Effect of salts on the anaerobic digestion of aerobic granular sludge

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Abstract

Aerobic granular systems are a good alternative to conventional activated sludge ones due to the better biomass settleability properties and the lower amount of sludge produced during the wastewater treatment. These aerobic granular systems are applicable to the treatment of saline wastes since the large amounts of biomass concentrations make up for the decrease of the biomass activity. Despite of the reduction in sludge production, it is necessary to treat the excess of biomass produced before disposal. Anaerobic digestion is usually applied to reduce the solids concentration with the advantage of biogas production. However, in this case, two aspects have to be taken into account: the biomass aggregated in granules can imply mass transfer limitations and the possible negative effect of salinity in the anaerobic operation.

In the present work the anaerobic biodegradability of the granular sludge is determined under brackish and non-brackish conditions together with the effect of sulphide in the liquid and in the gas phase. The obtained results show that the anaerobic biodegradability of granular sludge was similar under brackish and non-brackish conditions (44 and 50% respectively). However, the content of H_2S in the biogas produced was relevant (1.0-2.4%) when treating brackish sludge with the consequence that a pre-treatment is needed if the biogas is going to be of further use.

Keywords: aerobic granular sludge; anaerobic digestion; biodegradability; saline conditions

INTRODUCTION

The disposal of the solids in a wastewater treatment plant (WWTP) can represent up to 50% of the plant operational costs (Appels *et al.*, 2008). They are generated mainly from primary and secondary treatments. In the secondary treatment -where biological processes take place- the sludge produced contributes largely to the solids production in the plant. New developed technologies using aerobic granular systems (AGS) can reduce the amount of biomass produced in comparison with conventional activated sludge systems (Campos *et al.*, 2009) making this recent technology a feasible alternative to implement.

Frequently, industrial wastewaters contain important salty-water concentrations which can cause negative effects on nutrients biological removal processes. Salinity shocks can affect the microbial populations' activity and also the quality of the obtained effluents (Hamoda and Alattar, 1995). Some authors used synthetic wastes up to 10 g NaCl L^{-1} in order to study the effect of salinity on the AGS (Taheri *et al.*, 2012). In this sense, this can be a suitable technology to treat brackish wastewater since the high biomass concentrations achieved make up for the decrease of the biomass activity found under saline conditions. AGS have been used to remove phenol from saline wastes (Moussavi *et al.*, 2010) and also to treat fish canning effluents (Figueroa *et al.*, 2008).

Although the sludge production in AGS is lower than in other conventional processes, a post-treatment of the produced biomass excess is still necessary being the anaerobic digestion (AD) one of the most applied ones. However, the fact that the biomass is aggregated in granules and contains insoluble extracellular polymeric substances in the granule shell (Wang *et al.*, 2005) can limit its treatment by AD due to the recalcitrant nature of these extracellular polymeric substances to anaerobic and aerobic digestion (Mottet *et al.*, 2010). On the other hand, salinity can affect the biological processes in the water line but also can affect the efficiency of the anaerobic digestion during sludge treatment (Lefebvre and Moletta, 2006). Another problem related to salinity is the toxicity of the generated sulphide because of the sulphate reduction and also the presence of sodium

(Appels *et al.*, 2008, Chen *et al.*, 2008). However, there are no studies about the effect of salinity in the performance of anaerobic digesters treating granular sludge.

Therefore, the aim of the present work is to study the feasibility of application of AD to treat aerobic granular sludge and to compare the results obtained with and without brackish conditions. Evaluated parameters were methane production, biodegradability (BD) and solids reduction. The effects of sodium and sulphate concentrations over these parameters were also tested.

MATERIALS AND METHODS

Experimental set-up and characteristics of the feeding

Two continuous stirred tank reactors provided with thermostatic jackets and with a useful volume of 5 L were used. They were operated in complete mixing conditions at 100 rpm. The operational temperature was set in the mesophilic range (35 ºC) by the use of a thermostatic bath (Techne Inc., USA). The biogas volume was measured with a water displacement device (Veiga *et al.*, 1990).

The anaerobic reactors were operated in fed-batch mode. A volume of 500 mL was replaced in the reactor three times a week manually to avoid the use of peristaltic pumps, which could disintegrate the granules and produce the clogging of the used pipes. This means that they operated at a hydraulic retention time (HRT) of 20 days. Both reactors were operated for three HRTs in order to achieve stationary conditions. Compared stages were parallel in the time.

The two digesters were fed with aerobic granular sludge, one produced under no saline conditions (GSN) and the other under brackish conditions (GSB). The aerobic granular sludge was collected from a SBR pilot plant of 100 L with the operational conditions described in a previous work (Jungles *et al.*, 2011). This aerobic granular sludge was accumulated along several operational days in order to obtain the sufficient amount of solids to perform the experiments in the anaerobic digesters. The samples were left to settle and part of their supernatant was removed to concentrate the sludge. In order to simulate the brackish conditions of the biomass seawater was used to wash the aerobic granular biomass fed to the GSB anaerobic digester. The characteristic parameters of the feeding for each digester are presented on Table 1.

Table 1. Characteristic parameters of the feeding of the anaerobic digesters.

Parameter	GSN	GSB
COD_T (g L^{-1})	26.3 ± 0.2	24.4 ± 0.7
COD_S/COD_T (%)	11.3 ± 0.9	2.2 ±0.2
TS (g L^{-1})	22.5 ± 0.1	23.1 ± 1.3
VS/TS (%)	91.6 ± 0.4	84.8 ± 0.4
COD_T/VS (g g^{-1})	1.3 ± 0.1	1.3 ± 0.1
[Na^+] (g L^{-1})	< 0.3	2.5 ± 0.2
[SO_4^{2-}] (mg L^{-1})	< 150	516 ± 55
VFA (g L^{-1})	ND	ND
ϕ (mm)	1.6 ± 0.1	1.5 ± 0.1

COD_T: Total Chemical Oxygen Demand
COD_S: Soluble Chemical Oxygen Demand
TS: Total Solids
VS: Volatile Solids
VFA: Volatile Fatty Acids
ND: Not detected
ϕ: Average diameter of the granules content in the GS

Analytical Methods and Calculations

TS, VS, COD_T, ammonium (NH_4^+) and Total Alkalinity (TA) concentrations were analyzed according to the *Standard Methods* (APHA-AWWA-WPCF, 2005). The pH was measured with a pH-meter (Crison, Germany). Sulphate and sodium were analyzed by ionic chromatography (Metrohm, Switzerland) and VFAs concentrations by gas chromatography (Hewlett Packard, USA).

COD_S was determined by a semi-micro method (Soto *et al.*, 1989). Free Sulphide (FS) in the liquid phase was calculated according to Omil *et al.* (1995). Free ammonia concentration (FA) was related to the ammonium concentration according to Anthonisen *et al.* (1976). The diameter of the granules was measured by a stereomicroscope (Carl Zeiss, Germany). Biogas composition was analysed by using a gas chromatograph (Hewlett Packard, USA). The Biomethane Potential (BMP) was determined as the volume of methane produced per mass of substrate fed as COD and the BD was determined by dividing the actual production of CH_4 by its theoretical value (Mottet *et al.*, 2010).

RESULTS AND DISCUSSION

VFA, TA and FA concentrations and the pH value (Table 2) ranged within suitable values (Chen *et al.*, 2008). The two anaerobic digesters were operated under similar organic (OLR) and solids (SLR) loading rates (Table 2) in order to compare their operation. However the ratios COD_S/COD_T and VS/TS in the feeding were lower for the GSB reactor (Table 1) which could be due to the wash of the substrate with seawater in order to get brackish conditions which led to the removal of part of the COD_S and VS in suspension.

Table 2. Characteristic parameters of the operation of the anaerobic digesters.

Parameter	GSN	GSB
SLR (g VS_{fed} L^{-1} d^{-1})	1.03 ± 0.04	0.98 ± 0.06
OLR (g COD_T L^{-1} d^{-1})	1.32 ± 0.01	1.22 ± 0.03
pH	7.5 ± 0.1	7.1 ± 0.1
VFA (g L^{-1})	ND	ND
TA (g $CaCO_3$ L^{-1})	5.1 ± 0.4	3.3 ± 0.2
FA (mg NH_3-N L^{-1})	32.1 ± 13.9	9.7 ± 1.7
$VS_{reactor}$ (g L^{-1})	14.6 ± 0.8	14.7 ± 1.6
$VS_{removed}$ (%)	29.2 ± 3.0	25.1 ± 8.2
Gas composition (CH_4 %)	67 ± 3	60 ± 1
Gas composition (H_2S %)	ND	1.7 ± 0.5
Gas production rate (L m^{-3} d^{-1})	335 ± 68	293 ± 53
CH_4 production rate (L m^{-3} d^{-1})	220 ± 35	178 ± 37
BMP (L_{CH4} kg^{-1} COD_{fed})	174 ± 25	149 ± 31
BD (%)	50 ± 7	42 ± 7
[Na^+] (g L^{-1})	< 0.3	2.6 ± 0.2
[SO_4^{2-}] (mg L^{-1})	< 80	108 ± 38
FS (mg H_2S-S L^{-1})	ND	47 ± 9

The methane percentage in the gas phase was 67% for GSN and 60% for GSB (Table 2) and both were within the expected values for sewage anaerobic digestion (55-65%; Appels et al., 2008). The BMP of the GSB was 14% lower than the BMP of the GSN (149 vs. 174 L_{CH4} kg^{-1} COD_{fed}) but this could be explained by the lower soluble fraction of organic matter in the medium of the latter.

The volatile solids removal was 29 and 25% for GSN and GSB respectively (Table 2) which are similar to the values observed during the AD of waste activated sludge without saline conditions and under similar OLRs (Bolzonella *et al.*, 2005). The BD of GSB was 42% which was similar to the value of 40-44% found during the anaerobic digestion in mesophilic conditions of sludge coming from a fish farm (Gebauer and Eikebrokk, 2006) but the BD of GSN was higher (50%) than the BD of GSB and similar to the values obtained for different waste activated sludge samples (Mottet *et al.*, 2010).

Sodium concentration had low values when treating GSN but 2.5 g Na^+ L^{-1} was used in the digestion of GSB (Table 1). The reduction of SO_4^{2-} into hydrogen sulphide when treating sludge under brackish conditions is favoured in anaerobic systems and a reduction of 80% of the initial sulphate was achieved. The FS concentration was negligible when treating GSN but it was 47 mg H_2S-S L^{-1} when treating GSB. Although values for BD, BMP and solids reduction of GSB are lower in comparison with GSN (Table 2) the differences cannot be attributed to inhibitory events because they are lower than 15% and can be justified by the difference in the ratio COD_s/COD_T (Table 1) and the lower content in soluble carbon fraction in GSB because of the exchange between interstitial and brackish water during initial washing. With regards to the biogas composition, H_2S was produced and provoked the corrosion of the metallic parts of the system. The limits for the content of hydrogen sulphide in the biogas depend on its further use but, in general, concentrations in the gas phase of hydrogen sulphide over 300 ppm (0.3%) damage the energy conversion technique (Holm-Nielsen *et al.*, 2009). The values obtained in the present work are above these limit concentrations: the highest H_2S content in the biogas was 2.4%. This means that a pre-treatment should be required to eliminate the sulphide in order to avoid corrosion, odours or any other derived problem.

At the sight of these results, it can be demonstrated the potential of the anaerobic digestion of aerobic granular sludge with and without the presence of salts. Good results were obtained in both cases but taking into account that the AD of GSB is a little less efficient than the AD of GSN.

CONCLUSIONS

The results obtained show that the BD of GSN and GSB is similar and also comparable with the AD of waste activated sludge, which demonstrates the feasibility of the anaerobic digestion of aerobic granular biomass independently of the biomass aggregation. The concentrations of salts used in this work have shown no influence over the operation but sulphide presence in the gas phase can cause problems of corrosion and odours.

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