# ANAEROBIC CO-DIGESTION OF SOURCE SELECTED ORGANIC WASTE AND SEWAGE SLUDGE

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SUMMARY: The paper is concerned with the anaerobic co-digestion of wastewater treatment plant sludge and organic waste coming from the fresh food department of a large market store where a source separated collection system is installed. In particular the study is aimed to verify – by means of pilot plant operation – if the reactor is able to work in stable conditions for increasing organic loading rates – due to the organic waste addiction - with respect to the wastewater sludge simple digestion. In this way, different organic loading rates were tested, which corresponded to different scenarios of organic waste feeding to the anaerobic digestion plant. For the carried out experiments the pilot reactor showed a considerable improvement in biogas production while the reactor working conditions remained stable. An economical analysis – based on energy recovery assumptions - was carried out for each tested scenario, evaluating the specific industrial treatment cost for the considered organic fraction.

## 1. INTRODUCTION

The anaerobic co-digestion process, which can be defined as the simultaneous treatment of two – or more – organic biodegradable waste streams by anaerobic digestion (Mata-Alvarez, 2002) (Yen and Brune, 2007) (Fernández et al., 2005), offers great potential for the proper disposal of the organic fraction of solid waste coming from source or separate collection systems.

This type of treatment offers the possibility of using existing anaerobic reactors in wastewater treatment plants, with minor modifications and some additional requirements (Cecchi et al., 1996) (Gómez et al. 2006) (Neves et al., 2006) (Sosnowski et al., 2003) (Krupp et al., 2005). This is of particular interest since in the European Community there are some 36.000 wastewater treatment plants which adopt the anaerobic stabilisation of primary and waste activated sludge or waste activated sludge alone: very often these plants are oversized, due to the low sludge mass loadings originated from wastewater treatment which derives from the general tendency to reduce sludge production (Bolzonella et al., 2005).

Within this frame, the study is concerned with the co-digestion of wastewater treatment sludge and the organic fraction (OF) of solid waste coming from the fresh food department of a large market store, where both vegetables and meats are processed and packaged: the residues

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and scraps from the processing are collected separately. In this specific case the high separation level obtained at the source, does not require an additional separation pre-treatment before digestor feeding. It is necessary, indeed, to carry out a thermal pre-treatment (pasteurization) for the OF, as required by the European Regulation 1774/2002, since it contains not only vegetal but also animal residues.

The paper deals with the experimental study carried out – by means of pilot plant - to investigate the co-digestion of wastewater treatment sludge and the above mentioned OF of solid waste, with the aim of verifying if the reactor is able to work in stable conditions and improve the gas production, when the organic waste is added to the wastewater sludge.

Also an economic evaluation of the specific industrial treatment cost for the OF is presented.

## 2. EXPERIMENTAL STUDY

### 2.1 Pilot plant

The pilot plant consists of a single cylindrical reactor (diameter 0,6 m; height 0,8 m) in stainless steel with an available volume of 200 litres (Figure 1), which was borrowed in courtesy from the Dipartimento Scientifico e Tecnologico of the Università di Verona (Italy) and located within a wastewater treatment plant of Tuscany (Italy). The reactor has a level valve which keeps a constant volume of sludge inside, bleeding the excess. It is equipped with a thermal insulation and the temperature is kept constant at 37 °C (mesophilic conditions).

The pilot is also equipped with gas volumetric flow measurement instrument and with an infrared gas analyser to measure carbon dioxide and methane concentration, which allow an almost continuous monitoring of biogas flow rate and composition.

The reactor effluent was sampled daily and pH, Total Alkalinity (TA) and Volatile Fatty Acids (VFA) were measured, by means of laboratory procedures (APHA, 1998), in order to monitor the process stability.

Figure 1. View of the pilot reactor

## 2.2 Substrates characteristics

The anaerobic co-digestion involved two different substrates:

- wastewater treatment sludge
- OF of solid waste coming from the fresh food department of a large market store where a source separated collection system is installed .

Both the wastewater sludge and the organic fraction were periodically analysed and Table 1 reports the average values of the characterisation of the two substrates, in terms of Total Solids (TS), Total Volatile Solids (TVS) and Chemical Oxygen Demand (COD).

The organic fraction has quite variable characteristics, however its average composition can be roughly estimated as 30% animal origin and 70% vegetable origin. The source separated collection system installed at the large market store includes material shredding and mixing, hence the aspect of the processed OF is a quite thick sludge as reported in Figure 2.

## 2.3 Experimental conditions

The pilot reactor was fed with only wastewater sludge for a first period in order to reproduce the same stable operating conditions of the real scale anaerobic digestor of the wastewater treatment plant, in which the pilot was hosted. The real scale digestor has a volume equal to 3.000 $m^3$ and it works with 20 days of hydraulic retention time (HRT), being fed by 150 $m^3$/day of sludge. In order to reproduce the same operating condition, the pilot was fed as reported in Table 2.

After the only sludge feeding period, also the organic fraction was fed to the pilot reactor. The amount of the feeding organic material to the pilot was established on the basis of the amount of organic waste really available from the large market store, where the organic waste is accumulated in an about 10.500 kg capacity tank. It was assumed that when the tank is full the organic waste could be delivered to an anaerobic digestor located in a wastewater treatment plant, in order to be co-digested with the wastewater treatment sludge.

Figure 2. Aspect of the considered organic fraction of solid waste.

Table 1. Substrate characteristics

| | SLUDGE | OF |
|---|---|---|
| TS [g/kg] | 28,9 | 171,1 |
| TVS [g/kg] | 19,4 | 142,8 |
| COD [$gO_2$/l] | 1166,7 | 1565,7 |

Table 2. Real scale digestor and pilot reactor operating conditions

| | Real scale digestor | Pilot digestor |
|---|---|---|
| Volume [$m^3$] | 3.000 | 0,2 |
| Sludge feeding [$m^3$/day] | 150 | 0,01 |
| $OLR_{TS}$ [gTS/day] | 4.335.000 | 289 |
| $OLR_{TVS}$ [gTVS/day] | 2.910.000 | 19,4 |

According to the hypothesis of discontinuous feeding, four scenarios were simulated, corresponding to different available amounts of organic waste, which could arrive from a single or from several market stores:

- Scenario 1: one feeding of 10.500 kg per week, in one day
- Scenario 2: two feedings of 10.500 kg per week, in two days
- Scenario 3: three feedings of 10.500 kg per week, in three days
- Scenario 4: daily feeding of 10.500 kg per day (six days per week)

Adding 10.500 kg to the real scale digestor in one day means to increase its organic loading rate (OLR) of 39% in terms of TS and 55% in terms of TVS, according to the characterisation of Table 1. In order to reproduce this increasing OLR in the pilot reactor, 0,66 kg per day of organic waste must be fed.

According to this approach four experimental periods were arranged as following:

- Scenario 1: one feeding of 0,66 kg per week (length of the experiment: two weeks)
- Scenario 2: two feedings of 0,66 kg per week (length of the experiment: two weeks)
- Scenario 3: three feedings of 0,66 kg per week (length of the experiment: one week)
- Scenario 4: daily feeding of 0,66 kg per day (length of the experiment: one week)

In order to evaluate the effect of the required thermal pre-treatment, some OF samples (correspondent to the scenario 3 and 4) were kept at 70°C for one hour in a ventilated oven.

## 2.4 Experimental results

Figure 3 shows the daily biogas production during the different experimental periods. The first data correspond to the last period of conventional operation of the pilot with only sludge. Then the effect of the first reactor charge with the OF produce an immediate raising of the biogas production, which decreases to previous level until the following charge. Also in the experimental period corresponding to the Scenarios 2, 3 and 4 the immediate raising of the biogas production can be highlighted in correspondence of the OF charging day, followed by a decrement until the next charge, but in these cases values of biogas production are on average higher. Table 3 reports the average biogas production values during the different experimental periods, together with $CO_2$ and $CH_4$ production and percentage composition. As a matter of fact, specific gas production (SGP) during the last experimental period (daily charging) shows a lower value, due to the high surcharge of the reactor, but even in this conditions the overall gas production is much higher with respect to the simple sludge digestion. From the point of view of the composition, the biogas showed an average good quality, not different from the only sludge digestion case.

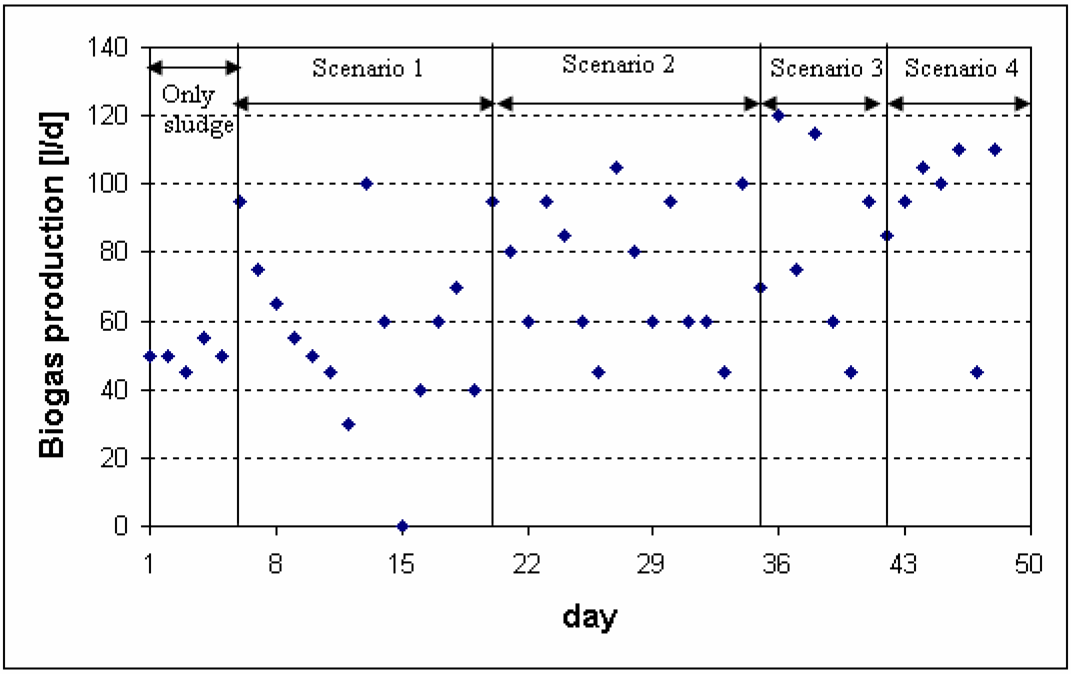


Figure 3. Biogas production during the experiments.

Table 3. Average biogas production and composition during the experiments.

| | Biogas [l/d] | $CH_4$ [l/d] | $CO_2$ [l/d] | $CH_4$ [%] | $CO_2$ [%] | Biogas [l/week] | Increment [l/week] | OF [kg/week] | SPG [l/kg] | SPG [l/$g_{TVS}$] |
|---|---|---|---|---|---|---|---|---|---|---|
| Only sludge | 50 | 32,4 | 14,9 | 64,91 | 29,76 | 350 | - | - | 6 | 0,30 |
| Scenario 1 | 60 | 38,8 | 19,4 | 64,75 | 32,37 | 420 | 70 | 0,66 | 106 | 0,74 |
| Scenario 2 | 74,3 | 47,6 | 24,1 | 64,08 | 32,49 | 505 | 155 | 1,32 | 117 | 0,82 |
| Scenario 3 | 83,6 | 53,1 | 27,5 | 63,54 | 32,92 | 585 | 235 | 1,98 | 118 | 0,83 |
| Scenario 4 | 90,7 | 58,05 | 30,5 | 63,47 | 33,35 | 635 | 285 | 3,96 | 72 | 0,50 |

In order to show the stable operating conditions of the reactor during the different experimental periods, Figure 4 reports the results of the analysis on the reactor effluent for pH, TA and VFA. These parameters show a substantial stability (Mata-Alvarez, 2002). The occasional raising of VFA for a number of days is to be ascribed to external factors (composition of feeding sludge) rather than to process issues.

Finally, Figure 5 shows the comparison of biogas production after few hours later than OF feeding, in the case of absence/presence of thermal pre-treatment. The results highlighted that there are no substantial differences in gas production between the cases without a thermal pre-treatment and the cases with the thermal pre-treatment. Hence, it is possible to conclude that the compulsory thermal pre-treatment does not affect the yield of the anaerobic products.

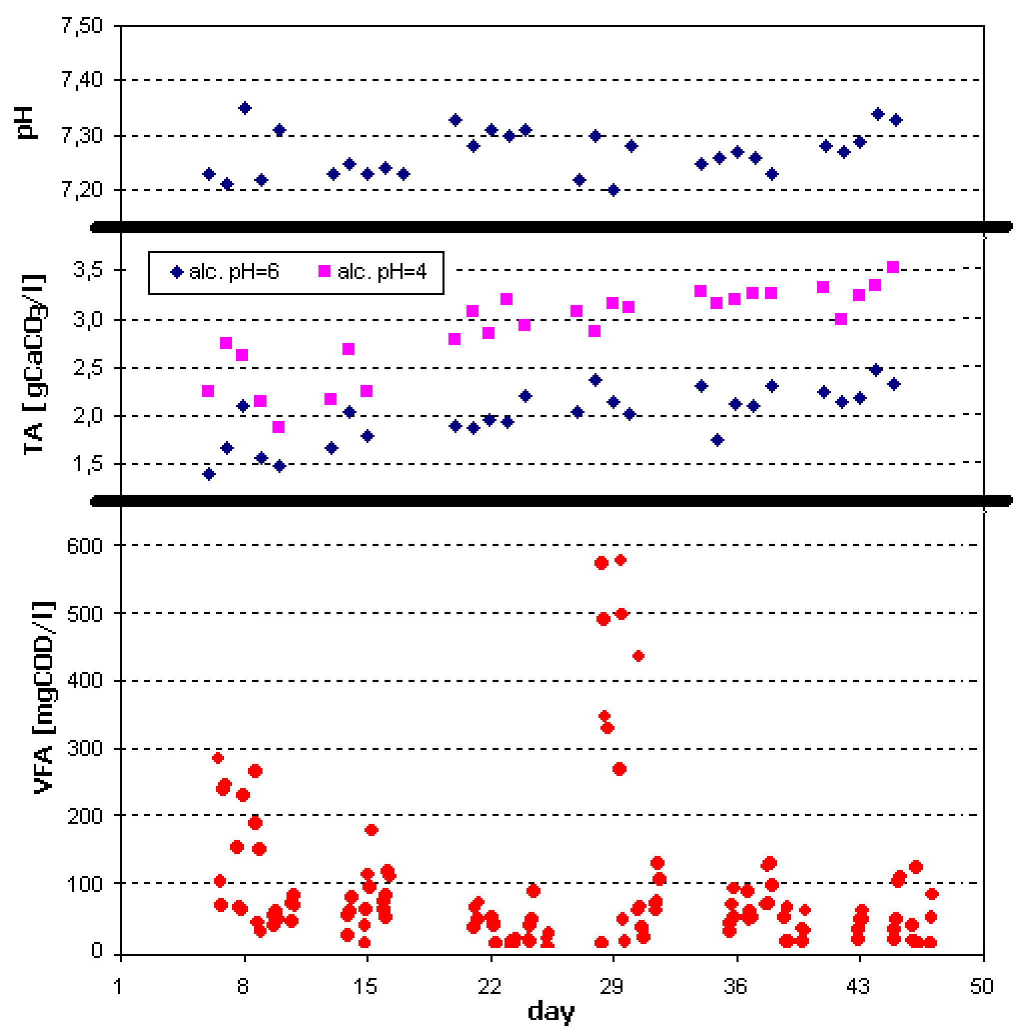


Figure 4. Trend of pH, Total Alkalinity and Volatile Fatty Acids during the experiments.

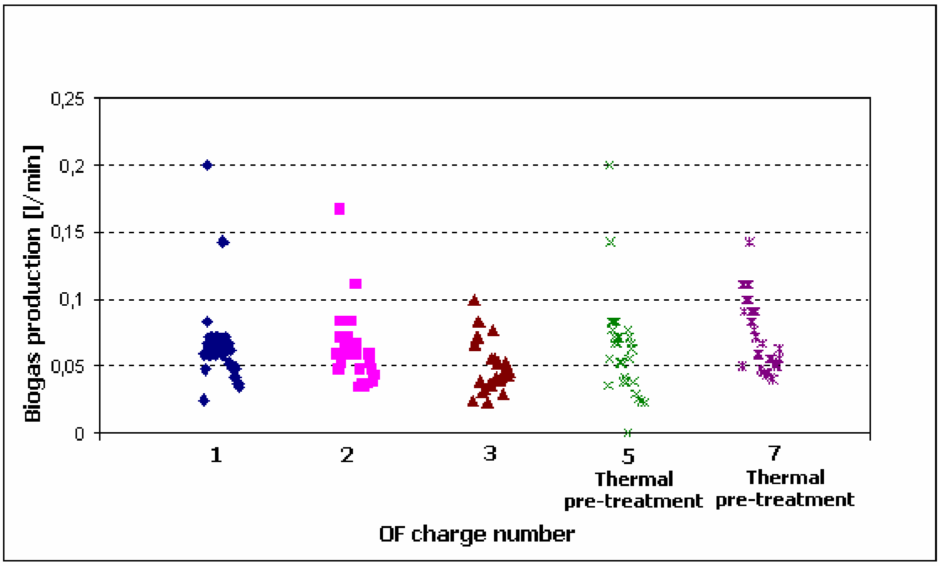


Figure 5. Comparison of biogas production after few hours later than OF feeding, in the case of absence/presence of thermal pre-treatment.

Table 4. Additional input and output streams from co-digestion process. Overall biogas production from sludge and OF.

| | OF [t/y] | Digested sludge [t/y] | Recirculated supernatant [$m^3$/y] | Biogas from OF [$m^3$/y] | Overall biogas [$m^3$/y] |
|---|---|---|---|---|---|
| Only sludge | - | - | - | - | 328.500 |
| Scenario 1 | 546 | 195 | 2.555 | 65.700 | 394.200 |
| Scenario 2 | 1.092 | 268 | 5.840 | 159.505 | 488.020 |
| Scenario 3 | 1.638 | 324 | 9.125 | 220.460 | 549.077 |
| Scenario 4 | 3.276 | 800 | 14.235 | 267.545 | 596.030 |

## 3. ECONOMIC ANALYSIS

In order to evaluate whether the OF co-digestion with wastewater sludge within the conventional anaerobic digestor is sustainable from an economical point of view, a cost analysis was carried out, on the basis of the experimental results, with reference to the real scale plant. According to the previously defined scenarios, the OF amount processed per year, on industrial scale, was calculated and reported in Table 4.

The cost considered in the analysis are:

- Investment and operating costs for OF thermal pre-treatment (pasteurization) (required by the European Regulation 1774/2002);
- Disposal of digested sludge, with reference to the additional amount due to the OF digestion;
- Supernatant recirculation at the wastewater treatment, with reference to the additional amount due to the OF digestion;
- Investment and maintenance costs for biogas energy recovery engine
- Profits from recovered energy selling.

Concerning the OF thermal pre-treatment, a device with the following characteristics was considered: capacity 10.000 kg/h; power 1.130 kW; operating temperature 70°C; cost 65.000 €. The annual cost for the thermal pre-treatment was calculated considering the annual depreciation instalment (considering 6,5% interest rate and 9 years), the maintenance (as 3,36% of investment cost), electric energy consumption (0,084 €/kWh) and personnel cost.

Concerning the digested sludge and the supernatant, the yearly produced amounts were evaluated (Table 4), with reference to the additional amount due to the OF digestion, on the basis of the pilot results. For the digested sludge a disposal cost of 44 €/t was assumed and also the electric consumption costs for the dewatering belt-press system, were included (Table 5). For the treatment of the recirculated supernatant, a cost of 0,28 €/$m^3$ was assumed (Table 5).

Concerning the energy recovery, it was assumed to feed all the amount of biogas from co-digestion to an engine for electrical and thermal energy production, assuming respectively 36% and 50% conversion efficiency. The engine investment and maintenance costs were evaluated in about 50.277 €/year. Part of the thermal energy is assumed to be used for the digestor heating (about 850.000 kWht/year), while the remaining part is sold to final users, assuming a selling price of 0,026 €/kWht (value calculated considering thermal energy produced from natural gas). The net produced electric energy (after subtracting the 8% for internal auxiliary consumption) can be sold, assuming a price of 0,1033 €/kWh. Values are reported in Table 5.

Table 5. Costs and profits in the four considered scenarios.

| | Pasteurization [€/year] | Digested sludge disposal [€/year] | Supernatant treatment [€/y] | Engine [€/y] | EE selling [€/y] | ET selling [€/y] |
|---|---|---|---|---|---|---|
| Scenario 1 | -17.318 | -8.816 | -706 | -50.277 | +14.029 | +5.735 |
| Scenario 2 | -22.688 | -12.270 | -1.613 | -50.277 | +33.080 | +13.462 |
| Scenario 3 | -28.058 | -14.952 | -2.520 | -50.277 | +43.807 | +17.782 |
| Scenario 4 | -44.166 | -36.633 | -3.931 | -50.277 | +54.700 | +22.147 |

## 4. RESULTS AND DISCUSSION

The economic analysis allows evaluating which is the specific industrial treatment cost for the OF, according to the hypothesis stated above. Table 6 shows the net cost for the treatment (obtained by the algebraic sum of profits and expenses in Table 5) and the obtained specific industrial treatment cost, in the four considered scenarios.

According to these results, the specific industrial cost decreases with an increasing frequencies of addiction of organic waste to the conventional process, due to the higher amount processed, even if the operating costs grow as well.

However, if the estimated cost is compared with the specific cost of other types of treatments for organic waste, it seems quite competitive, leaving also some possibilities for a net earning for the company.

Table 6. Industrial cost for the OF co-digestion.

| | Net cost for the treatment [€/year] | Treated OF [t/year] | Industrial treatment cost [€/t] |
|---|---|---|---|
| Scenario 1 | 57.353 | 546 | 105 |
| Scenario 2 | 40.306 | 1.092 | 37 |
| Scenario 3 | 34.218 | 1.638 | 21 |
| Scenario 4 | 58.160 | 3.276 | 18 |

## 5. CONCLUSIONS

The co-digestion of wastewater treatment sludge and the organic fraction of solid waste, coming from the fresh food department of a large market store, was studied by means of a pilot plant. Different reactor charging scenarios were considered with the aim of verifying if the reactor is able to work in stable conditions and improve the gas production, when the organic waste is added to the wastewater sludge.

Biogas production shows an immediate increasing at the charging time, decreasing in the days after charging. However an average enhanced value of biogas production is registered during all the experimental periods, with higher increase for more frequent feeding, even if in the case of daily feeding a lower SGP was measured, due to the high charge of the reactor. The quality of biogas was of a good level throughout the experiments.

The economic analysis, based on the pilot results up-scaled to an industrial size hypothesis, considered the assumption of using an engine to recover and sell both electric and thermal energy from the biogas, including the engine costs in the assessment. Additional costs linked to the waste organic fraction treatment were considered (thermal pre-treatment, sludge disposal, supernatant treatment) leading to the evaluation of the specific industrial cost for the treatment of the organic fraction which appears competitive with respect to average costs for the treatment/disposal of biodegradable organic fraction of solid waste, also leaving some margins for company net profit.

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