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A combination of ammonia stripping and low temperature thermal pre-treatment improves anaerobic post-digestion of the supernatant from organic fraction of municipal solid waste treatment

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ABSTRACT

Municipal Solid Waste is mostly composed of organic material which is often treated in anaerobic reactors in waste treatment plants. In most cases, the obtained digestate undergoes a solid/liquid separation step, producing a liquid fraction (known as anaerobic supernatant) rich in ammonium nitrogen that has to be further treated in order to meet discharge standards. The objective of the present work was to evaluate the feasibility of anaerobic post-digestion (37 °C) of a supernatant rich in carbon and nitrogen from a municipal waste treatment plant. In order to increase the efficiency of the process, a combined pre-treatment consisting of a low-temperature thermal process (75 °C) and ammonia stripping ($1.3\ L_{air}\ L_{supernatant}^{-1}\ min^{-1}$) was applied. The effects of pre-treatment contact time (4 and 8 h) and the hydraulic retention time (HRT) in the anaerobic reactor (20–40 d) were studied. Supernatant pre-treatment with 8-h contact time caused 13% organic matter solubilisation, thus improving methanisation by 18% when the HRT was 40 d. At the same time, ammonia stripping allowed to maintain ammonia concentration in the digester below inhibitory values (less than 100 mg $N\text{-}NH_3\ L^{-1}$) enabling therefore high methanogenic activity (>0.23 g COD g^{-1} VS d^{-1}). The final effluent characteristics (low total ammonia nitrogen and aerobically biodegradable organic matter levels) would permit implementing subsequent less energy intensive and more environmental-friendly technologies (such as partial nitritation/anammox) to comply with discharge limits.

1. Introduction

Municipal Solid Waste (MSW) is mostly composed of organic material, the so called Organic Fraction of Municipal Solid Waste (OFMSW), which is an interesting substrate for Anaerobic Digestion (AD) due to its significant moisture and high organic matter content. The possibility of producing biogas (between 100 and 170 $m^3\ t_{OFMSW}^{-1}$ depending on the AD technology employed and waste composition), together with the implementation of credits (e.g. green certificates) for the renewable energy sector within the European Union, led to the development of full-scale digesters in many European waste treatment plants (Cecchi et al., 2011; Malamis et al., 2014).

However, AD cannot be the only treatment applied, since it solubilizes nutrients instead of removing them, producing a digestate rich in nitrogen and phosphorus which needs further post-treatment. In addition, organic matter removal is often not complete during AD due to several factors (the presence of hardly hydrolysable material, non ideal mixing, dead volumes in the digester, etc.) and the high concentrations of total ammonia nitrogen (TAN) produced from the hydrolysis of OFMSW proteins can lead to potential biomass inhibition (Cecchi et al., 2011; Malamis et al., 2014; Akindele and Sartaj, 2018).

The first step of the digestate post-treatment scheme is usually a solid/liquid separation process, which originates two streams: the solid fraction, which is commonly composted in order to obtain a product suitable to be used as fertilizer, and the liquid one, commonly known as anaerobic supernatant (Malamis et al., 2014), which is often subjected to the conventional nitrification/denitrification process (Cecchi et al., 2011). This technology is very effective in reducing nitrogen and organic matter concentrations till reaching the discharge limits for the sewerage system, but also quite expensive due to the high energy (aeration) and chemical (external carbon source for denitrification, alkalinity for nitrification, etc.) inputs (Tchobanoglous et al., 2003; Andreottola et al., 2012; Zanetti et al., 2012). Therefore, efforts to improve the

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treatment of the OFMSW anaerobic supernatant are ongoing in several directions.

The choice of the most suitable approach depends on the characteristics of the supernatant, which in turn depend on the specific OFMSW composition, AD operating conditions and the efficiency of the solid/liquid separation step (Malamis et al., 2014). Physico-chemical processes were found more expensive than the biological ones (Siegrist, 1996), and therefore, the latter are still the preferred option, especially when new energy-saving technologies, such as N removal via nitrite and partial nitritation/anammox, are applied (Malamis et al., 2014). Macé et al. (2006) and Fatone et al. (2011) successfully removed nitrogen from anaerobic supernatant via nitrite, while Caffaz et al. (2008) showed the feasibility of treating anaerobic supernatant from a co-digestion (OFMSW and olive mill wastewater) reactor by means of struvite precipitation and subsequent partial nitritation/anammox. However, most of these new energy-saving processes are limited by the organic matter concentration, thus requiring a prior step for its elimination. An alternative to take advantage of this residual organic matter is additional biogas production, like Kheradmand et al. (2010) did with municipal landfill leachate by combining post-anaerobic digestion and an activated sludge system. Still, the high ammonium concentration of anaerobic supernatants (Malamis et al., 2014) can seriously affect the performance of the post-digester (Rajagopal et al., 2013). To avoid this, ammonia stripping is an appealing choice to control nitrogen presence in the digester, as it is a relatively simple and stable process (De la Rubia et al., 2010). In addition, if the alkalinity content of the supernatant is high enough, chemical dosing for pH rising in the stripping column can be avoided (Pedizzi et al., 2017). The temperatures (60–80 °C) needed for the stripping process to work efficiently, could be reached with minimal operational expenses by using the excess heat of the waste treatment plant (De Feo et al., 2012), and they could also work as moderate thermal treatment, thus improving supernatant biodegradability (Carlsson et al., 2012).

The objective of the present work was to study the influence of the combination of low-temperature thermal treatment and ammonia stripping as a pre-treatment to improve mesophilic anaerobic post-digestion of an OFMSW anaerobic supernatant rich in nitrogen and organic matter. In addition, the final digestate was thoroughly characterized to discuss the subsequent treatment steps.

2. Materials and methods

2.1. OFSMW anaerobic supernatant

The anaerobic supernatant (Fig. S1A) came from a Spanish waste treatment plant, which include two mesophilic anaerobic reactors treating 80,000 t_{OFMSW} y^{-1} with more than 70% of organic fraction. The digestate was conditioned in a two-step solid/liquid separation compartment comprising screw presses followed by decanter centrifuges. The liquid fraction (anaerobic supernatant) was collected in a homogenizing tank, where the samples used in the laboratory experiments were taken from. Three different samples of supernatant (named SP1, SP2 and SP3) were used throughout the operational periods and were stored at 4 °C. They were characterized in terms of pH, total and partial alkalinity (TA and PA, g $CaCO_3$ L^{-1}), total (TS, g TS L^{-1}) and volatile (VS, g VS L^{-1}) solids, total and soluble chemical oxygen demand (tCOD and sCOD, g O_2 L^{-1}), total and soluble total Kjeldhal nitrogen (TKN and sTKN, g N-TKN L^{-1}), total ammonia nitrogen (TAN, g N-TAN L^{-1}), SO_4^{2-} (mg L^{-1}) and volatile fatty acids (VFA, mg L^{-1}). This characterization was repeated weekly to check waste stability and the results are summarized in Table 1. The differences observed, especially between the first sample (SP1) and the other two (SP2 and SP3), were associated with different centrifuge settings and flocculant dosing. Biochemical Methane Potential (BMP) tests were performed with SP1.

2.2. Pre-treatment procedure

The low-temperature thermal treatment and ammonia stripping were performed simultaneously in a glass column with a height of 1.45 m and a working volume of 7 L (Fig S1B). The temperature was set at 75 °C and controlled by an external water jacket connected to a thermostatic bath (Fisher Scientific Isotemp 4100 H7). Compressed air was supplied through a pierced metal ring (Φ = 0.3 mm) at the bottom of the column. Mild mixing was provided with a mechanical stirrer (IKA RW20) in order to enhance mass transfer.

The column was operated in batch mode. In each batch, 3 L of supernatant were pumped (Marlow Watson peristaltic pump) into the stripping column which was previously preheated to 75 °C. 0.5 mL antifoam (Antifoam A, SIGMA ALDRICH) were added to prevent excess foaming. An airflow of 1.3 L_{air} $L^{-1}_{supernatant}$ min^{-1} without pH control was used with two contact times: 4 and 8 h. The pH of the pretreated supernatant was decreased to around 8.2 (similar value as the raw supernatant) by dosing 0.5–1 mL of sulphuric acid (30% v/v), a chemical often present in the waste treatment plant. SP1 was pretreated with two different contact times, while only 8 h were tested with SP2 and SP3. The pre-treated supernatant was characterized in terms of pH, TA, PA, TS, VS, tCOD, sCOD, TKN, sTKN, TAN, SO_4^{2-} and VFA. The anaerobic biodegradability of 4 h- and 8 h-pretreated supernatant was assessed with BMP tests.

2.3. Anaerobic reactors

The experiments were carried out in two (R1 and R2) continuous stirred tank reactors (CSTR) of stainless steel with 14 L of working volume. Mixing was provided by mechanical stirrers (IKA RW20, 150 rpm) and temperature was kept in mesophilic range (37 ± 1°C). The reactors were inoculated with biomass from a mesophilic sewage sludge anaerobic digester (Table S1) and feeding was performed semi-continuously (once a day draw-off and feeding).

Both reactors were operated for 360 days and 5 different periods can be highlighted (Table 2). After inoculation, the reactors were left acclimated for 20 days, and then fed with a mixture of primary and biological sludge (70:30, v/v, Table S1) from the same wastewater treatment plant as the inoculum for 53 days till system stability was assured. Hydraulic retention time (HRT) was adjusted to 20 d in order to reach an organic loading rate (OLR) of around 1.7 ± 0.1 g COD L^{-1} d^{-1}. In Periods 1 and 2, the mixed sludge was gradually replaced (10% of the OLR every one or two weeks) by raw and pre-treated anaerobic supernatant (SP1) in R1 and R2, respectively, but maintaining the OLR constant (HRT varying between 22 and 27 d). In Period 3, 100% supernatant (SP2 and SP3) feeding was reached with the HRT varying between 20 and 24 d. In Period 4, SP3 was fed to the digesters using a HRT of 40 d.

Temperature, stirring speed and biogas production were monitored on-line. Biogas composition and other physico-chemical parameters (pH, TA, PA, TS, VS, tCOD, sCOD, VFA, SO_4^{2-}, TKN and TAN) were measured two or three times per week. Biochemical oxygen demand (BOD_5) was measured four times in triplicate at the end of Periods 3 and 4. Specific methanogen activity tests (SMA) were performed with the biomass of each reactor on days 45, 94, 129, 164, 199, 213, 297 and 360.