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Effect of thermal hydrolysis and ultrasounds pretreatments on foaming in anaerobic digesters

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HIGHLIGHTS

- Foaming is a common problem in anaerobic digesters at WWTP.
- Thermal hydrolysis at 170 °C mitigated foaming in continuous pilot scale reactors.
- Thermal hydrolysis and ultrasounds are efficient tools to prevent foaming.
- Filamentous bacteria abundance is drastically reduced after pretreatments.
- Foam potential and stability parameters do not predict anaerobic foaming.

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ABSTRACT

Foam appears regularly in anaerobic digesters producing operational and safety problems. In this research, based on the operational observation at semi-industrial pilot scale where sludge pretreatment mitigated foaming in anaerobic digesters, this study aimed at evaluating any potential relationship between foaming tools applied to activated sludge at lab-scale (foam potential, foam stability and *Microthrix parvicella* abundance) and the experimental behavior observed in pilot scale and full-scale anaerobic digesters. The potential of thermal hydrolysis and ultrasounds for reducing foaming capacity was also evaluated. Filamentous bacteria abundance was directly linked to foaming capacity in anaerobic processes. A maximum reduction of *M. parvicella* abundance (from 5 to 2) was reached using thermal hydrolysis with steam explosion at 170 °C and ultrasounds at 66.7 kWh/m^3, showing both good anti-foaming properties. On the other hand, foam potential and stability determinations showed a lack of consistency with the bacteria abundance results and experimental evidences.

1. Introduction

Foam appears regularly in the biological reactors and secondary clarifiers from wastewater treatment plants (WWTP). One of the main sources of foam formation is attributed to the presence of bacteria such as *Microthrix parvicella*, *Gordonia amarae*, *Type 0041*, *Rhodococcus*, *Dietzia*, *Mycobacterium*, *Skermania*, *Tsukamurella*, *Nocardia*, *Nostocoida*... (Iwahori et al., 2001). Among them, *M. parvicella* and *G. amarae* appear to be the main responsible of foam formation as a result of two mechanisms: filament hydrophobicity due to the high content of mycolic acid in their wall and the production of surfactant extracellular enzymes inducing stabilization of air bubbles, causing foam (Pagilla et al., 2002).

When activated sludge (WAS) with filamentous bacteria is anaerobically treated, foam is found as well in the digesters. Anaerobic foaming is caused by WAS filamentous bacteria, which could survive and even grow under anaerobic mesophilic conditions despite being obligate aerobes (Ganidi et al., 2009). In this context, Pagilla et al. (1997) found a direct relationship between excessive *Nocardia (G. Amarae)* levels in WAS and foaming events in the anaerobic digester. Likewise, Westlund et al. (1998b) stated that the prevention of foaming in the anaerobic digesters can be achieved by controlling the growth of *M. parvicella* in activated sludge. On the other hand, non-biological factors such as organic loading rate, mixing, and primary/activated sludge solids ratio also influence foaming in anaerobic digesters (Subramanian and Pagilla, 2014). The generation and accumulation of foam in anaerobic digesters causes a wide variety of operational problems such as clogging of pumps, fouling of gas collection pipes, blockage of gas mixing devices, a loss of effective digester volume, and a decrease

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in both biogas production and volatile solids removal (Dalmau et al., 2010).

Different methods for controlling foam in activated sludge systems are available (Martins et al., 2004), which could also be implemented in anaerobic digesters to prevent foaming. Of them, non-specific methods such as chlorination, ozonation or addition of hydrogen peroxide, water sprays or polymers involve the addition of external chemicals, do not entail a long term corrective action and present detrimental downstream effects in the WWTP; on the other hand, specific preventive methods by operational adjustments allow a permanent foam control. Ganidi et al. (2009) reviewed the main operational parameters that influence foaming in anaerobic digesters and the preventive measures against it: reactor mixing configuration (mechanical preferable), operation temperature (high temperatures reduce foaming), organic loading rate (low preferable), reactor shape (egg-shaped preferable as cylindrical) and surface active agents addition (no supportive experimental data found). There is a need for cost-effective technologies capable of reducing foaming in anaerobic digestion without compromising the performance of anaerobic digestion.

In this regard, different reviews (Neyens and Baeyens, 2003; Pérez-Elvira et al., 2006; Carrère et al., 2010; Carlsson et al., 2012) indicated that sludge pretreatments before digestion could mitigate or even suppress the risk of foaming in the digester while improving the anaerobic digestion process (enhancement in methane production, kinetics, or digestate hydrodynamics and dewaterability...). However, the anti-foaming potential of sludge pretreatments was rather speculative and no supportive data were indeed provided in the above mentioned reviews. Concerning experimental works that confirm these effects, scarce studies have been published in this area. One of the first reported studies in which a pretreatment was applied in order to prevent foaming showed that aerobic thermophilic pretreatment to mixed sludge was able to reduce pathogens and control *Nocardia* (Pagilla et al., 1996). Pagilla et al. (1998) applied chemical hydrolysis (chlorination) to prevent foaming in anaerobic digesters but obtained unsuccessful results since foaming capacity was increased. Pilli et al. (2011) claimed that filaments disruption takes place after just 2 min of sonication, while Sandino et al. (2005) reported foaming reduction with the application of ultrasounds to waste activated sludge in mesophilic digesters. On the other hand, Barjenbruch and Kopplow (2003) showed the superior performance of thermal hydrolysis (121 °C for 60 min) compared to mechanical or enzymatic pretreatments to prevent foaming. As well, the effect of *Cambi* thermal hydrolysis pretreatment in anaerobic foaming was studied, showing a positive influence on foaming mitigation (Marneri et al., 2003). On the other hand, Hoyle et al. (2006)and Marneri et al. (2003) established a systematic analysis of foaming prevention by the assessment of foaming tools: foam potential, foam stability and bacteria abundance.

Based on the operational observation at semi-industrial pilot scale where sludge pretreatment mitigated foaming in anaerobic digesters, this study aimed at evaluating any potential relationship between foaming tools applied to activated sludge at lab-scale and the experimental behavior observed in pilot scale and full-scale anaerobic digesters. As well, two pretreatment technologies (thermal hydrolysis and ultrasounds) at different pretreatment conditions will be tested to assess their effect on foam mitigation.

2. Methods

2.1. Sludge sampling

Waste activated sludge was sampled from the sludge recirculation line of the aerobic section in the WWTP of Valladolid (Spain) during episodes of foaming in the aeration basins, secondary clarifiers and anaerobic digesters (March–April 2013). All samples were immediately transported to the laboratory, characterized and subjected to the pretreatments below descried. The WAS, characterized according to Standard methods (APHA, 2005) contained a total solid content of 9.7 g/L (70% volatile solids) and total and soluble chemical oxygen demands of 11.3 g/L and 1.9 g/L, respectively.

2.2. Pretreatments

Thermal hydrolysis pretreatment was carried out in a pilot plant (Fdz-Polanco et al., 2008) in the WWTP of Valladolid. A thermal hydrolysis reactor containing 10 L of WAS was heated with direct steam injection in batch mode. The pilot plant was equipped with automatic valves and a data acquisition and control system that controlled the steam inlet (to maintain the desired operation temperature) and sludge outlet (steam explosion to the flash tank) once the reaction time had elapsed. This device operated at different temperatures (from 100 °C up to 200 °C), hydrolysis times and with or without steam explosion. In addition, a thermal pretreatment was performed at laboratory scale at lower temperatures (below 100 °C) in a simpler device without steam explosion. Thermal hydrolysis tests were performed in two different series corresponding to the two experimental devices. Laboratory scale trials were devised to study the influence of low temperature pretreatments at 50 and 90 °C at three different hydrolysis times (15, 30 and 60 min) with no steam explosion. Pilot scale plant trials evaluated the influence of higher temperatures (over 100 °C) applying or not steam explosion Three levels for hydrolysis time and temperature were selected for each operational variable according to typical values obtained from previous experience (Ferreira et al., 2014): hydrolysis times at 5, 15 and 30 min and temperatures at 120, 150 and 170 °C (Table 1).

The ultrasound homogenizer converts electrical energy in mechanical vibrations (ultrasounds), which are transmitted to the sample by a sonotrode to produce cavitation. Test samples were sonicated in a UP400S Hielscher ultrasound equipment (Germany) with a nominal power of 400 W and 24 kHz frequency. The sonication time and power level (up to 200 W, which was the maximum attainable power) could be varied and controlled. Four ultrasounds tests series of batch experiments with WAS were carried out varying sonication time and power. Sonication time was manually controlled for each batch at two different levels (1 and 5 min) and power was set at two different levels for each sonication time (200 and 100 W). Unfortunately, for the highest power and time, the device broke and the final test could not be completed. Table 2 compiles the experimental design.

Table 1
Experimental setup for thermal hydrolysis tests.

Thermal hydrolysis		
Temperature (°C)	Time (min)	Steam explosion (Yes/No)
50/90	15 30 60	No
120/150/170	5 15 30	No
120/150/170	5 15 30	Yes