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Performances comparison between laboratory and full-scale anaerobic digesters treating a mixture of primary and waste activated sludge

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ABSTRACT

Laboratory-scale semi-continuously digesters were used as test platforms to evaluate a full-scale application of anaerobic co-digestion of primary sludge (PS) and activated sludge (AS) in Tunisia. Effects of the PS:AS ratio and the organic loading rate (OLR) on digester performances were examined at a hydraulic retention time (HRT) of 20 d. Increasing PS proportion in the feedstock significantly improved the biogas production yield. The digester that was fed with a PS:AS ratio of 80:20 showed the highest total volatile solids (TVS) removal efficiency and specific biogas production (SBP) of 72.1% and 0.6 L g^{-1} TVS added, respectively. However, the digester that was fed with a PS:AS ratio of 20:80 as the full-scale fed stock showed 51% and 0.38 L g^{-1} TVS added of TVS removal and SBP, respectively. The full-scale digester showed a biogas production rate up to 11,000–12,000 m^3 d^{-1} with a SBP of 0.31 L g^{-1} TVS added. The comparison between the two scale results demonstrates that lab-scale experiments with real substrates and close to reality digestion conditions can serve to predict the digestion capability of the full-scale digester.

1. Introduction

In the last few years, the number of municipal wastewater treatment plants (WWTPs) in Tunisia was increased significantly which results in the production of large quantities of sludge (Lahdheb et al., 2009). WWTPs have not only PS production, while they produced high amount of waste AS. The amount of sludge generated is dependent on the size of the WWTP and the treatment option used. Previous to any land disposal, the sludge should undergo stabilisation.

Anaerobic digestion process is a well established process for treating many types of organic wastes, both solid and liquid (Borzacconi et al., 1995; Murto et al., 2004; Yen and Brune, 2007). Anaerobic digestion of sludge is often employed to reduce the mass of solids, reduce their pathogen content and lead to an energy recovery bonus in the form of methane gas production (Dinsdale et al., 2000). However, the rate-limiting step for AS anaerobic digestion is the hydrolysis step (Bougrier et al., 2007; Borowski and Szopa, 2007). Except for the resistant to biodegradation, the low C/N ratio of AS in order of 6/1–16/1 is also regarded as a serious problem to the anaerobic digestion (Stroot et al., 2001). It should range from 20 to 30 in order to ensure sufficient nitrogen supply for cell production and the biological degradation of the carbon matter (Yen and Brune, 2007).

The co-digestion of AS with PS to overcome the difficulties of treating AS alone and to adjust its unbalanced nutrients constitutes an interesting solution. In fact, the large quantities of PS generated from sewage pre-treatment step are another type of residue that is characterised by high level of biodegradable organic matter with high C/N ratio. Treatment of this organic fraction is currently carried out through composting or anaerobic digestion. While, anaerobic digestion seems to be a more attractive method for the treatment of this waste (Sharma et al., 2000).

Co-digestion is a technology that is increasingly being applied for simultaneous treatment of several solid and liquid organic wastes (Callaghan et al., 2002; Alatriste et al., 2006; Perez et al., 2006; Bouallagui et al., 2009). It combines different organic substrates to generate a homogeneous mixture as input to the anaerobic reactor in order to increase process performance (Viotti et al., 2004; Zhang and Banks, 2008). It permits the exploitation of complementarily in waste characteristics, e.g. avoidance of nutrients (N, P) addition when a co-digested waste contains nutrients in excess (Pavan et al., 2005; Neves et al., 2006).

Because of the scaling issues identified, operational data should not be directly projected from laboratory-scale results to the full-scale designs. This work discusses the performance of full-scale digesters treating a mixture of PS and AS produced at Chotrana

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municipal WWTP of Tunis by using the operation data of the digesters and laboratory experiments.

2. Materials and methods

2.1. Characteristics of used substrates

The PS and AS were collected from the WWTP of Chotrana (Tunis), treating domestic wastewaters. It is composed of settled suspended solids. Both types of sludge were analysed for various parameters such as: pH, total solids (TS), total volatile solids (TVS), total suspended solids (TSS), volatile suspended solids (VSS), total carbon (TC), total chemical oxygen demand (COD_t) and total nitrogen (TN). The tested mixture ratios of PS:AS were 100:0, 90:10, 80:20, 50:50, 30:70, 20:80 and 0:100 bay volume. These mixtures were analysed for the most of the parameters mentioned above. The characteristics are summarised in Table 1.

Table 1 shows that the TS and TVS contents were the lowest in the AS and the highest in the PS. TVS values in all mixtures indicated that organic contents were very high. As the PS addition increased, the C/N of the feed mixture gradually increased from 10 to 28.2 and ranged within the C/N ratio (20–30) required for stable and better biological conversions reported by others on the anaerobic digestion (Yen and Brune, 2007). The low C/N of the AS implies a large source of nitrogen, mainly in the form of proteins from lysed cells.

2.2. Reactors design and operational conditions

2.2.1. Full-scale WWTP of Chotrana (Tunis)

The treatment plant of Chotrana has a capacity of 78,000 $m^3\,d^{-1}$, corresponding to an organic loading rate (OLR) of 40,000 kg TVS d^{-1}. However, it receives currently a loading rate of 120,000 $m^3\,d^{-1}$ and an OLR of 50,000 kg VS d^{-1}. This plant includes four independent semi-continuously sludge digesters having volumes of 5250 m^3 each, making a total digesters volume of 21,000 m^3. The digesters are fed simultaneously with sludge from the WWTP from the sludge thickener. The hydraulic retention time (HRT) is currently 20 d, calculated with a PS and AS throughputs corresponding to a PS/AS mixture ratio of 20%:80% approximately. Biogas is stocked in two containers with a total capacity of 2700 m^3, and then used in a boiler and converted to electric energy using a combined heat and power engine.

2.2.2. Laboratory-scale digesters

The lab-scale digesters comprised seven identical glass reactors (D1–D7) with a 2 L capacity. The digesters were operated on a semi-continuously basis under mesophilic condition (35 °C). The temperature was controlled by a thermostatically regulated water bath. Mixing in the reactors was done by a system of magnetic stirring. Digesters were fed after undertaking gas measurements and following the venting of the gas from the collection bag with different thickened mixtures of PS and AS daily to achieve a HRT of 20 d. Digesters (from D1 to D7) were operated under different ratios of PS/AS 100:0, 90:10, 80:20, 50:50, 30:70, 20:80 and 0:100 corresponding to OLRs of 2.7, 2.21, 1.9, 1.65, 1.55, 1.37 and 0.67, respectively.

2.3. Technical analysis

The biogas produced was measured daily by gas meter (Ritter-Bochum Langendreer, Germany) and its composition was estimated using an ORSAT apparatus (Bouallagui et al., 2003). TS, TVS, TSS, pH, alkalinity and total volatile fatty acids (VFAs) were determined according to the APHA Standard Methods (1995). TC was measured by catalytic oxidation on a TC Euroglace analyser. TN was estimated by the Kjeldahl method.

2.4. Statistical analysis

In order to determine whether the observed differences between digester performances were significantly different, data were subjected to the ANOVA tests (StatSoft Inc, 1997). Differences between PS:AS ratio effects on the digester performances (p) were compared with 0.05.

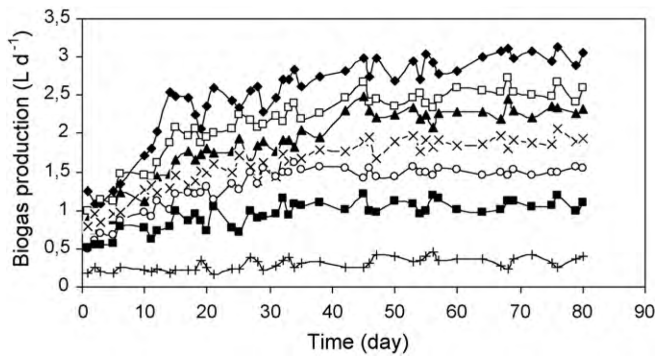

Fig. 1. Biogas production during lab-scale anaerobic co-digestion of primary and activated sludge in digesters D1 (♦) (100% PS), D2 (□) (90% PS/10% AS), D3 (▲) (80% PS/20% AS), D4 (×) (50% PS/50% AS), D5 (○) (20% PS/80% AS), D6 (■) (10% PS/90% AS) and D7 (+) (100% AS).

3. Results and discussion

3.1. Performances of laboratory-scale digesters

The performance parameters of the seven lab-scale digesters are illustrated in Figs. 1 and 2. Table 2 summarises the steady state data for the lab-scale and the full-scale digestion processes.

3.1.1. Biogas production and TVS removal at different PS:AS ratios

Daily overage biogas productions by digestions of PS, AS and the different mixture ratios of PS:AS at the steady state varied between 0.38 L d^{-1} and 3.0 L d^{-1} (STP) depending to the substrate composition (Fig. 1). The extent of biogas production increased with the addition of PS. From all mixture ratios, the 100:00 (PS:AS) ratio yields the maximum volumetric biogas production (VBP) because it contains the highest organic matter content. The methane content was relatively the same for the different applied PS:AS ratios, it varied between 62% and 65% (Table 2).

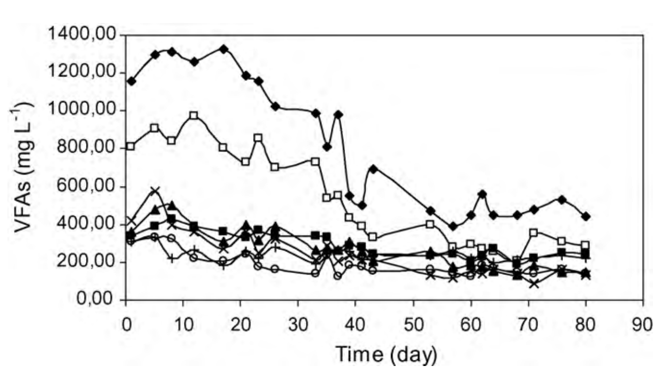

Fig. 2. Total VFAs variation during lab-scale anaerobic co-digestion of primary and activated sludge in digesters D1 (♦) (100% PS), D2 (□) (90% PS/10% AS), D3 (▲) (80% PS/20% AS), D4 (×) (50% PS/50% AS), D5 (○) (20% PS/80% AS), D6 (■) (10% PS/90% AS) and D7 (+) (100% AS).