# Producing biofuels from urban organic waste

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**Abstract**

This study explored the possibility to biologically produce hydrogen and methane through the thermophilic single and two stages anaerobic codigestion of waste activated sludge and the organic fraction of municipal solid waste. Specific gas productions in single and double-stage processes working with an hydraulic retention time of 20 days were 493 L/kgTVS and 572 L/kgTVS, respectively. In the two stage process hydrogen and methane productions reached values of 24 $LH_2$/kgTVS and 272 $LCH_4$/kgTVS, respectively. Obtained biohythane, after upgrading, is particularly valuable for the automotive sector.

**Keywords:** waste activate sludge, organic municipal solid waste, thermophilic anaerobic digestion, hydrogen, methane

## 1. Introduction

In urban areas of Europe and Western Countries a single person produces every day some 120 g COD in the wastewater which will then origin some 50-60 g dry matter of excess sludge and some 300 grams of household food waste, equivalent to some 50-60 g dry matter per day. As a consequence, some 100 g dry matter per person are produced every day in our urban areas. This mass can be conveniently treated in order to recovery both energy and nutrients while disposing it off. The best option to achieve this goal is the application of the anaerobic codigestion approach. Co-digestion is the simultaneous anaerobic decomposition of two or more organic substrates mixture. Several studies showed benefits of the co-digestion, e.g. dilution of potential toxic compounds, nutrients balance improvement, synergistic effects of microorganisms, increased load of biodegradable organic matter and better biogas yield. Among the different organic substrates studied, the anaerobic co-digestion of sewage sludge (SS) and organic fraction of municipal solid waste (OFMSW - biowaste) is the most popular co-digestion research subject (Mata-Alvarez *et al.*, 2011) because of the possible exploitation of existing infrastructures: the anaerobic digesters of waste water treatment plants (WWTPs) (Cavinato *et al.*, 2013, Koch *et al*, 2015). In fact, because of over-sizing design or the treatment of very diluted streams, these reactors are very often operating at low organic loading rate (OLR); large spare volumes are therefore available for the co-treatment of sludge and other organic waste in WWTPs (Koch *et al.*, 2015). Anaerobic co-digestion can be considered as one of the most promising way to give a proper treatment of the organic fraction of municipal solid waste, considering both economic and environmental aspects (Shen *et al.*, 2015). This approach allows to recover renewable energy and also bio-products: each tonne of organic waste sent to the anaerobic treatment in fact, can produce up to 150-250 $m^3$ of biogas, depending from the quality of the treated substrate (mainly linked to collection approach), which can be conveniently converted into useful energy forms: heat, electricity and the combined production of electricity and heat (cogeneration). The actual tendency, at European level, is to move towards an additional approach upgrading, considering the anaerobic digestion (AD) as the base to produce a real biofuel, to be used not only in situ (cogeneration), but also in the automotive sector (Porpatham *et al.*, 2007). The aim of the work is to demonstrate, through experiments at pilot scale, how produced bio-fuels can help to reduce greenhouse gas emissions in the automotive sector (). In particular, the application of anaerobic co-digestion to obtain two energy carriers for the automotive sector, biomethane and biohythane, was investigated. Different scenarios related to single stage (product: biomethane) or double stage (product: biohythane) anaerobic co-digestion showed how the biofuels produced can substitute fossil fuels generally used for the organic waste collection-transportation.

## 2. Materials and methods

Three continuously stirred reactors (CSTR) with working volumes of 230 liters, 760 liters, and 200 liters, respectively, were used in the experimentation. The reactors were heated by an hot water recirculation system and maintained at 55 °C using electrical heater controlled by a PT100-based thermostatic probe. The feeding system was semi – continuous, arranged once per day. Before feeding the organic waste was reduced in size using a grinder, mixed with waste activated sludge (WAS) and then fed to the single stage reactor (230 liters) or to the first stage reactor of the (200 litres fermenter) of the two stage system. The OFMSW / WAS ratio in the feedstock was determined considering the typical productions of 250 g per person per day for biowaste at 25% dry matter, therefore equivalent to some 60 g per person per day dry matter, and 60 g dry matter per person per day for excess sludge. The OFMSW / WAS ratio adopted in this study was therefore 1/1 on a VS basis. The anaerobic digested sludge used as inoculum for the methanogenic reactors was collected in the WWTP located in Treviso (northern Italy) where a 2000 $m^3$ mesophilic anaerobic digester treats the waste activated sludge produced within the process. The inoculated sludge was then acclimatized for two weeks to the thermophilic temperature increasing the temperature of the reactors and without feeding (Cavinato *et al*., 2013). The fermentative reactor, the one used as first stage in the two phase process, was inoculated with separately collected biowaste, collected in the municipality of Treviso, and waste activated sludge (WAS), coming from the WWTP above mentioned, kept at thermophilic temperature and then regularly fed once a day. Table 1 and 2 show the main characteristics of these two substrates. Waste activated sludge (table 1) showed an average concentration of 47 g/kg and a VS content of 69%. N and P contents were 3.2 and 0.9 g/kg. These characteristics can be considered typical for this substrate. The organic fraction of municipal solid waste used in the experimental trials was characterized by an average content of total solids approximately at 25% and a fraction of volatile solids of 90% over TS. The COD/TS ratio was around 1.0, on average. These data highlighted the high level of biodegradability of OFMSW, which combined with a good ratio of macronutrients (COD : TKN : P), makes organic waste a very suitable substrate for biological treatment processes. In particular, the COD/TKN ratio turned out to be on average equal to 36, more than twice that of the WAS considered. The effluents of the reactors were monitored 2/3 times per week in terms of total and volatile solids content, chemical oxygen demand, Total Kjeldahl Nitrogen (TKN) and total phosphorus. The process stability parameters, namely pH, volatile fatty acid content and speciation, total and partial alkalinity and ammonia, were checked daily. All the analyses, except for VFAs, were carried out in accordance with the Standard Methods. Volatile fatty acids content was monitored using a gas chromatograph (Carlo Erba instruments) with hydrogen as gas carrier, equipped with a Fused Silica Capillary Column (Supelco NUKOLTM, 15 x 0.53 x 0.5 μm film thickness) and with a flame ionization detector (200 °C). The temperature during the analysis started from 80 °C and reaches 200 °C trough two other steps at 140 and 160 °C, with a rate of 10 °C/min. The analysed samples were centrifuged and filtrated on a 0.45 μm membrane. Gas productions were monitored continuously by a gas flow meter (Ritter Company, drum-type wet-test volumetric gas meters), while the hydrogen content was measured by a gas-chromatograph (GC Agilent Technology 6890 N) equipped with the column HP-PLOT MOLESIEVE, 30 x 0.53 mm ID x 25 um film, using a thermal conductivity detector and argon as gas carrier.

## 3. Results and discussion

The experimental period lasted in total one year and the overall performances of both the single stage process and the two-phase thermophilic anaerobic co-digestion process are summarized in table 4. During the whole experiment, the organic loading rate (OLR) and hydraulic retention time (HRT) were maintained at about 17 $KgTVS/m^3d$ and 2.5 days for the first stage of the two phase process, and about 3.5 $KgTVS/m^3d$ and 17 days for the second reactor. The global HRT of the system was therefore 20 days. The single stage reactor operated at an OLR of 3.5 $KgTVS/m^3d$ and an HRT of about 20 days. The HRTs of the two systems were therefore equivalent and obtained results are comparable.

**Table 1.** Waste activated sludge characteristics

| Parameter | Units | Average | Std.Dev | Min | Max |
|---|---|---|---|---|---|
| TS | g/Kg | 47.86 | 14.28 | 20.91 | 96.34 |
| TVS | g/Kg | 33.06 | 10.10 | 13.24 | 63.41 |
| TVS/TS | % | 69.06 | 4.10 | 46.67 | 80.95 |
| COD | g/Kg | 51.30 | 11.50 | 28.75 | 73.13 |
| TKN | g/Kg | 3.29 | 0.75 | 1.63 | 4.50 |
| $P_{TOT}$ | g/Kg | 0.91 | 0.33 | 0.49 | 1.50 |

**Table 2.** Organic waste characteristics

| Parameter | Units | Average | Std.Dev | Min | Max |
|---|---|---|---|---|---|
| TS | g/Kg | 259.9 | 38.8 | 198.97 | 334.10 |
| TVS | g/Kg | 226.1 | 41.3 | 153.45 | 282.15 |
| TVS/TS | % | 90.7 | 2.58 | 82.08 | 96.84 |
| COD | g/Kg | 241.3 | 48.9 | 165.43 | 306.41 |
| TKN | g/Kg | 6.7 | 1.3 | 4.87 | 10.98 |
| $P_{TOT}$ | g/Kg | 1.5 | 0.7 | 0.84 | 2.85 |

The characteristics of the final digestate were very similar in the two processes studied: the total and volatile solids were some 25 and 15 g/kg, respectively. N and P contents were 35 and 10 g per kg dry matter, respectively. When considering the overall yields of the two thermophilic processes, however, the differences were more evident (figure 1): the single phase process produced on average 0.49 $Nm^3$ $CH_4$/kg TVS while the two phase process produced 0.57 $Nm^3$ $CH_4$/kg TVS in the methanogenic reactor (second stage) and 0.024 $Nm^3$ $H_2$/kg TVS in the first reactor. The global recovered energy was therefore different for the two processes with a small advantage for the two stage process. The obtained biogas can be upgraded and after $CO_2$ removal either biomethane or biohythane can be obtained (Micolucci *et al*., 2014). These energy vectors can be conveniently used in the automotive sector because of their benefits in terms of reduced reduction of greenhouse gases (GHG). As for the environmental impacts, in this study we considered the emissions of pollutants such as $CO_2$, $NO_X$, and PM into the atmosphere; emissions of conventional diesel were assumed as benchmark and then the emissions of biomethane and biohythane were considered.

**Table 3.** Digestate characteristics and yields

| Parameters | Units | First phase | Second phase | Single stage |
|---|---|---|---|---|
| Total Solids | g/kg | 48±5 | 25±4 | 26±2 |
| Total Volatile Solids | g/kg | 37±4 | 16±2 | 17±1 |
| COD | g/kg TS | 40±3 | 19±2 | 18±2 |
| TKN | g/kg TS | 34±1 | 35±1 | 34±1 |
| P tot | g/kg TS | 11±0 | 12±1 | 10±1 |
| pH | | 5.3±0.01 | 8.2±0.5 | 8.0±0.26 |
| Yields | | | | |
| Hydrogen | % | 36±8 | - | - |
| Methane | % | - | 64±2 | 60±9 |
| SHP | $Nm^3$ $H_2$/kg TVS | 0.024±0.005 | - | - |
| SMP | $Nm^3$ $CH_4$/kg TVS | - | 0.29±0.04 | 0.27±0.03 |
| SGP WAS | $Nm^3$ $CH_4$/kg TVS | 0.06±0.005 | 0.25±0.02 | 0.75±0.03 |
| SGP OFMSW | $Nm^3$ $CH_4$/kg TVS | 0.12±0.005 | 0.88±0.01 | 0.22±0.03 |
| SGP CO-DIGESTION | $Nm^3$ $CH_4$/kg TVS | 0.09±0.005 | 0.57±0.01 | 0.49±0.04 |

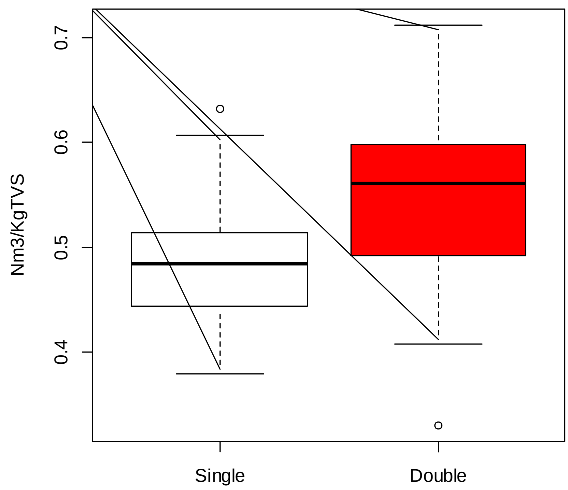


**Figure 1.** Statistical analysis of the SGP obtained in single and two stage AD

According to the European Environmental Agency inventory for the different contributions to air quality, transports are a fundamental factor. When conventional diesel fuel is used the impacts are the following: 139 g/kg $CO_2$, 0.433 g/kg $NO_X$, 0.018 PM g/kg. When biomethane is used the emissions are lowered to the following levels: 108.68 g/kg $CO_2$, 0.045 g/kg $NO_X$, 0.017 PM g/kg with a clear benefit in terms of the emissions. Finally, when biohythane was used as biofuel it could be calculated that emissions for $CO_2$ and particulate matter PM remained the same found for the use of biomethane while the PM level was further decreased down to $NO_X$ 0.036 g/kg.

## Conclusions

In this study waste activated sludge and food waste were codigested in thermophilic conditions both in single and two phase configuration. Results showed that the single phase process produced on average 0.49 $Nm^3$ $CH_4$/kg TVS while the two phase process produced 0.57 $Nm^3$ $CH_4$/kg TVS in the methanogenic reactor (second stage) and 0.024 $Nm^3$ $H_2$/kg TVS in the first reactor. The use of biomethane and biohythane in the automotive sector clearly decreased the potential impacts on air quality when compared with emissions from the use of conventional diesel.

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