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Analysis of the stability of high-solids anaerobic digestion of agro-industrial waste and sewage sludge

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HIGHLIGHTS

- Similar evolution of the parameters evaluated was observed in different experiments.
- The experiments ran stably although the thresholds in the literature were exceeded.
- The results reveal that the dynamics are key for imbalance and inhibition phenomena.
- The results are useful in developing new control strategies for high-solids AD.

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ABSTRACT

The pilot-scale high-solids anaerobic digestion (HS-AD) of agro-industrial wastes and sewage sludge was analysed in terms of stability by monitoring the most common parameters used to check the performance of anaerobic digesters, i.e. Volatile Fatty Acids (VFA), ammonia nitrogen, pH, alkalinity and methane production. The results reflected similar evolution for the parameters analysed, except for an experiment that presented an unsuccessful start-up. The rest of the experiments ran successfully, although the threshold values proposed in the literature for the detection of an imbalance in wet processes were exceeded, proving the versatility of HS-AD to treat different wastes. The results evidence the need for understanding the dynamics of a high-solids system so as to detect periods of imbalance and to determine inhibitory levels for different compounds formed during anaerobic decomposition. Moreover, the findings presented here could be useful in developing an experimental basis to construct new control strategies for HS-AD.

1. Introduction

High-solids anaerobic digestion (HS-AD) or dry anaerobic digestion is a technology specially developed for the treatment of waste with high total solids (TS) content, in the range of 20–35%. In particular, HS-AD is an advantageous management option compared to wet anaerobic digestion since it involves smaller space requirements, a high volumetric organic loading rate, lower water and energy consumption, and easy handling of digested waste. Despite its numerous advantages, it has been mainly applied to the treatment of Organic Fraction of Municipal Solid Waste (OFMSW) (Fernández et al., 2008; Guendouz et al., 2010). At present there are many research studies available in the literature that are devoted to the anaerobic digestion treatment of waste with TS content ranging from 5% to 15%, although recent studies dealing with HS-AD (Dai et al., 2013; Duan et al., 2012; Kim and Oh, 2011; Shi et al., 2013) can also be found, reflecting the fact that interest in this technology is rising.

Several authors have analysed anaerobic digestion processes in terms of stability for different types of waste by means of monitoring parameters such as pH, alkalinity, the Volatile Fatty Acid (VFA) concentration, the VFA/alkalinity ratio and biogas or methane production (Björnsson et al., 2000; Nielsen et al., 2007; Raposo et al., 2009; Razaviarani et al., 2013). Even though the selection of the most convenient parameters for detecting periods of imbalance is a subject of discrepancy, certain values for the abovementioned parameters have been accepted to some extent as being indicative of unstable performance. However, there are few studies dealing with the stability of HS-AD processes and consequently no value ranges that are indicative of imbalance have been described so far. With regard to the VFA that is commonly monitored in anaerobic digestion, it is noteworthy that special attention has been paid to propionic acid, and its importance as a process imbalance indicator has been discussed by several authors. In a study carried out by Nielsen et al. (2007), the authors concluded that propionate is a key parameter for indicating process imbalances as well as for

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regulating and optimising the biogas process. Similarly, in previous studies, the propionic acid concentration was found to increase prior to digester failure (Fischer et al., 1981; van der Berg and Lentz, 1977). In contrast, Pullammanappallil et al. (2001) stated that high propionic concentrations do not necessarily indicate process imbalance. Moreover, these authors suggest that isobutyric acid could be more interesting from the point of view of process control, which is in line with the findings by Ahring et al. (1995), who proposed a combined parameter that reflects the concentrations of butyrate and isobutyrate. Among the substances that can have toxic effects on anaerobic digestion, ammonia nitrogen is another one that has been studied (Angelidaki and Ahring, 1993; Calli et al., 2005; Gallert et al., 1998). Nonetheless, there is no clear consensus on the ammonia levels that are inhibitory for the anaerobic digestion process. To a great extent, the variability in the values that have been reported to cause inhibition in anaerobic digestion is due to the capability of methanogenic bacteria to adapt to increasing concentrations of ammonia. Furthermore, although many authors refer to TAN (Total Ammonia Nitrogen) when discussing the performance of anaerobic reactors, the use of free ammonia nitrogen (NH_3) can be considered more accurate owing to the fact that this form is commonly regarded as the truly inhibitory one.

An important feature to consider when analysing process performance and stability is the configuration of the anaerobic digester. In this respect, systems with leachate recirculation working under high-solids conditions have been investigated by several authors. Veeken and Hamelers (2000) concluded that the leachate recirculation rate has a strong effect on reactor performance, whereas El-Mashad et al. (2006) studied leachate recirculation during the fed-batch digestion of solid manure and demonstrated that it increases the system performance (i.e. methane production) in comparison to a system without leachate recycle. With regard to systems with mechanical mixing, some authors have analysed the effect of mixing intensity on the performance, such as Kaparaju et al. (2008). Likewise, Stroot et al. (2001) analysed the effect of the mixing level on the performance of anaerobic digestion, suggesting a negative effect of intensive mixing under high organic loading rates. Nevertheless, it must be pointed out that mixing is important in order to encourage distribution of enzymes and microorganisms throughout the reactor.

With respect to co-digestion, it is an attractive alternative that consists of mixing different wastes and treating them together in the same facilities. Although co-digestion is not a new practice, the number of publications on this issue has grown markedly in the last 5 years. It has been reported that the addition of a co-substrate positively affects anaerobic digestion processes since methane production can be increased, depending on the operating conditions and the characteristics of the co-substrates mixed (Mata-Alvarez et al., 2011). Moreover, co-digestion has the added potential of bringing about the dilution of toxic or inhibitory compounds and providing a better-balanced nutrient pool (Capela et al., 2008).

The aim of this study is to evaluate the performance of HS-AD in terms of stability by treating different organic wastes, namely sewage sludge and several agro-industrial wastes. For that purpose, a single-substrate experiment was conducted in addition to various co-digestion assays by using a lab-scale reactor equipped with a leachate recirculation system as well as a completely mixed pilot-scale digester. During the experiments, biogas production was on-line monitored and daily analyses of the biogas composition were carried out in order to follow methane production. Furthermore, VFA concentration, pH, TAN and alkalinity were analysed so as to check the performance of the process.

2. Methods

2.1. Equipment: anaerobic digesters

In this study, a pilot-scale 300 L reactor similar to a CSTR (Continuous Stirring Tank Reactor) but adapted to work under high-solids conditions was used (Fig. 1). The horizontal cylinder-shaped reactor is made of stainless steel, and it was operated in batch-mode under continuous mixing conditions. The temperature was kept within the mesophilic range (36 °C) with a heating system that is composed of six electric resistances and thanks to temperature signals collected by means of a Pt100 sensor. The mixing equipment consists of a 0.25 kW motor that is responsible for turning a central axle with shovel shaped arms. Moreover, the digester is equipped with a flow meter (Bronkhorst Hi-Tec v. Low-dP, Ref. F-101D-HAD-11-E), which enabled on-line measurement of biogas production.

Apart from the pilot-scale reactor, an 8 L (useful volume) lab-scale reactor was employed to conduct experiment 1 (Fig. 1). The digester is a vertical cylinder-shaped tank that contains a leachate recycling system. This digester was operated as a batch process and under mesophilic temperature as well. Biogas production was measured by means of a gas meter by using the liquid displacement technique.

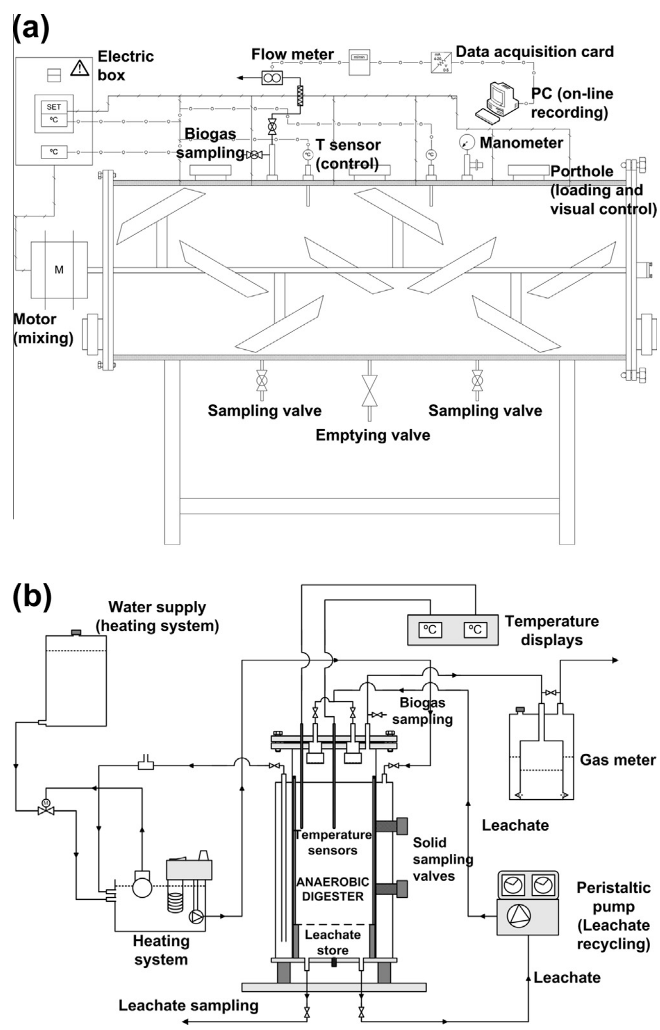

Fig. 1. Layout of the anaerobic digesters: pilot-scale reactor (a) and lab-scale reactor (b).