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Monitoring foaming potential in anaerobic digesters

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ABSTRACT

Foaming in anaerobic digestion (AD) systems for biogas generation can give serious operational problems. The cause of such foaming events is often unclear, and it is therefore not an easy task to predict and subsequently apply preventative measures. Methods for the measurement of the foaming potential of digester sludge are often implemented, but no standardized method is available. In this study, we investigated parameters influencing the foam formation during experimental aeration tests of full-scale digester sludge, including air flow, time, and total solids concentration, and proposed an optimized method for standard use. In a survey of 16 full-scale AD systems located at wastewater treatment plants in Denmark, all sludge samples were classified into three groups (non-foaming, pre-foaming, and actually foaming) according to their foam height/propensity and stability. Extensive surveillance of plants with the proposed classification system will enable the determination of cut-off values to help to identify foaming or pre-foaming sludge, and to associate these with operational conditions leading to foaming episodes.

1. Introduction

Foaming is a serious operational problem in full-scale biogas plants at wastewater treatment plants (WWTPs), where it causes inefficient gas recovery, blockages of gas mixing, fouling of gas collection pipes and covering the digester wall with foam solid (Ganidi et al., 2009; Pagilla et al., 1997). Besides reduced gas production, it is very costly in repairing and cleaning (Ganidi et al., 2009; Moeller and Görsch, 2015; Westlund et al., 1998). A combination of factors are thought to lead to stable foam formation in anaerobic digestion (AD) systems, including gas bubbles surrounded by liquid film, and hydrophobic particles in the form of microorganisms or suspended solids (Boe et al., 2012; Ganidi et al., 2009). Although this phenomenon has been known for decades, and numerous studies have addressed it in AD, the exact mechanism of how foaming is initiated and stabilized is still not fully understood (Barjenbruch et al., 2000; Ganidi et al., 2009, 2011; Pagilla et al., 1997; Ross and Ellis, 1992; Westlund et al., 1998). Several methods have been implemented to measure the foaming propensity of both activated sludge wastewater treatment plants and their associated anaerobic digester systems. Foaming is also a well described operational problem in the activated sludge part of the WWTPs, where it is easy to observe on top of the process or settling tanks. In the closed AD tanks, it is very difficult to observe the foam layer, hence therefore it is necessary to develop simple methods that can monitor the general foaming state of the sludge and detect the onset of foaming events for early intervention measures, such as reducing loading or addition of anti-foaming chemicals.

The foaming potential aeration test, also known as the bubble test, is one of most popular methods applied for monitoring or evaluating the foaming propensity of sludge. It is a simple analysis attempting to generate and measure foam to determine foaming tendency. It was first applied in activated sludge systems (Blackall and Marshall, 1989), but may not represent the full-scale plants due to different wall effect and hydraulic conditions (Fryer and Gray, 2012; Hug, 2006). However, there are some studies that found a correlation between foaming potential and foam event in the plant (Blackall et al., 1991; Hladikova et al., 2002; Hug, 2006; Torregrossa et al., 2005).

In AD systems, aeration test were initially applied to determine foaming tendency by measuring foaming height and surface tension, but it was unsuccessful as no significant difference was observed in foam height among foaming and non-foaming samples (Ross and Ellis, 1992). However, there seems to be a number of issues that make the aeration tests more difficult in AD, such as high and varying total solids (TS), and a wide range of salinity values that may affect the surface properties of the particles.

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In recent years, the foaming potential has been defined by two new terms: foaming propensity and foam stability describing how easily foam forms and how stable it is. Foaming propensity was found to be able to evaluate foaming potential. However, it is doubted whether the foam stability is sensitive enough to predict foaming in digesters (Boe et al., 2012; Ganidi et al., 2011; Kougias et al., 2013). Additionally, foaming potential was calculated in terms of an unstable and stable foam ratio, and analyzed in two full-scale digesters (Subramanian and Pagilla, 2014; Subramanian et al., 2015). However, the results of these two studies showed that the foam potential test may not be well-suited to the prediction of foaming in full-scale digesters due to the complexity of the mechanisms that contribute to foaming.

The aeration tests applied in the past 10 years on ADs are very diverse in terms of apparatus, test parameters, and calculation methods (Table 1), and in many cases, key information is not given in the original papers, such as apparatus size, aeration time, flow rate, etc. Moreover, the effect of TS concentration on foaming potential aeration test was only investigated in one study, where it was shown to be of key importance to the outcome of the test (Boe et al., 2012). Consequently, the outcome of these tests is questionable and hard to compare, thus there is a strong need for an easy, fast, and reliable procedure and evaluation scale of the foaming potential of digester sludge.

The aim of this study is to establish and test a protocol for monitoring foaming potential in anaerobic digesters. We investigated parameters influencing the foaming propensity during the foaming potential aeration test in digester sludge and optimized the experimental conditions by using an orthogonal design experiment. This is a statistical design where an orthogonal table is used to mix and analyze the multifactors in order to obtain optimal combinations of factors and levels. The proposed protocol was used in a survey into sludge samples from sixteen full-scale mesophilic and thermophilic digesters located at 14 WWTPs in Denmark. The foaming properties of these digester sludges were characterized and classified, some of which with serious foaming.

2. Materials and methods

2.1. Sample collection and physico-chemical analyses

Digester sludge samples were obtained from 16 anaerobic digesters at 14 Danish WWTPs. Fresh samples were investigated immediately when they arrived in the laboratory with a transportation time less than 24 h. Most digesters were mesophilic (14), one of which had thermal hydrolysis process pre-treatment (THP), and two were thermophilic. Primary and secondary sludge were fed to all the digesters, except Fredericia, which only had secondary sludge. The primary sludge fraction was 50–70% of the organics. The TS, volatile solids (VS) values, and foam status of digester sludge samples are listed in Table 2, and other characteristics of the anaerobic digester plants and sludge are presented in Table S1 in supplementary materials.

TS, VS, pH, total nitrogen, ammonia nitrogen, and orthophosphate were measured according to APHA (2005). Short chain organic acids (C1-C6) were analyzed by High Pressure Ion Chromatography (HPIC, Dionex ICS-5000 system), equipped with an IonPac AS11-HC capillary column and a Conductivity Detector (CD). Potassium hydroxide (60 mM) was used as eluent for a multi-step gradient elution. All measurements were performed in triplicate.

2.2. Foaming potential aeration test apparatus and calculation

The apparatus used to measure foaming potential was constructed from a plexiglass tube (inner diameter of 3 cm, height of 85 cm) containing a diffuser stone attached to the bottom (Fig. 1). Air, which was used in most studies (Table 1), was supplied

Table 1
Literature review of methods to characterize the foaming potential foaming potential in ADs.

NO.	Digester	Parameter	Apparatus	Aeration Time	Flow Rate	Sludge Volume	Reference
1	WWTPs digester	Foam height (while bubbling and 1 min after the bubbling was stopped)	A graduated plexiglass tube 130 cm long and 4.5 cm diameter	NA	Air, NA	NA	Ross and Ellis (1992)
2	WWTPs digester	Foam height	A vertical glass tube 33 cm long and 2.2 cm diameter	1 min	Air, 40 L/h	3 mL	Westlund et al. (1998)
3	WWTPs digester	Foaming potential (calculated based on the level of foamy sludge after 5 min of the aeration over the volume of digester sludge) Foam stability (percentage of foaming remaining in the cylinder at 5 min after aeration compared with the volume of foam right after aeration)	Sintered glass with porosity S1 in 2 L cylinder	5 min	Nitrogen, 1 L/min	1 L	Zábranská et al. (2002)
4	WWTPs digester	Foaming propensity (calculated based on the amount of foam generated from a sample after aeration normalized over the solids content of the sample) Foam stability (monitored indirectly by measuring the foam height 1 h after aeration ceased)	A column 1 m long and 5.2 cm diameter	10 min	Air, 0.5 L/min	NA	Ganidi et al. (2011)
5	Manure digester	Foaming tendency (the volume of foam right after aeration divided by air flow rate) Foaming stability (percentage of foam remaining in the settling cone at 1 h after aeration compared with the volume of foam right after aeration)	NA	10 min	Air, 60 mL/min	50 mL	Boe et al. (2012); Kougias et al. (2013)
6	Sugar beet pulp digester	Foaming potential, Foaming Tendency, Foaming Stability, Foaming Propensity	NA	1 min	Air, 1 L/min	100 mL	Suhartini et al. (2014)
7	WWTPs digester	Foaming potential (calculated in terms of an unstable foam and stable ratio)	2 L graduated cylinder	NA	Air, 1.5 L/min	200 mL	Subramanian and Pagilla (2014), Subramanian et al. (2015)

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