Squeezing wastes in a wastewater treatment plant

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Abstract

In this study, the performance of an anaerobic digester placed in a conventional wastewater treatment plant was evaluated. For that purpose, two different kinds of sludges were studied: a mixture of primary and secondary sludge, i.e. waste sludge, and the sludge after being anaerobically degraded, i.e., stabilized sludge. The practical biogas potential of the two wastes was studied in batch anaerobic reactors under mesophilic conditions and was compared with the theoretical methane potential that was expected from the analyses of different organic fractions of the two wastes. The obtained results indicated that there was approximately a 30% of biogas potential without recovering when the waste sludge was treated in the anaerobic digester. The theoretical and practical methane potential of the stabilized sludge, 0.16 L CH_4 g VS^{-1} and 0.33 L CH_4 g VS^{-1} respectively, showed that there were still organic fractions in the stabilized sludge that could be anaerobically degraded. That means that it is possible to enhance the methane production of the anaerobic digester of a conventional wastewater treatment plant by changing some operational conditions, for instance, the hydraulic retention time.
Keywords: anaerobic digestion, waste sludge, wastewater treatment plant.

1 Introduction

The rapidly increase of population in recent years has resulted in the generation of a large amount of organic wastes. That makes necessary to change the methodology for treating those wastes or to improve the existing infrastructure.

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One of the most important organic wastes generated in the industrialised countries is the sludge produced in the wastewater treatment plants (WWTPs). In Spain, the production of the sludge generated in the WWTPs has increased a 39 percent within the period from 1997 to 2005. For example, in the region of Castilla-La Mancha (Spain), the production of sludge was 42,917.51 Tons [1] in 2003. In the old days the sludge was directly dumped to the landfills. Currently, there are specific regulations for avoiding landfill disposal of the sludge generated in the WWTPs or for minimising its dump, at the same time, these regulations are mainly focused on the energetic valorisation of that sludge [1, 2].

The stabilization of the sludge is mainly carried out by the own WWTP. The most used technology in the WWTP to stabilize this organic waste is the anaerobic digestion, since organic matter has been acknowledged as a source of renewable energy as the anaerobic decomposition process generates fuel biogas containing 55 to 75% of methane. In addition, using anaerobic biological treatments to stabilized the sludge, an organic residue is produced that can be used as a soil-beneficial substrate, i.e., as a fertilizer. It has been reported that a hygienic stabilization step is sometimes needed for subsequent land application [3, 4].

Some studies suggest the improvement of the anaerobic digestion of the sludge generated in a WWTP by co-digesting the sludge with other organic wastes [5, 6] or by pre-treating the sludge with mechanical, thermal or chemical pre-treatments prior to its digestion [7–9]. However, the low performance of the anaerobic digesters located at the conventional WWTPs is commonly attributed to some technical problems or to their oversized [10].

In this context, the aim of this work was to study both the practical and theoretical methane potential of the waste sludge and the stabilized sludge generated in a WWTP in order to evaluate the success of the anaerobic digester of the WWTP.

2 Material and methods

2.1 Inoculum

Mesophilically digested sludge from the anaerobic digester of a conventional activated sludge wastewater treatment plant was used as inoculum for the anaerobic experiments. The anaerobic inoculum was kept at 35ºC during two weeks in order to ensure that all biodegradable organic fractions were consumed.

2.2 Substrate source

Waste sludge and stabilized sludge from a conventional activated sludge wastewater treatment plant were used as organic substrates.

The waste sludge was a mixture of both primary and secondary sludge. The stabilized sludge was previously digested in an anaerobic digester, which operated at 20 days of hydraulic retention time (HRT) in the same wastewater treatment plant.

2.3 Anaerobic experiments

2.3.1 Calculation of theoretical methane potential

The stabilization of the organic wastes by anaerobic degradation is directly related to both methane and carbon dioxide production, thus the formula for predicting the methane and carbon dioxide production from a knowledge of the waste chemical composition is as following [11, 12]:

$$C_nH_aO_b + \left(n - \frac{a}{4} - \frac{b}{2}\right)H_2O \rightarrow \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right)CH_4 + \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right)CO_2 \quad (1)$$

The knowledge of the atomic composition of the most organic wastes is sometimes very difficult to achieve and it is necessary to take into account the analytical organic fractions. Therefore, the theoretical methane potential ($\beta_{0,th}$) expressed as litres of CH_4 in standard conditions of temperature and pressure per gram of volatile solids (VS) added, can be assessed as followed [13]:

$$\beta_{o,th}\ (STP\ L\,CH_4\ g\,VS^{-1}) = 0.415 \cdot carbohydrates + 0.496 \cdot proteins + \\ + 1.014 \cdot lipids + 0.373 \cdot acetate + 0.530 \cdot propionate \quad (2)$$

where the organic fractions (carbohydrates, proteins, lipids, acetate and propionate) are expressed as % of the total VS, and the coefficients are obtained from stoichiometric conversion of the different organic fractions according to eqn (1).

2.3.2 Biogas potential experiments

For the study of the biogas potential of the different organic wastes, anaerobic experiments were carried out in 1 L-batch reactors with a working volume of 400 mL. In the wall of the reactors were fitted two sampling valves to take liquid and gas samples of the liquid phase and gas phase, respectively. Additionally, a pressure sensor was incorporated in the top of the reactor to measure the biogas pressure in the gas phase. The reactors were placed in an incubator, which had a temperature control allowing for maintaining the temperature at 35ºC. A magnetic stirred ensured that solids remain in suspension and a good degree of contact between the organic wastes and the microorganism population contained in the inoculum. At the beginning of the experiments, a mixture of nitrogen/carbon dioxide gas was flushed during 15 minutes into the reactors for ensuring anaerobic conditions.

The food/microorganism (F/M) ratio was set in at 1 g VS g VS^{-1}. In addition, reference experiments were carried out to take into account the endogenous biogas production.

Cumulative methane production (β) from the wastes was assessed from experimental biogas production and methane content data after subtracting the amount of biogas generated by the reference experiments.

2.4 Analytical methods

Methane and carbon dioxide concentrations in gas samples were determined with gas chromatography using a thermal conductivity detector (TCD). For the quantification of volatile fatty acids (VFA): acetate, propionate, i-butirate, n-butirate, i-valerate and n-valerate; acidified samples with 34% H_3PO_4 were analysed on a gas chromatography using a flame ionization detector (FID). Total Solids (TS), volatile solids (VS), ammonia-nitrogen (NH_4^+-N), total-phosphorus (T-P), lipids and pH were determined according to standard methods [14]. Heavy metals were measured using an ICP-Mass Spectrometry.

3 Results and discussion

3.1 Characterization of the organic wastes

Prior to the anaerobic experiments, an exhaustive characterization of the organic wastes was needed with the aim of determining the different organic fraction (carbohydrates, proteins, lipids, acetate and propionate) contained in each waste.

The characterization of the waste sludge and stabilized sludge is shown in Table 1.

Table 1: Characterization of the wastes.

Parameters	Waste Sludge	Stabilized Sludge
TS (%)	4.12 ± 1.05	2.02 ± 1.72
VS (%)	3.84 ± 0.82	1.23 ± 0.70
pH	6.40 ± 0.20	7.00 ± 0.30
Total-P (mg L^{-1})	920 ± 83	1,020 ± 302
NH_4^+-N (mg L^{-1})	290 ± 12	340 ± 103
Lipids (mg L^{-1})	4,100 ± 350	3,300 ± 421
Acetate (mg L^{-1})	2,941 ± 120	1,600 ± 582
Propionate (mg L^{-1})	1,300 ± 47	860 ± 274
Proteins (mg L^{-1})	1,812 ± 121	2,125 ± 230
Carbohydrates (mg L^{-1})	31,247 ± 500	4,415 ± 117
Cd (mg kg^{-1}) *	0.51 ± 15	<det.lim
Cr (mg kg^{-1})*	46 ± 7	21 ± 7
Cu (mg kg^{-1})*	231 ± 42	310 ± 13
Pb (mg kg^{-1})*	48 ± 21	<det.lim
Ni (mg kg^{-1})*	89 ± 19	25 ± 13
Hg (mg kg^{-1})*	0.03 ± 0.01	<det.lim

* Composition given in dry matter; det.lim: detection limit.

In Table 1 it is only shown the content of acetic acid and propionic acid, since the amount of the rest of VFA analysed (i-butirate, n-butirate, i-valerate and n-valerate) was practically negligible. Although the values of acetate and propionate in stabilized sludge were high compared to the values found in the literature [16], the performance of the anaerobic digestion process was high with regards to the organic solids removal achieved, since TS removal and VS removal after the anaerobic treatment of the waste sludge were approximately 51% and 68%, respectively.

The results of the characterization indicate that both waste sludge and stabilized sludge could be used to agricultural purposes according to the content of the heavy metals analysed [15].

3.2 Biogas potential experiments

Anaerobic experiments under mesophilic conditions were performed in triplicate in order to determine the practical biogas potential (β) of the two sludges subject to study: waste sludge and stabilized sludge (Figure 1).

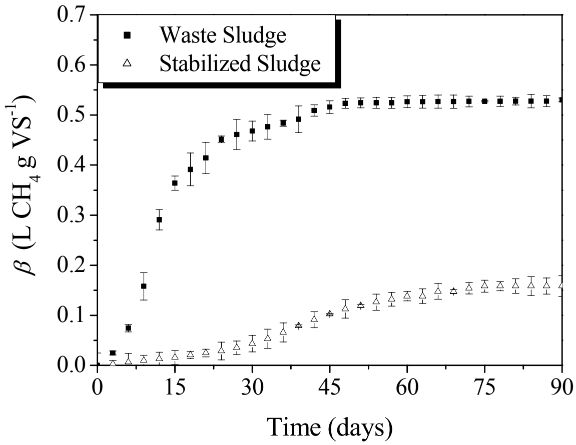

Figure 1: Cumulative methane production per gram of VS loaded experiments of the different wastes.

The length of the anaerobic experiment was 90 days to assure that all biodegradable organic fractions of the wastes were totally degraded. Regarding Fig. 1, a lag phase could not be observed during the digestion of the waste sludge. That could be explained as the inoculum used for carrying out the anaerobic experiments was taken from the anaerobic digester of the WWTP were the waste sludge was generated, therefore the inoculum was acclimated to this kind of waste.

During the first 20 days of digestion of the waste sludge, the methane potential achieved was 0.37 L CH_4 g VS^{-1}. At the end of the experiments, the methane potential reached a value of 0.53 L CH_4 g VS^{-1}. Taking into account that the anaerobic digester of the WWTP operated at 20 days of HRT, these results show that there was about a 30% of methane potential without recovering when the waste sludge was treated under anaerobic conditions in that WWTP, value that was coincident with the methane potential achieved when digesting the stabilized sludge, 0.16 L CH_4 g VS^{-1}. That means that there was still an organic fraction in the stabilized sludge that could be anaerobically degraded.

Figure 2 shows the evolution of the VFA concentration during the anaerobic digestion of the different wastes.

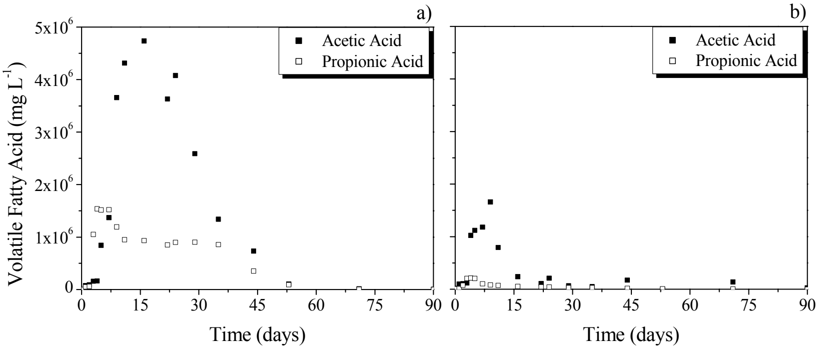

Figure 2: Acetic and propionic acid production. a) Waste sludge; b) Stabilized sludge.

High levels of acetate and propionate were noticed in comparison with the concentration of the rest of VFA (i-butirate, n-butirate, i-valerate and n-valerate), which values were negligible, therefore those values are not shown in Fig. 2.

A typical behaviour in VFA production was observed during the batch anaerobic degradation of the biodegradable organic fraction of the two wastes, since VFA are intermediate reaction products when the degradation of the complex organic polymers (lipids, carbohydrates, proteins) takes place.

A higher production of acetate and propionate was observed during the digestion of waste sludge due to the high organic matter presented in the waste sludge in contrast with the organic content of the stabilized sludge (Table 1).

3.3 Comparison of theoretical and practical methane potential

Table 2 shows the theoretical methane potential of both waste sludge and stabilized sludge at different temperature and pressure conditions. The practical methane potential achieved during the anaerobic degradation of each waste is also shown in Table 2.

Table 2: Theoretical methane potential ($\beta_{0,th}$) and practical methane potential (β) of the different wastes.

Waste type	$\beta_{0,th}$		β
	(STP) LCH_4 gVS^{-1}	(35ºC, 1 atm) LCH_4 gVS^{-1}	(35ºC, 1 atm) LCH_4 gVS^{-1}
Waste Sludge	0.48	0.55	0.53
Stabilized Sludge	0.29	0.33	0.16

In Table 2 it can be observed that the practical methane potential was lower than the theoretical methane potential for both wastes under the same temperature and pressure conditions.

For the assessment of the theoretical methane potential was necessary to know the waste composition (Table 1), and based on that composition, an approximate calculation of the expected biogas production could be achieved. Nevertheless, the practical methane potential obtained in an anaerobic reactor is always lower due to, for instance, some part of the organic matter is used to synthesize new biomass or a part of the organic matter can not be degraded due to its structure, which makes impossible the access of the anaerobic bacteria to the organic matter [13].

As expected, the methane potential (theoretical and practical potential) of the stabilized sludge was much lower than that obtained for the waste sludge, since the stabilized sludge was previously digested.

4 Conclusions

The main conclusions of this study are shown below:

- The anaerobic digestion process had a high efficiency, with a VS removal of 68%.
- Both sludges could be used to agricultural purposes according to the content of the heavy metals analysed.
- There was about a 30% of methane potential without recovering when the waste sludge was treated in the anaerobic digester of the WWTP.
- It is possible to enhance the methane production of an anaerobic digester of a conventional WWTP by changing some operational conditions such as the hydraulic retention time.

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