Evaluation of biogas potential of some organic substrates from agriculture and food industry and co-digestion in large scale biogas plant

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Abstract

Interest in biogas technology is increasing due to the benefit of transforming waste in renewable energy production, possibility of cogeneration and reduction of harmful emissions. Operating a large scale biogas plant is always a challenge, as the properties of the main substrate can vary in time and the availability of new substrates demand re-formulation of the mixture used to feed the digester. In this work, the biogas and methane production potential of some organic materials have been evaluated (triticale, potatoes, sugar beet pulp and expired food) comparing with the main substrate (maize silage) used in a large scale biogas plant. According with the energy production potential and operating parameters of the anaerobic digestion process, these materials have been subsequently used as co-substrates in large scale biogas plant to increase energy production.

Keywords: anaerobic digestion, biogas, crops, food waste.

Introduction

Operating a biogas plant, high output feedstock crops are a necessity, due to the content of necessary micronutrients, as well as constant and predictable output. At the same time, for farmers in the neighbourhood, cropping feedstock for biogas might represent a useful source of income. The best practice on biogas technology shows clearly that the selection of crops for biogas has the same importance as farming for food or feed production.

Ideally biogas production would benefit from a consistent mix of feedstock materials, chopped, blended and stored to ensure optimum methane yield.

In practice, Anaerobic Digestion (AD) units might also use a proportion of food waste. This brings wide beneficial for waste management, as there is no need to spend money for evacuation of waste and the obtained digestate is a valuable fertilizer, bringing benefits for the environment. It might be also a benefit for biogas operators due to the possibility of getting feedstock at low price or even getting paid to process those wastes.

However a single feedstock used can present challenges in the consistency of gas output and therefore income(Burgess J, Witherford S. [1]). Yield is the main consideration for efficient crop production or waste consistency. The main objective in operating a biogas plant is to use a feedstock mix that allows the digestion process to function effectively, and
maximize methane output. The digestion rate of different substrates might vary from two days up to two months. Material that has a high level of sugar or starch is quicker to ferment than lignocellulosic substrates for example. However, in terms of methane yield, both agriculture crops and organic waste can be mixed in a synchronized manner in accordance to digestibility and gas production dynamics.

Since the Renewable Energy Sources Act (EEG) was first amended in 2004, particular importance has been attached to Agriculture crops (renewable raw materials) in connection with the generation of electricity and heat from biogas. Agriculture crops are used in most of the new biogas plants that have been built since that time. A selection of the agriculture crops commonly used in biogas production is described in Table 1, regarding biogas yields.

**Table 1.** Biogas yields and methane content of main substrates used in Romania as feedstock in biogas production (Karagiannidis, [2])

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Dry matter</th>
<th>Biogas yield (\text{m}^3\text{·t}^{-1}) (fresh)</th>
<th>Methane content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture crops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize silage</td>
<td>29-35</td>
<td>210</td>
<td>53</td>
</tr>
<tr>
<td>Wholecrop cereals</td>
<td>28-31</td>
<td>215</td>
<td>54</td>
</tr>
<tr>
<td>Organic waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potatoes processing</td>
<td>24-26</td>
<td>80</td>
<td>57</td>
</tr>
<tr>
<td>Sugar beet pulp</td>
<td>16-18</td>
<td>110</td>
<td>52</td>
</tr>
</tbody>
</table>

**Materials and methods**

1. **Characterization of organic materials**

   **Crops (maize and triticale)** freshly harvested were ensiled (stored and compacted) separately into special concrete silos. The harvesting period vary depending on soil and climate conditions, but however it has been done at the late milk ripe to early dough stage when accordingly, there is a DM (Dry Matter) of 30-38% and in case of triticale, a grain straw ratio of 1:1. As the triticale stalks are essentially hollow, due to the oxygen brought into the silage mass, the shredding field machinery must be set up to achieve chop length not bigger than 12 mm length. By a correct compaction on the silo, the bulk density of triticale must reach appx. 700 kg of FM per \text{m}^3. The ensiling period of triticale and maize must not be less than 6 weeks before opening the silo in order to enable lactic acid bacteria to propagate and ferment available substrate in the crops.

   Before using the **potatoes** as substrate a shredding is demanded in order to ensure a permissive flowing into the digester as well as to increase the organic degradability of this feedstock. In this regard a shredder as in the right picture has been used in order to achieve particles size less than 15 mm.
In general, in this substrate type molding can occur and fungal toxins may accumulate in the feedstock. Still, in order to not affect the activity of fermenting microorganisms in the digester, the maximum limit of molding should be under 5% of the substrate. Old potatoes being considered as waste category, this feedstock is not ensiled but is desired to be used before getting the mold critical mass mentioned above.

The expired food used in this work consisted mainly on a mixture of depreciated vegetables and fruits (tomatoes, cucumbers, oranges, apples) and fats from meat processing and sausage products as in the right picture. For improving the organic degradation, these organic materials have been shredded before feeding into the digester to achieve particles size up to 15 mm.

2. Process evaluation and sample analysis

Process evaluation is carried out by analyzing and interpreting measured values. As already established, balancing of the mass flows is the most reliable method of describing the process. In practice, however, this is not economically viable because of complexity involved. Furthermore, various particularities arise in practice in relation to the recording of measured values, so the differences between laboratory analysis and sensors installed online in the process are examined. All lab analyses require representative sampling; subsequently the samples have to be transported to a laboratory. Although analyses of this type are time-consuming and there is a delay before the results are available, without laboratory analyses, operating a biogas plant is a blind-random activity. Sensors that take measurements directly within the process, on the other hand, have a considerably higher measurement density, and the measured values are available immediately. Unfortunately, the measured variables required for mass balancing cannot be metered with online sensors, so supplementary laboratory analyses are indispensable.

The samples were sent to laboratory Bonalytic GmbH Germany, to be analysed in terms of dry mater, organic dry mater, and laboratory batch tests for the measurement of biogas and methane potential according to VDI4630 (Fermentation of organic materials - characterization of the substrate, sampling, collection of material data, fermentation tests). Each substrate in particular have been analysed before using it as co-substrate.

3. Feedstock used as co-substrates in large scale biogas plant

After laboratory analyses where performed and biogas and methane potential of each substrate was established, the obtained data are used to formulate substrate mixtures in order to increase energy production and efficiency of the process. The type and rates of mixtures are
chosen by basic principles used in a biogas plant, such as: availability, organic loading rate, C/N ratio, hydraulic retention time, FOS-TAC etc. Additionally, in order to have a reference for underlining the synergy of substrates mixture, the following principles have been compiled: (i) the organic loading rate of the biogas installation has been constantly kept at 18.9 tones ODM·day⁻¹; (ii) the trace elements ratio of the mixture has been kept within the green range as presented in table 2.

Table 2. Guiding values of trace elements in a large scale anaerobic digestor

<table>
<thead>
<tr>
<th>element</th>
<th>unit</th>
<th>digester</th>
<th>supply region</th>
<th>recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt (Co)</td>
<td>mg/kg</td>
<td>0.07</td>
<td>0.69</td>
<td>&gt; 1.6</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>mg/kg</td>
<td>10.4</td>
<td>110</td>
<td>&lt; 70</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>mg/kg</td>
<td>291</td>
<td>3070</td>
<td>&lt; 3000</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>mg/kg</td>
<td>19.9</td>
<td>209</td>
<td>&lt; 5000</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>mg/kg</td>
<td>0.13</td>
<td>1.34</td>
<td>&gt; 2</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>mg/kg</td>
<td>0.23</td>
<td>2.38</td>
<td>&gt; 3</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>mg/kg</td>
<td>621</td>
<td>6540</td>
<td></td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>mg/kg</td>
<td>0.07</td>
<td>0.737</td>
<td></td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>mg/kg</td>
<td>16.5</td>
<td>174</td>
<td></td>
</tr>
</tbody>
</table>

DM = dry matter  FM = fresh matter  con. = concentration

Results and discussions

Applying the standard assay for Measurement of Biogas and Methane Formation Potential according to VDI4630 (Fermentation of organic materials - Characterization of the substrate, sampling, collection of material data, fermentation tests) of each substrate in particular, before using it as a multi-substrate, data presented in figures 1 – 5 were obtained. These results indicate high differences between biogas and methane potentials of tested substrates. Regarding maize silage, the main substrate used in the anaerobic digestion for biogas production in the biogas plant used in this research, our results indicate a biogas producing potential of maximum 160 NL·kg⁻¹ ODM, obtained after 25 days of anaerobic digestion. After this period, the production virtually stops, while other substrates, like triticale for example, releases biogas much faster (in the first 6 days, indicate a biogas producing potential of 300 NL·kg⁻¹ ODM). This substrate can be digested in a shorter period of time, after 16 days the anaerobic batch test was stopped as the growth curve was prolonged, the stationary phase was not achieved, but the biogas and methane production rate was much lower in the period of 6 – 16 days.
In the case of potatoes, the biogas and methane yields are comparable with those displayed for maize silage (around 150 NL·kg\(^{-1}\) ODM of biogas and 100 NL·kg\(^{-1}\) ODM of methane). The differences are in the dynamics of gas production: in the potatoes case, the biogas production started much earlier (after 2 days, comparing with 5 days in the case of maize) and the production reached maximum until the tenth day of digestion, in contrast to maize, where the maximum production was reached after 20 days of digestion.

Regarding biogas and methane production potential in sugar beet pulp, the obtained results are comparable with those obtained in triticale, both in terms of gas volume and dynamics of production.
Finally, regarding the biogas and methane production potential of expired food, the results indicate the highest yields, around five times more than yields obtained in maize (up to 800 NL·kg⁻¹ ODM of biogas and 550 NL·kg⁻¹ ODM of methane). Although the substrate is readily available and easy to digest by the microorganisms, the production is prolonged up to 30 days, probably due to the high concentration of organic matter.

These results indicate high-yielding substrates, as expired food, sugar beet pulp or triticale to be used in large scale biogas plant to increase biogas and methane yields. The temptation is to recommend feeding the large scale digester exclusively with those high-yielding substrates, but there are several reasons making this not applicable, such as: availability (especially expired food), price, acidification of the fermentation medium due to high yields of organic acids, storing and preservation of feedstock, application of obtained digestate etc. Consequently, taking into account these reasons and consideration that co-

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digesting substrates, the gas yield is higher than the average yield of each substrate, it is recommended to feed the large scale digester with mixtures of substrates. The type and rates of mixtures are chosen by basic principles used in a biogas plant, such as: availability, organic loading rate, C/N ratio, hydraulic retention time, FOS-TAC etc. Additionally, in order to have a reference for underlining the synergy of substrates mixture, the following principles have been comploded:

- The organic loading rate of the biogas installation has been constantly kept at 18.9 tonesODM·day⁻¹;
- The trace elements ratio of the mixture has been kept within the green range as presented in table 2 in materials and methods.

By mixing the above mentioned substrates with maize silage, it has been observed that each of the mixture shows an improvement of potential in terms of gas yield and calorific power as well, in comparison of using each substrate as single feedstock (table 6). These results are in concordance with those reported by other authors (Vintila & al. [3], Nikolic & al. [4], Diguta & al. [5]), namely that the use of co-substrates mixtures in anaerobic digestion systems improves biogas yield by positive synergies established by combination of nutrients supplied by each substrate complementing each other. It has been demonstrated, experimentally, that in co-digestion processes using combinations of substrates, the biogas production is higher than the arithmetic mean of the biogas production potential of each single substrate.

Figure 6. Methane yield in co-digestion of substrate mixtures
Conclusions

- Biogas and methane production potentials of several organic materials available to be used as substrates in a large scale biogas plant have been established and compared.
- Addition of high-yielding substrates to the main substrate (maize silage) is recommended to increase biogas and methane yield of the large scale biogas plant.
- Feeding large scale anaerobic digester with mixtures of substrates improves biogas and methane yield by positive synergies established in the digestion and nutrients supply completion of co-substrates.

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