</th>
<th>Zn</th>
<th>As</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorted waste</td>
<td>1.1</td>
<td>59</td>
<td>0.27</td>
<td>31</td>
<td>129</td>
<td>0.52</td>
<td>78</td>
<td>434</td>
</tr>
<tr>
<td>NFU44-051</td>
<td>3</td>
<td>120</td>
<td>2</td>
<td>60</td>
<td>180</td>
<td>12</td>
<td>300</td>
<td>600</td>
</tr>
</tbody>
</table>

Table 4 | Methane potential of the sorted waste

<table>
<thead>
<tr>
<th>Sample</th>
<th>TS %</th>
<th>VS %</th>
<th>Methane yield 1 CH₄/g VS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50.3</td>
<td>70.8</td>
<td>0.27</td>
</tr>
<tr>
<td>B</td>
<td>46.0</td>
<td>69.0</td>
<td>0.29</td>
</tr>
<tr>
<td>C</td>
<td>48.6</td>
<td>69.4</td>
<td>0.26</td>
</tr>
<tr>
<td>Average</td>
<td>48.3</td>
<td>69.7</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Table 5 | Performances of the digestion unit

<table>
<thead>
<tr>
<th>TSin %</th>
<th>TSout %</th>
<th>Gas production m³ STP/ton</th>
<th>CH₄ content % v/v</th>
<th>Methane yield m³ STP/kg VS</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>22</td>
<td>140</td>
<td>54</td>
<td>0.24</td>
</tr>
</tbody>
</table>
89% of the methane potential previously determined, which was expected from an efficient industrial digestion.

CONCLUSION

The biological mechanical pre-treatment implemented on the Varennes Jarce plant make it possible to separate biodegradable organics—including paper—from unwanted material—such as plastics and glass—with a high efficiency and a high recovery yield. The sorted waste contained about 2% contaminants (on TS), and could compete with source separated bio-waste. More than 80% of biodegradable organics could be recovered. The pretreatment does not affect global anaerobic digestion performances in a negative way. The production of biogas and high quality compost from MSW could be achieve using this technology.

REFERENCES