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Mesophilic anaerobic co-digestion of sewage sludge and a lixiviation of sugar beet pulp: Optimisation of the semi-continuous process

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HIGHLIGHTS

- Lixiviation of sugar beet pulp used as co-substrate.
- Improved efficiency of anaerobic digestion of sewage sludge.
- Improved biogas production and organic matter removal.
- Low solid retention times in the system.

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ABSTRACT

This study examine the effect of an increased organic loading rate on the efficiency of the stirred tank reactor treating sewage sludge and sugar beet pellets and to report on its steady-state performance. The digester was subjected to a program of steady-state operation over a range of hydraulic retention times (HRTs) of 30 to 6 days and organic loading rates (OLRs) of up to 1.7 kgCOD/m^3 d to evaluate its treatment capacity.

The COD removal efficiency was found to be 84.23% COD in the digester when treating mixture sewage sludge/lixiviation of sugar beet pulp at 1.27 kgCOD/m^3 d (10-days SRT). The volumetric methane level produced in the digester reached 0.7 m^{3}CH$_4$/m^3 d and the methane yield was 0.64 m^{3}CH$_4$/kgCOD$_{removal}$.

Therefore, anaerobic co-digestion of sewage sludge and lixiviation of sugar beet pulp improve the biogas productivity and the organic matter removal in addition to lowering solids retention times in the system.

1. Introduction

Sludge production in Spain has grown constantly over the last few years. The increasing production of sludge from household and/or urban wastewater treatment is leading to problems arising from its correct management, treatment and, above all, elimination. With the aim of solving these problems, the National Water Quality Plan (2007–2015) is contemplating a raft of measures to ensure full compliance with Directive 91/271/EEC (1991). This Plan anticipates the construction of new wastewater treatment plants and the correct exploitation, maintenance and management of existing installations.

The National Sewage Sludge Plan established 2007 as the deadline for recovering 80% of wastewater treatment plant (WWTP) sludge and reducing the sludge sent to landfill by 20%. The increase in WWTP sludge production due to application of both Directive 91/271/EEC (1991) and the National Sewage Sludge Plan brings with it the need to manage this sludge correctly. One of the solutions to achieve environmentally friendly sludge management is to use this sludge as agricultural fertiliser.

Excessive sludge generation is the main problem facing WWTPs. Approximately 0.5–2% of the treated water in a WWTP becomes sludge that needs to be treated before final disposal in the environment. Furthermore, production of the beet crop has risen in recent years, justified by its high energy productivity (3.5–4.5 t bioethanol/Ha). This crop generates high quantities of waste, such as sugar beet pulp, which has to be treated. In this regard, the anaerobic co-digestion of organic waste is a successful methodology for the joint treatment of waste from different sources and therefore, suitable for treating the waste produced by WWTPs.

The joint digestion of sewage sludge and vegetable waste from energy crops has the advantages of shared treatment facilities, combined management methodologies, a reduction in the investment and operating costs, and a decrease in the temporal variations of the composition and production of each waste residue.

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Furthermore, co-digestion of organic waste from different origins has been proven to be as successful as both mesophilic and thermophilic regimens. Hence, these approaches can be applied to the co-digestion of these wastes (Gómez at al., 2006; Demirel and Scherer, 2008).

Most renewable energies, and in particular, agricultural biomass waste, are energy sources scattered around a given country. The agro-industrial biomass waste generated is concentrated and its management in the same places from where it originates requires sufficient quantities of waste for energy recovery to be technically and economically viable. Therefore, large plants are needed to centralise collection from urban WWTPs, which are widespread at the country and regional levels.

Co-digestion is the simultaneous anaerobic digestion of a mixture of two or more substrates. This technology is an attractive option to improve the yields of the anaerobic digestion of wastes due to the positive synergisms established in the digestion medium, a fact that increases the economic viability of the biogas plants (Mata-Alvarez et al., 2000). The main advantage of this technology-based system is an improved methane yield created by the supply of additional nutrients to the mixture. Moreover, co-digestion could lead to the following benefits (Alatriste-Mondragón et al., 2006; Mata-Alvarez et al., 2000): (1) dilution of inhibitory and/or toxic compounds; (2) increase in the organic content inside the digester, eliciting better utilisation of the digester volume; (3) enhancement of the digestate stabilisation; (4) procurement of the required moisture contents in the digester feed, with an easier handling of blended wastes; (5) large reduction of the emission of greenhouse gases into the atmosphere; and (6) economic advantages from the sharing of equipment and costs. However, some drawbacks exist as well: (1) the high cost of waste transfer from the co-substrate generation point to the anaerobic plant; (2) the risk of spreading poisonous substances from the industrial or municipal waste; and (3) the harmonisation of the different policies regarding the waste generators. What is more, co-digestion changes digestion behaviour and the quality of the digestate. Furthermore, the addition of unknown co-substrates should be prevented. To improve the co-digestion process and detect the amounts of inhibitory or toxic compounds, which can lead to a process breakdown or reduced methane production, it is necessary to carry out several laboratory experiments such as biodegradability tests and/or laboratory-scale digester assessments.

Pretreatment with sugar dried pellets yields a homogeneous liquid effluent with high organic load, suitable for use in batch type co-digestion assays. When mixed with sewage sludge, it produces a final effluent with good characteristics for anaerobic co-digestion.

The feasibility of co-digestion of two or more organic waste streams (e.g., organic fraction from municipal solid waste, sewage sludge or biosolids, animal waste, and agricultural solid waste, among others) has been demonstrated at both the laboratory-scale (Poggi-Varaldo and Oleszkiewicz, 1992; Stenstrom et al., 1983) and the full-scale level (Angelidaki and Ahring, 1994; Cecchi et al., 1988).

This study aimed to examine the effect of an increased organic loading rate on the efficiency of the stirred tank reactor treating sewage sludge and vegetable waste (sugar beet pellets) and to report on its steady-state performance. The digester was subjected to a program of steady-state operation over a range of hydraulic retention times (HRTs) of –six to 30 days and organic loading rates (OLRs) of up to 1.7 kgCOD/m^3·d to evaluate its treatment capacity. Five different experimental conditions corresponding to the solid retention times (SRTs) of 30, 20, 15, 10 and 6 days were tested.

2. Methods

2.1. Experimental equipment

In this study, a semi-continuous laboratory-scale stirred tank reactor, operating at the mesophilic range, was used. The equipment consisted of a reactor with a stainless steel vessel that was agitated and heated, and with a total volume of 6 L and a working volume of 5 L. The digester featured a lid that allowed it to be sealed to maintain anaerobic conditions within the digester. The stainless steel lid had several openings (for the output of biogas, insertion of a pH probe, insertion of a temperature probe, two inputs to correct the pH balance, a power input and an agitation system). The bottom of the digester had a release valve used for sampling the material inside the digester, which was made possible by the sealing system between the vessel and the cap. The assembly included an agitator (operating at 17 revolutions per minute) that homogenised the waste using stainless steel blade scrapers. To maintain the operating temperature, the digester was heated by recirculating water through a thermostatic jacket. Biogas was collected in 10-L Tedlar bags, and a special syringe was used for sampling gases.

2.2. Operational conditions

The digester was initially loaded with a mixture of inoculum and substrate, resulting in a final concentration of 20% w/w of inoculum, which is considered optimum for biogas production. The inoculum came from a full-scale mesophilic digester for the treatment of waste sludge from a WWTP. Once the inoculum was mixed with the substrate, a mixture of sewage sludge and the lixiviation of sugar beet pulp, the system remained unfed for a period of one week to acclimatise the inoculum to the waste at the selected temperature (35 °C).

The digester was fed a mixture of sewage sludge and sugar beet pulp, diluted in water to give a final concentration of 10% w/w. Based on the information found in the literature and previous experience of our group (Fernández et al., 2012), SRTs of 6, 10, 15, 20 and 30 days were selected for study until process breakdown. Each condition was maintained for an operational period lasting three times the duration of the HRT to ensure that steady-state conditions were reached.

Table 1
Main characteristics of the test conditions.

	TS (kg TS/m^3)	VS (kg VS/m^3)	COD (kg/m^3)	OLR (kg COD/m^{3}digester d)	OLR (kg VS/m^{3}digester·d)	F:M (kg COD/kg VS d)
30-days SRT	33	22	9.9	0.5	1.1·(10^{-3})	0.025
20-days SRT	28	19	10.1	0.67	1.2·(10^{-3})	0.034
15-days SRT	25	18	8.5	0.85	1.8·(10^{-3})	0.043
10-days SRT	25.2	17	10.1	1.3	2.1·(10^{-3})	0.073
6-days SRT	25.3	22	10.2	1.7	5·(10^{-3})	0.085