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Potential use of the organic fraction of municipal solid waste in anaerobic co-digestion with wastewater in submerged anaerobic membrane technology

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ABSTRACT

Food waste was characterized for its potential use as substrate for anaerobic co-digestion in a submerged anaerobic membrane bioreactor pilot plant that treats urban wastewater (WW). 90% of the particles had sizes under 0.5 mm after grinding the food waste in a commercial food waste disposer. COD, nitrogen and phosphorus concentrations were 100, 2 and 20 times higher in food waste than their average concentrations in WW, but the relative flow contribution of both streams made COD the only pollutant that increased significantly when both substrates were mixed. As sulphate concentration in food waste was in the same range as WW, co-digestion of both substrates would increase the COD/SO_4-S ratio and favour methanogenic activity in anaerobic treatments. The average methane potential of the food waste was 421 ± 15 mL CH_4 g^{-1} VS, achieving 73% anaerobic biodegradability. The anaerobic co-digestion of food waste with WW is expected to increase methane production 2.9-fold. The settleable solids tests and the particle size distribution analyses confirmed that both treatment lines of a conventional WWTP (water and sludge lines) would be clearly impacted by the incorporation of food waste into its influent. Anaerobic processes are therefore preferred over their aerobic counterparts due to their ability to valorise the high COD content to produce biogas (a renewable energy) instead of increasing the energetic costs associated with the aeration process for aerobic COD oxidation.

1. Introduction

Wastewater (WW) and municipal solid waste (MSW) from household activities are constantly growing due to the ever expanding worldwide population. To protect the environment, stricter regulations have been imposed requiring innovations and/or optimization of existing treatments. The European Directive 2008/98/CE has encouraged the recovery of resources from household waste and other materials in order to conserve natural resources. The target is that by 2016 EU countries should reduce the quantity of organic waste sent to landfills by 35% of the total amount of biodegradable municipal waste produced in 1995 (1999/31/CE Directive). Untreated biodegradable waste is known to cause many environmental problems, such as contamination of soil, water, and air during collection, transportation and final landfill disposal due to its degradation (Han and Shin, 2004).

A considerable reduction in the organic matter currently sent to landfills could be achieved by more efficient handling of domestic organic waste. Source control systems constitute an interesting potential solution for increased biogas production as well as nutrient recovery (Kjerstadius et al., 2015). Different technical solutions are available to take advantage of domestic organic waste collection, transportation and treatment for its valorisation. One of these options is to incorporate the organic fraction of municipal solid waste (OFMSW) into the sewage system for joint treatment with urban wastewater in wastewater treatment plants (WWTP) (Kujawa-Roeleveld and Zeeman, 2006). The combined process could lead to improved treatment, savings in MSW transportation, together with the environmental benefits of reduced fossil fuel consumption and landfill volumes. According to these authors, food waste is one of the main constituents of OFMSW.

The increased influent organic load due to OFMSW incorporation will have different impacts according to the wastewater treatment scheme involved (Evans et al., 2010). Aerobic-based

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wastewater treatment schemes are energy intensive, produce significant quantities of sludge and do not recover the potential resources available in wastewater (Tchobanoglous, 2003). In these systems the higher the organic content of the influent, the higher the energetic cost of aeration (Serralta et al., 2002). In contrast, anaerobic treatment schemes can recover energy by converting organic matter into methane-rich biogas besides other advantages such as low sludge production, fewer pathogens and the possibility of recovering nutrients from wastewater for reuse in agriculture (Fang and Zhang, 2015).

The low growth rate of the microorganisms involved in anaerobic processes without biomass retention require high sludge retention times (SRT) and thus high reaction volumes, which rules out the use of this technology as a mainstream process. However, the application of membrane technology allows the hydraulic retention time (HRT) to be decoupled from the solids retention time (Giménez et al., 2011), making it possible to operate anaerobic processes at high SRT while keeping reactor volumes low. Submerged MBR technology has been reported as a successful application for anaerobic wastewater treatment (Huang et al., 2011).

Although a few systems have been investigated for the separate collection of food waste on both experimental and full scales in different countries (Battistoni et al., 2007; Evans et al., 2010; Bernstad et al., 2013) no previous study has focused on the potential benefits of the co-digestion of food waste together with wastewater for valorisation with submerged anaerobic membrane bioreactor technology (AnMBR).

A study of the feasibility of AnMBR technology for the joint treatment of OFMSW and urban wastewater requires the previous comprehensive characterization of the new wastewater influent (OFMSW + WW) in order to determine whether the chemical, physical and biological characteristics are appropriate for the proposed treatment. These characteristics include particle size distribution, COD concentration, anaerobic biodegradability, nutrient concentration, sulphur concentration, etc. The aim of this study was therefore to thoroughly characterize this substrate for possible future co-digestion with urban wastewater using AnMBR technology, to make a preliminary assessment on the fate of the OFMSW within the treatment scheme based on the characterization, and finally to estimate biogas production of the OFMSW through anaerobic co-digestion with wastewater.

2. Materials and methods

2.1. Source of substrates

The OFMSW used in this study were leftovers from a number of restaurants on the campus of the Universitat Politècnica de València. The restaurants provided the OFMSW source separated from other waste. The substrate was weighted and stored in bags at 4 °C the day prior to experimental use. The study was carried out during the academic year, from October 2012 to May 2013. The occurrence of the different food waste components was: rice (which appeared in 88% of the samples), fruit remains and peel (80%), potatoes (fried, baked, in omelettes) (68%), bread (64%), pasta (56%), seafood (52%), cooked vegetables (44%), chicken (32%), salads (20%), fish (16%), pork chops (8%) and beef steak (8%).

2.2. Sample pre-treatment

An experimental device was constructed to simulate a household OFMSW grinder and consisted of a structure with a kitchen sink fitted with a commercial food waste disposer (InSinkErator Evolution 100). This was installed in the Carraixet WWTP (Alboraya, Valencia) next to the existing AnMBR pilot plant.

The OFMSW was manually screened to remove materials (e.g. shells, cutlery and other foreign objects present in the leftovers) that could negatively affect the disposer operation. Since the wastewater influent of the existing AnMBR pilot plant is pre-filtered through a 0.5 mm space screen to protect the membranes, the OFMSW was also pre-treated in the same way (i.e. with a 0.5 mm space screen sieve after the grinding process). Ground OFMSW samples were previously pre-treated through a 5 mm space screen sieve to simulate typical WWTP fine screening. Fats and oils were removed by 30-min aeration and surface scraping.

2.3. Analytical procedures

pH was measured by a portable pH meter (WTW pH315i). Settleable, total (TS), dissolved (DS) and volatile (VS) solids were analysed according to the Standard Methods: 2540-F, B, C, E (APHA, 2012) respectively. Total chemical oxygen demand (COD_t) was measured according to Standard Methods: 5220-B, using a Metrohm 702 SM Titration. Ammonium (NH_4^+–N), nitrite (NO_2^-–N), nitrate (NO_3^-–N), phosphate (PO_4^{3-}–P) and sulphate (SO_4^{2-}-S) were determined according to Standard Methods (APHA, 2012) (4500-NH3-G, 4500-NO2-B, 4500-NO3-H, 4500-P-F and 4500-SO4-E, respectively) in a Smartchem 200 automatic analyzer (Westco Scientific Instruments, Westco). Carbonate alkalinity and VFA concentration were determined according to the method proposed by WRC (1992). Total Nitrogen was measured using standard kits (Merck, Darmstadt, Germany, ISO 11905-1) and total phosphorous according to the acid peroxodisulphate digestion method (4500-P-B), which can be found in Standard Methods (APHA, 2012). Biochemical methane potential tests (BMP) were carried out by the Automatic Methane Potential Test System (AMPTS) [Bioprocess Control, Sweden]. Particle size distribution was measured by a laser diffraction technique on a Mastersizer 2000E [Malvern Instruments].

Due to the heterogeneity of the OFMSW samples in the first stage of the characterization, some practical issues were considered to improve the representativeness of the results: (1) The presence of some relatively large particles after grinding hampered the collection of representative samples, due to the small volume required to determine total parameters (COD_T, N_T and P_T). To ensure that the parameters were determined from homogeneous samples, the samples were ground again in a kitchen blender in the laboratory. (2) To speed up the determination of the soluble fraction, prior to 0.45 μm filtration, samples were centrifuged at 9600 rpm for 8 min, sieved through a 0.5 mm and filtered under vacuum through 1.2 μm. (3) Suspended solids were determined using two different approaches to verify the consistency of the results: the APHA (2012) protocol and as the difference between total and dissolved solids.

2.4. Biochemical methane potential tests

To determine the Biochemical Methane Potential (BMP) of OFMSW in an anaerobic treatment system, bench-scale experiments were carried out by the Automatic Methane Potential Test System (AMPTS) [Bioprocess Control, Sweden]. These experiments were performed in duplicate for each sample and blank in batch reactors of 500 mL capacity each with a working liquid volume of 400 mL and 100 mL of head space, hermetically sealed to simulate the anaerobic degradation of the OFMSW at a constant temperature of 35 °C. No nutrient solution was added in these experiments. The pH was measured in all batch reactors before the test started and at the end of the test to confirm that the reactors were not acidified. When preparing a sample, a blank was also prepared to determine the methane production from the inoculum. This