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Thermophilic anaerobic co-digestion of sewage sludge with grease waste: Effect of long chain fatty acids in the methane yield and its dewatering properties

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HIGHLIGHTS

- Thermophilic anaerobic codigestion of sewage sludge and grease waste (GW) doubles methane yield.
- High GW doses in the influent leads to instability and LCFA accumulation in the effluent.
- GW addition promotes acetoclastic activity whilst worsening the hydrogenothrophic activity.
- The mesophilic codigestion with GW performs better than the thermophilic one.

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ABSTRACT

Thermophilic co-digestion of sewage sludge with three different doses of trapped grease waste (GW) from the pre-treatment of a WWTP has been assessed in a CSTR bench-scale reactor. After adding 12% and 27% of grease waste (on COD basis), the organic loading rate increased from 2.2 to 2.3 and 2.8 $kg_{COD}\ m^{-3}\ d^{-1}$ respectively, and the methane yield increased 1.2 and 2.2 times. Further GW increase (37% on COD basis) resulted in an unstable methane yield and in long chain fatty acids (LCFA) accumulation. Although this inestability, the presence of volatile fatty acids in the effluent was negligible, showing good adaptation to fats of the thermophilic biomass. Nevertheless, the presence of LCFA in the effluent worsens its dewatering properties. Specific methanogenic activity tests showed that the addition of grease waste ameliorates the acetoclastic activity in detriment of the hydrogenotrophic activity, and suggests that the tolerance to LCFA can be further enhanced by slowly increasing the addition of lipid-rich materials.

1. Introduction

Wastewater treatment plants (WWTPs) play an important role in the protection of the environment, but they also work with energy intensive processes that use up large amounts of non-renewable energy. In the current context of scarcity of resources any likely savings on energy have become an important issue for the sustainable management of WWTPs.

Disposal of sewage sludge (SS) generated as a by-product in WWTPs, is a problem of growing significance, representing up to 50% of the entire operating costs of all WWTPs [1]. Anaerobic digestion, for its ability to transform organic matter into biogas, is the usual treatment method employed to stabilize organic matter and to reduce solids, destroying at the same time most of the pathogens. However, in most cases biogas production from SS can be further optimized.

Thermophilic conditions can optimize this process accelerating biochemical reactions and increasing the efficiency of organic matter degradation to methane. The growth rates of thermophilic bacteria are 2–3 times higher compared to those of its mesophilic homologues. Hence, this can lead to an increase of the biogas yield and of the organic loading rate [2]. However, said increase in biogas yield does not always occur, and thermophilic AD could also bring non-desirable consequences such as a lower stability of the whole process, higher sensitivity to inhibitors, higher energy requirements, higher VFA concentrations in the effluent, and poor dewaterability [2,3]. Moreover, if a thermophilic inoculum is not available, the biomass must be acclimated to temperature and so it will take more time to reach a stable biogas production [4].

In order to optimize biogas production, co-digestion with other organic wastes is another attractive strategy. Adding highly biodegradable substrates increases the organic load and enhances

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the biochemical conditions that favour the growth of the different groups of bacteria involved in the process [5]. Grease waste (GW) from the dissolved air flotation unit of the pre-treatment step in WWTPs, as previously described by Silvestre et al. [6], is a suitable co-substrate for mesophilic SS anaerobic digestion. The use of this intermediate waste generated inside the WWTP, leads to an optimization of the entire plant, since the costs of managing the GW to landfill decreases, and its high fat content increases biogas yield. Nevertheless, GW, as many other lipid rich wastes, has high methane potential but its intermediate products (long chain fatty acids (LCFA)) could lead to inhibition phenomena [7]. LCFA inhibition depends on the type of LCFA; on microbial population and on temperature regime. Oleic acid, followed by palmitic and stearic acid, has been described as the LCFA with the highest inhibitor effect on the thermophilic biomass [8,9].

Many authors have studied the anaerobic co-digestion of SS with different kinds of grease waste in mesophilic conditions, obtaining good performances [10,6,11], but few studies have been conducted in a thermophilic regime. Kabouris et al. [12] found that the thermophilic anaerobic co-digestion of grease coming from restaurants and kitchen waste produced less increase in methane yield, compared with the mesophilic digestion. Likewise, Dinsdale et al. [13] studied the mesophilic and thermophilic anaerobic digestion of coffee wastes rich in fats, reporting a poor performance in the thermophilic regime, with a methane yield 5 times below the mesophilic one.

Aside from biogas production, the dewatering properties of the SS are essential for the energetic and economic optimization of the WWTPs. It still remains unclear whether AD—particularly thermophilic AD—does or does not favour the SS dewatering as contradictory results have been reported in many studies [14,15]. Moreover, adding a new substrate could affect the dewatering properties of the digested sludge [16]. Hence, further studies are necessary in order to understand the behaviour of a thermophilic biomass in presence of grease waste, the characteristics of the digestate produced, and its implications regarding the global energetic balance of WWTPs.

This study aims, as a whole, to assess the anaerobic co-digestion of SS and trapped grease waste (GW) from the pre-treatment of a WWTP in thermophilic regime. The biodegradability of the substrates, the methane yield, the stability of the process—in relation to the presence or absence of intermediate-LCFAs—the changes in the methanogenic activities of the biomass, and the dewatering properties of the effluent, were all used to assess the process performance. Moreover, results have been compared with the results obtained for mesophilic SS co-digestion with the same grease waste, as described and analyzed in Silvestre et al. [6].

2. Material and methods

2.1. Characteristics of the substrates and inoculums

The SS used was a mixture of 70% primary sludge and 30% activated sludge (v/v) coming from a WWTP located in La Llagosta (Barcelona). The SS was sampled every second week and kept refrigerated at 4 °C. The grease waste (GW) was collected only once, from the same WWTP, and kept frozen before use.

The effluent of the full scale anaerobic mesophilic reactor from the WWTP was the inoculum used in the continuous thermophilic reactor. The biomass acclimatisation to the thermophilic conditions took 302 days.

Three samples from the anaerobic effluent, namely inoculums I1, I2 and I3, were taken at the end of three periods (PI, III, and IV) in order to analyse the changes in the biomass activity over time. In order to remove the residual COD, these inocula were stored for 3 days at a temperature of 55 °C before carrying out the specific activity tests.

2.2. Analytical methods

Total solids (TS), volatile solids (VS), total suspended solids (TSS), volatile suspended solids (VSS), total chemical oxygen demand (COD), total Kjeldhal nitrogen (TKN), ammonia nitrogen (NH_4^+—N), total and partial alkalinity (TA, PA), as well as sulphate (SO_4^{2-}—S), phosphate (PO_4^{3-}—P) and fat concentrations, were all determined according to Standard Methods [17].

The biogas composition was determined using a gas chromatograph (VARIAN CO-300). CH_4 and CO_2 were determined with a packed column (Varian Haysep-Q 80-100 MESH) and a thermal conductivity detector (TCD), and H_2 with a capillary column (Varian Molecular Sieve 5A 80-100 MESH) and a TCD, as described elsewhere [6]. Volatile fatty acids (acetate, propionate, iso-butyrate, n-butyrate, iso-valerate and n-valerate acids) were determined by gas chromatography (VARIAN CO-300) with a flame ionisation detector (FID) and a capillary column (TRB-FFAP). LCFAs were determined, in accordance with Palatsi et al. [7], using a gas chromatograph (GC 3800 Varian, USA) equipped with a capillary column and a FID detector.

2.3. Continuous experiment set-up

The continuous co-digestion experiment was performed in a 5.0 L CSTR anaerobic reactor (Fig. 1). The reactor was built of glass with a water jacket connected to a thermostatic bath. The temperature was controlled at 55 °C with a temperature probe connected to a data acquisition system (DAS, by STEP S.L.). The reactor was continuously stirred with a mechanical stirrer at 25 rpm. The reactor was fed twice a day (every 12 h) using a temporized peristaltic pump, allowing for 20 days of hydraulic retention time (HRT). Biogas production was measured with a volumetric gas counter (Ritter Apparatebau GMBH & CO. KG). The characteristics of the influent and effluent were measured once a week, and the biogas composition twice a week.

The experiment was held for 566 days, divided into four different periods. Period I corresponds to the biomass acclimatisation, which lasted for 302 days, and where SS was the sole substrate, while periods PII, PIII, and PIV, correspond to the co-digestion of SS with different amounts of GW.

2.4. Anaerobic biodegradability and specific activity tests

The methane potential (MP) of SS and GW was determined by means of an anaerobic biodegradability test (ABT) [18]. As explained elsewhere [6], 1.2 L capacity glass vials were filled with a mixture of 0.5 L of inoculum (5 $g_{VSS}\,L^{-1}$), substrate (5 $g_{COD}\,L^{-1}$) and deionised water. The thermophilic inoculum used was a sample taken from a thermophilic lab-scale reactor.

Changes in the activity of the methanogenic biomass through time were assessed by means of specific activity tests [18]. These tests were carried out in duplicate, on 120 mL glass vials filled with a mixture of 50 mL of anaerobic biomass (5 $g_{VSS}\,L^{-1}$), macro and micro nutrients, bicarbonate (1 $g_{NaHCO3}\,{g_{COD}}^{-1}$) and specific substrates (acetic acid (10 mM), and hydrogen (4.6 mM). Vials were bubbled with N_2, in order to ensure the complete removal of O_2, and airtight sealed with rubber stoppers and metallic clamps.

The time course of the methane production was monitored by gas chromatography, periodically sampling the head space of the vial. Methane production profiles were fitted to the modified Gompertz equation (Eq. (1)) [19,20].