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Microaerobic pretreatment of sewage sludge: Effect of air flow rate, pretreatment time and temperature on the aerobic process and methane generation

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A B S T R A C T

The effect of air flow rate (AFR), pretreatment time, and temperature on a microaerobic pretreatment were determined, including its effect on CH_4 generation. For this, four AFR (0.1, 0.3, 0.5 and 1 vvm), three temperatures (20, 25 and 35 °C) and three aeration times (24, 48 and 60 h) were evaluated in 1-L and 5-L bioreactors. The effect on CH_4 production was evaluated in 280-mL bioreactors, using previously aerated sewage sludge. It was found that the micro-aerobic pretreatment improves the hydrolytic process, with an increase of proteins, total sugars, soluble chemical oxygen demand (COD), and a greater removal of volatile suspended solids (VSS) compared to a system without aeration. It was determined that an AFR = 0.3 vvm, 48 h of aeration time, and a temperature of 35 °C were the best operational conditions for increasing hydrolysis rate. VSS removal under the aerobic pretreatment follows first order kinetics. Finally, the aeration pretreatment allows a 211% increase of methane generation compared to a process without pretreatment, improving also total COD and VSS removal.

1. Introduction

Anaerobic digestion (AD) of sewage sludge is a valuable treatment that results in the reduction of sludge volume, destruction of pathogenic organisms, stabilization of the sludge, and production of an energy-rich biogas (Appels et al., 2008). This anaerobic digestion involves a number of metabolic reactions including hydrolysis, fermentation, and methane formation. According to the literature (Zhu et al., 2009; Abelleira-Pereira et al., 2015), the main limiting factors of sewage sludge AD are associated with the hydrolysis step. Therefore, various sludge disintegration methods have been studied as a pretreatment, where slowly degradable particulate organic matter is converted into low molecular weight readily biodegradable compounds, bypassing the rate-limiting hydrolysis stage. The pretreatments that have been reported are physical-chemical and mechanical methods (Mata-Alvarez et al., 2000; Divyalakshmi et al., 2015), thermo-chemical treatment (Zhen et al., 2014; Kim et al., 2015), and biological methods (Saidu et al., 2014; Liu et al., 2015; Mutschlechner et al., 2015).

Among the biological methods, the use of micro-aeration as a treatment prior to anaerobic digestion has received less attention, even though it has been reported that the limited oxygen supply increased the enzymatic hydrolysis rates for the case of complex organic matter in batch tests (Johansen and Bakke, 2006). With limited oxygen, it has been suggested that the facultative anaerobes maintain a low redox potential and supply more growth factors for the strict anaerobes (Gerritse et al., 1990; Kato et al., 2005). These findings suggest that hydrolysis, and therefore COD solubilization, might be improved by micro-aeration. Some studies about the effect of micro-aeration on anaerobic digestion have been reported, mainly using municipal solid waste (MSW) as substrate (Charles et al., 2009; Nguyen et al., 2007; Xu et al., 2014; Fu et al., 2015), indicating that micro-aeration has an important effect in terms of enhancing the anaerobic digestion process and this needs further investigation. Other studies using vegetable and flower wastes (Zhu et al., 2009) and grass silage (Jagadabhi et al., 2010) have also been carried out, indicating that the amount of oxygen supplied and the micro-aeration time needs to be further optimized. Mshandete et al. (2005) studied the aerobic pretreatment of sisal pulp in mesophilic anaerobic digestion using an mixed culture of activated sludge. They indicated that the correlation between high enzyme

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activity and high methane yield using an aerobic pretreatment suggests that such a short pretreatment period may be an alternative option for increasing solubilization of sisal pulp and promoting methane productivity.

Regarding the effect of micro-aeration on the AD of sewage sludge, few studies have been reported. Jenicek et al. (2011), using a continuous bioreactor and pumping air continuously into the sludge recirculation stream, showed that the VSS/TSS ratio of the digested sludge, soluble COD concentration, ammonia nitrogen, and phosphate concentration decreases in all experiments under micro-aerobic conditions. Jenicek et al. (2010), working with a continuous stirred tank reactor (CSTR) with continuous micro-aeration, indicated that efficient H_2S removal, higher specific methane production, lower methane concentration in the biogas due to dilution with nitrogen remained from the dosage of air, better sludge liquor quality, and lower foaming potential and foam stability were obtained using micro-aeration. Dumas et al. (2010) studied the efficiency of a hyper-thermophilic (65 °C) aerobic process coupled with a mesophilic (35 °C) digester, getting a 30% increase of COD removal and 20%–40% of biodegradability. However, the methanization yield of the process was similar to that of a conventional process, probably due to the uptake of carbon from the facultative biomass. Ramos and Fdz-Polanco (2013) performed anaerobic digestion in a continuous pilot reactor in order to see the effect of microaeration on the performance of anaerobic digestion under overload conditions, showing that oxygen seemed to form a more stable digestion system, which meant increased ability to deal successfully with overloads. Therefore, none of these studies had reported the effect of parameters such as pretreatment time, temperature, or air flow rate (AFR) on pretreatment. Also, the kinetics of the hydrolytic process in the aerobic pretreatment has been scarcely reported. Knowledge of the effect of these parameters on the pretreatment can help to determine an operation range within which both pretreatment and anaerobic digestion can be operated efficiently. Furthermore, the kinetics of the hydrolytic process can help in understand and optimiz the aerobic pretreatment.

Therefore, the goal of the present work was to determine the effect of AFR and aeration time and temperature on the pre-aeration process, including also its effect on the anaerobic digestion process. The kinetics of VSS degradation in the pre-aeration process was also determined.

2. Materials and methods

2.1. Substrate, inocula and experimental design

The substrate for all the assays was a mixture of primary (60%) and secondary (40%) sludge from "La Farfana", a municipal wastewater treatment plant operated by Aguas Andinas in Santiago, Chile. The inoculum had a specific methanogenic activity of 0.32 g CH_4 g^{-1}VSS d^{-1}, and it was obtained from an anaerobic reactor of La Farfana.

Five assays were performed at the laboratory scale under the conditions presented in Table 1. Each assay was ran on three samples of mixed sludge taken at different times, and they were run in duplicate. The goal of assay 1 was to know the influence of the micro-aeration pretreatment on the hydrolysis process. Assay 2 was meant to study the effect of different pretreatment times (24, 48 and 60 h) on the solubilization of sewage sludge. This assay also measured protein and total sugar in order to evaluate the solubilization grade. Assay 3 was carried out in order to determine the influence of temperature on hydrolysis in the microaerobic pretreatment. Assay 4 was run in order to determine the kinetics of hydrolysis in the micro-aerobic pretreatment. Finally, assay 5 was carried out to determine the effect of the micro-aerobic pretreatment on CH_4 generation; in this case, the contents of the aerobic reactors were taken and put in several 280-mL anaerobic bioreactors (200 mL of hydrolyzed sewage sludge plus 50 mL of inoculum), similar to the system used by Huilinir et al. (2015, 2014).

The kinetics of hydrolysis (Assay 4) was studied by the integral method using first order kinetics, since this is followed by the most widely used hydrolysis model (Vavilin et al., 2008). The first order kinetics indicates that

$$\frac{d(VSS)}{dt} = -k \cdot VSS \tag{1.1}$$

where VSS is the VSS concentration (g/L) and k (h^{-1}) is the kinetic constant. Integrating, we get:

$$\ln(VSS)_t = -k \cdot t + \ln(VSS)_0 \tag{1.2}$$

Equation (1.2) is a straight line and k can be calculated from its slope. Linearization was performed in *Microsoft Excel 2010*.

2.2. Experimental setup

Assays 1, 2 and 3 were run in 1-L glass reactors, operating with an effective volume of 900 mL. Assays 4 and 5 were ran in bigger reactors, with a total volume of 5 L and an operational volume of 4 L. In each pretreatment, air was injected continuously into the bioreactors by means of mini-compressors (0–10 Lpm) and distributed by small diffusers. The air flow rate (AFR) was calibrated before the pretreatment assays using the volume variation method. As shown in Table 1, assays 1 and 2 were carried out at room temperature without temperature contro, while assays 3, 4 and 5 were run with temperature control.

2.3. Chemical and statistical analysis

The following parameters were determined: total COD (t_{COD}), soluble COD (s_{COD}), total and suspended solids, volatile suspended solids, pH, ammonia, proteins, and total sugars. COD (total and soluble) was measured by the colorimetric method according to (APHA et al., 2012). Total and suspended solids, volatile suspended solids, ammonia and pH were measured according to APHA et al. (2012). Proteins were measured by the Bradford method (Kruger, 1994), and total sugars were measured by the colorimetric method (Dubois et al., 1956).

Methane production was measured by volumetric displacement, connecting an inverted falcon tube containing a 3% w/w NaOH solution in order to eliminate CO_2 and H_2S as the main impurities from the biogas, displacing only the methane volume. The resulting biogas travels through the flexible tubing to the Falcon tube, where it comes in contact with the NaOH solution, forming sodium carbonate and bubbling only methane. The methane collected in the Falcon tube was sucked with a syringe and released in a flame to observe its presence.

The Minitab 8 software was used for the statistical processing and analysis of the data. An ANOVA analysis was performed and a comparison of 95% confidence intervals for mean values was made.

3. Results and discussion

3.1. Effect of aeration flow rate (AFR) on hydrolysis (Assay 1)

The effect of different AFR on VSS, s_{COD} and pH is shown in Table 2. No significant differences in the behavior of duplicate reactors in all assays were seen. Therefore, only the results of one of the duplicate reactors will be reported. It is seen that VSS decreased