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Innovative test method for the estimation of the foaming tendency of substrates for biogas plants

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ABSTRACT

Excessive foaming in anaerobic digestion occurs at many biogas plants and can cause problems including plugged gas pipes. Unfortunately, the majority of biogas plant operators are unable to identify the causes of foaming in their biogas reactor. The occurrence of foaming is often related to the chemical composition of substrates fed to the reactor. The consistency of the digestate itself is also a crucial part of the foam formation process. Thus, no specific recommendations concerning substrates can be given in order to prevent foam formation in biogas plants. The safest way to avoid foaming is to test the foaming tendency of substrates on-site. A possible solution is offered by an innovative foaming test. With the help of this tool, biogas plant operators can evaluate the foaming disposition of new substrates prior to use in order to adjust the composition of substrate mixes.

1. Introduction

The problem of excessive foaming appears in a high percentage of biogas plants. Our own survey of biogas plants treating biogenic waste in north-eastern Germany showed that 12 out of 15 biogas producers reported foam formation in their biogas reactors, fifty percent of them regularly (Moeller and Görsch, 2015). Foaming also occurs in biogas plants that use renewable resources for biogas production. A survey of agricultural biogas plants in the federal state of Saxony (Germany) showed that foam formation occurred in five out of thirty-six biogas plants utilizing renewables (Brückner, 2013). A survey of biogas plants in Denmark showed that fifteen out of sixteen full-scale biogas plants had faced foaming problems in the digester and/or in the pre-storage feeding tank (Kougias et al., 2014). Excessive foaming also occurs in a high number of manure pits. Several recent reports in the public press have described explosions in pig barns in the USA as a result of the formation of very thick, gelatinous foam (e.g. Willyard, 2012). Another survey of experts and biogas plant operators in the German state of Baden-Württemberg showed that approximately 10–15% of 500 biogas plants had problems with foaming (Wissmann, 2014). The interviewees pointed out that there is an urgent need for research in this field to address the conditions that trigger foam generation in biogas reactors, as well as technical solutions for the forecast and prevention of foaming.

The consequences of excessive foam formation vary. They include problems in the microflora as a result of a deteriorated mixed state in the reactor, as well as technical problems (failure of feeders, recirculation pumps and measuring sensors; contamination of gas and condensate pipes) (Pagilla et al., 1997, Moeller et al., 2010). Foam can cause serious trouble for biogas plant operators. Those may range from pipe clogging, increased demand of pumping to lower the filling level during foam appearance or in a worst case to a damage of the digester roof. Foaming events lead in any case to a massive increase in monitoring, maintenance or environmental damage (Moeller and Görsch, 2015). The estimation of the costs caused by excessive foam formation is not easy to quantify because diverse parameters have to be included: anti-foaming and cleaning agents, enhanced deployment of staff,

Abbreviations: GSA, grass silage containing alfalfa; BP, biogas plant; CT, coarse triticale; GS, grass silage; MS, maize silage; MSF, maize silage originated from a foaming biogas plant; MV, mean value; PP, protein powder; SBS, sugar beet silage; SD, standard deviation; TS, total solids (%).

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replacement of destroyed plant equipment, as well as decreased gas production (Moeller and Görsch, 2015, Westlund and Hagland, 1998). Kougias et al. (2014) reported that foam formation results in a 20–50% loss of biogas production in full-scale biogas reactors, reaching up to 90% biogas production loss and total process failure in some cases. A operator from Bavaria (Germany) of a biogas plant with two fermenters (working volume of 1000 m^3 each) estimated the costs to be €500–€600 for each foaming event in the case of his biogas plant due to the enhanced effort of workforce, the required defoamer and the amount of water for rinsing the foam traps. Another biogas plant operator assessed that the costs of one foaming accident in his biogas plant reached €500,000 due to the great extent of the damage (Moeller and Görsch, 2015).

Foam is a gas dispersed in a liquid usually concentrated on top of the liquid surface, due to a density gradient. To establish and maintain a stable structure of gas bubbles above a liquid surface, two prerequisites are necessary: first, a source of gas and second, the presence of substances that decrease the surface tension of the liquid (Mollet and Grubenmann, 2000). In biogas plants, the main mechanism for gas formation is the production of biogas by the anaerobic microbial community. However, abiogenic processes are also possible, such as the release of dissolved carbon dioxide from the CO_2-saturated digestate triggered by a drop in pH value (for example, by addition of acidic substrates or by formation of acidic metabolites).

Some substrates are suspected to foam in biogas plants as they form acidic intermediates in rapid hydrolytic and acidogenic reaction steps or metabolites lowering the surface tension of the liquid phase. These are substrates that contain a high proportion of nitrogen and/or protein (e.g. clover, poultry manure, slaughterhouse wastes), easily degradable substrates (e.g. sugar beet chips, fruit and vegetable wastes) or substrates acting as surface active compounds by themselves (e.g. lecithin, grease separator contents, detergents) (Ganidi et al., 2009; Moeller et al., 2012; Moeller et al., 2015). Inadequate plant management, such as excessive feeding rates, improper agitation, use of spoiled, mouldy silage containing mycotoxins, and fluctuations of temperature or pH inside biogas reactor can lead to excessive foaming (Moeller et al., 2013). Kougias et al. (2014) reported that organic overload was the major cause of foam formation in Danish manure-based full-scale biogas plants.

To counteract foam formation, various methods have been deployed, such as stirring the foam, adding anti-foaming agents (Kougias et al., 2013a,b), the so-called "starvation diet" (i.e. minimization of substrate feeding for three or four days) and also alterations in biogas reactor management, such as changes in stirring periods and feeding cycles, (Moeller et al., 2013; Moeller and Görsch, 2015). However, the safest method of foam suppression is the prevention of its formation. Unfortunately, no effective early-warning systems for foam formation in biogas plants are currently available (Lienen et al., 2014). The development of early warning systems for foam formation in anaerobic digestion processes is a very challenging task because foaming is a complex phenomenon with many characteristics and causes. In the literature, several methods are described for the prediction and evaluation of foam formation in biogas reactors. Dalmau et al. (2010) introduced a risk model for foaming in anaerobic digestion due to microbial causes such as filamentous microorganisms (e.g. *Microthrix parvicella*). Nevertheless, the validation of this risk model in full-scale digesters is described to be very difficult as foaming events are often not recorded by common monitoring programs (Dalmau et al., 2010). Laboratory attempts to quantify, measure or predict foaming, for example by measuring surface tension, were not successful (Ross and Ellis, 1992; Boe et al., 2012). Zábranská et al. (2010), Boe et al. (2012) and Ganidi (2008) described an aeration method for the determination of foaming potential in mixtures of digestates and foaming substances by using a foaming apparatus. The apparatus consists of a 1 m high column with a diffuser placed on the bottom. After loading with the digestate, containing a tested substance, the process is aerated with gas by a certain flow rate for 10 min. The foaming potential is evaluated at the end of the aeration. Although this method was described by Boe et al. (2012) as the best possible, applicability under field conditions remains questionable due to the necessary precision. Moreover, the application of this method is more suitable for the determination of the foaming potential of substances in aqueous solutions than in complex materials, as is usually the case of digestates. This measuring tool helps to estimate the instant foaming potential of the digestate–substrate mixture but does not show the foam development due to the microbial conversion of foam-triggering substrates in the digestate–substrate system. Kougias et al. (2013c) discussed the use of foaming tendency as an on-site indicator of foaming in the biogas fermenter. The authors suggested that this tool is not sensitive enough to predict foaming in the manure digester. For this reason, the authors recommended to observe foaming directly inside the biogas reactor.

As foam formation can have severe impacts on biogas production and safety, there is a need to fully understand the foaming causes. Thus, the aim of our research was to search for a method to test the foaming tendency of liquid and highly fibrous substrates on-site, to give the biogas plant operators an effective tool for the prediction of foam formation of substrates before they are fed into biogas reactors. Moreover, the new method should be additionally applied in laboratory scale research in order to estimate the effects of substrate mix components on foam formation in anaerobic digestion (AD).

2. Materials and methods

2.1. Substrates and digestates

The digestates for the foaming experiments originated from six full-scale biogas plants. The main characteristics of the biogas plants are listed in Table 1. The substrates used for the foaming tests are summarized in Table 2.

2.2. Analyses and measuring methods

The total solid content (TS) and volatile solid content (VS) of the samples and substrates were determined according to DIN 12880 and DIN 12879, respectively. The samples of the digestates were filtered (pressure filtration device SM 16 249, Sartorius, Göttingen, Germany; nylon membrane filter: pore size 0.45 μm, Whatman, Germany) and the filtrate was used for the determination of the concentrations of VFA and ammonium-nitrogen (NH_4-N). VFA were analyzed using high performance liquid chromatography (Shimadzu, Japan) with an RID-10A detector, a VA 300/7.8 Nucleogel Ion 300 OA column and 0.01 N H_2SO_4 as the eluent (eluent flow: 1.5 mL/min). The ammonium-nitrogen concentration was determined according to DIN 38406 E5 using the Spektroquant® test kit (measuring range 0.01–3 mg/L NH_4-N, Merck, Germany). The viscosity of the sieved digestate from BP1, BP2 and BP3 was measured by use of the laboratory rotational viscometer (DV-I+ viscometer, Brookfield, USA) in two replications.

2.3. Experimental set-up

2.3.1. Foaming experiment

Fresh digestate was passed through a sieve with a mesh size of 10 mm in order to get a less fibrous and homogenous material. The