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Anaerobic digester foaming in full-scale cylindrical digesters – Effects of organic loading rate, feed characteristics, and mixing

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HIGHLIGHTS

- Full-scale modification of anaerobic digestion parameters to investigate foaming causes.
- The suspected contributors to anaerobic digester foaming were present in all 3 cases.
- No foaming occurred because primary foaming cause was absent.
- Reduced mixing to abate foaming did not affect homogeneity in digesters.

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ABSTRACT

Cylindrical anaerobic digesters (AD) were investigated to determine the causes and contributors of AD foaming due to the following: organic loading rate (OLR) and mixing effects, waste activated sludge (WAS) storage effects and foam suppression mixing at the surface of AD, and the effects of primary sludge (PS) solids fraction in the feed sludge. No foaming was observed over the duration of the study, indicating absence of a primary foaming cause even though the suspected contributors to AD foaming were present. Total solids and temperature profiles showed that reducing mixing frequency did not significantly impact digester performance or the homogeneity of the digester contents. The results showed that high organic loading rates, reduced mixing, and feed sludge storage by themselves do not cause foaming in most ADs when the primary foaming cause is absent. Reduced mixing and surface sludge sprays are practical strategies to control AD foaming.

1. Introduction

The issue of foaming has plagued the anaerobic digestion (AD) process for several decades now. AD foaming is a complex three-phase phenomenon (liquid–solid–gas) contributed by surface active materials or surfactants (solids and soluble constituents) and effects of biogas produced within the digester. Introduction of gas as well as mixing/whipping/mechanical agitation are methods used for foam structure formation in several applications, where foam bubble size and stability is maintained by careful process control (Campbell and Mougeot, 1999). Uncontrolled foam bubble creation in AD is coupled with presence of surface active materials, liquid–surfactant/solid–gas bubble size, and solids concentration dynamics between liquid and bubble-phases. However, excessive foam formation and stability in ADs, which becomes an operating problem, occurs when all the conditions are present at minimum threshold levels. This could be the reason as why only a fraction of the ADs experience foaming problems despite gas–liquid–solids/surfactant conditions for foam formation being present in all digesters. A certain degree of foaming is always present in all AD systems, but becomes evident when it begins to adversely affect the process, (popularly, termed as foaming problem or episode). In practice, severe AD foaming may be caused by a combination of several factors, initiated by one or more primary causes. The complexity of the AD system and the foaming phenomenon makes it difficult to correlate the type of foaming to a single cause

Abbreviations: AD, anaerobic digester; AS, activated sludge; FISH, fluorescence in situ hybridization; FOG, fats, oils, grease; HRT, hydraulic retention time; MGD, million gallons per day; MPA, *Microthrix parvicella* (probe); MYC, Mycolata (probe); ND, north digester; OLR, organic loading rate; PS, primary sludge; PS:WAS, primary sludge:waste activated sludge (ratio); SD, south digester; SRT, sludge retention time; TS, total solids; TWAS, thickened waste activated sludge; VA/A, volatile acids/alkalinity (ratio); VFA, volatile fatty acids; VS, volatile solids; WAS, waste activated sludge; WWTP, wastewater treatment plant.

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directly. Due to all these reasons and more, full-scale AD foaming assessment is particularly difficult.

However, several causes have been listed in the literature and been popularly accepted to cause/contribute to AD foaming to various extent (Barjenbruch et al., 2000; Dalmau et al., 2010; Ganidi et al., 2009, 2011; Massart et al., 2006b; Moen, 2003; Pagilla et al., 1997, 1998; Westlund et al., 1996, 1998). In this paper, we attempt to distinguish between a cause and a contributor. A primary cause or group of causes leads to a foaming episode. In contrast, a supplementary factor or a contributor is defined as one that enhances the foaming cause and favors the foam persistence if the potential to foam or a fundamental cause already exists in a digester. The distinction between the causes and supplementary factors is pivotal for the correct prognosis of effective control measures. Though these may be case specific to each full-scale digester, clear differentiation between foaming causes and contributors does not exist in literature with ample experimental evidence. We also present a classification of various popularly accepted digester foaming causes and contributors from inlet to in-digester conditions (Table 1). Most of these contributors/causes have been popularly accepted to cause/contribute to AD foaming but experimental full-scale evidence is lacking for several of the factors mentioned in Table 1 and threshold estimates of their magnitude for foam formation are unknown from full-scale information.

Organic loading rate (OLR) is a process characteristic, though popular knowledge of AD foaming still considers it a feed parameter. Case specific instances of foam formation and stabilization in AD signify that the digestion process may be overloaded not by just the absolute quantity of feed but the combination of the feed quality, digestion process as well as digester operation and physical properties. The ratio of primary sludge (PS) to waste activated sludge (WAS) solids fed to the digesters is an important characteristic that is related to the OLR and foaming (Dalmau et al., 2010). Foam in several cases seems to have been caused by higher and in some cases lower PS:WAS solids ratio in the digester feed. It has been reported that foaming could occur if the ratio of WAS solids to total sludge solids exceeds 40% (or feed PS:WAS solids ratio of 3:2) (Massart et al., 2006a). It is unclear if this ratio was indicated for filamentous or non-filamentous foaming. WAS solids could cause significant foaming in AD if they contain filamentous bacteria such as *Gordona amarae* and *Microthrix parvicella*, which are commonly known to cause foaming in the activated sludge process (Pagilla et al., 1996). WAS cells are more difficult to digest and yield less digester gas production (Girault et al., 2012; Parkin and Owen, 1986). Due to lesser gas production, WAS could contribute to lesser fraction of gas phase in AD foam formation. On the downside, it could also mean that more undigested particulate matter is available for foam stabilization. This could be true for WAS containing no foaming filamentous bacteria. More PS in feed sludge versus WAS increases instantaneous gas production rate and subsequently gas holdup, resulting in more gas bubbles causing foam. Longer retention times of these feed sludge solids in holding tanks prior to digestion leads to fermentation and higher production of volatile fatty acids (VFAs), which when fed to digester in higher quantity can contribute to foaming. The specific PS:WAS solids ratio for foaming is a function of the biodegradability of the solids in each stream and operating sludge retention time (SRT) of the digester. Other non-sludge three-phase foams exhibit increasing foamability until 38% particulates by weight in solution after which the bubbles collapsed due to particle agglomeration (Vijayaraghavan et al., 2006). It is not certain whether this particle content threshold is applicable to all types of particles and solutions since AD sludge usually contains less than 6% solids by weight. Due to these factors, similar to specific OLR thresholds, PS:WAS ratio could be specific to each digester with respect to foaming occurrence.

Mixing is also another factor that has been under debate for long with regard to AD foaming and performance. Excessive mixing seems to increase entrapment of gas bubbles in the liquid, similar to whipping, thereby generating foam (Campbell and Mougeot, 1999). Gas evolved during digestion diffuses into the bubbles incorporated by mixing/whipping/mechanical agitation thereby providing for possible nucleation sites for foam formation (Chiotellis and Campbell, 2003). Intermediate mixing seems to be most optimal with respect to foaming, but, optimal mixing in AD still remains a very ambiguous concept. The most important function of mixing seems to be to maintain a homogeneous environment in the digester, both to enhance digester performance and reduce foaming.

In this research paper, full-scale digesters were operated with modified parameters under real plant conditions to establish if critical threshold values for foam initiation and stabilization, if they exist, could be identified. The objective of this study was to quantify the influence of OLR, PS:WAS solids ratio, as well as mixing in full-scale AD foaming, which has not been reported in the literature, though has been studied in lab-scale digesters. Additionally, the effect of reduced mixing on digester performance and homogeneity has also been investigated.

2. Methods

2.1. Experimental procedure

The research included extensive plant evaluations via meetings with operation personnel, plant visits and review of historical data

Table 1
Classification of the causes of foaming.

Classification	
	Causes
Sludge feed characteristics	Surface active agents in feed sludge Foam causing filaments in feed sludge
Digestion process-related characteristic	Organic loading aspects – overload and inconsistent loading PS:WAS solids feed ratio to digester VFA production – Imbalances between the successive hydrolysis, acidogenesis and methanogenesis, upstream fermentation in the WWTP
	Contributors
Digester operating conditions	Gas production rate/withdrawal variations Temperature; pressure changes Mixing intensity and patterns
Digester configuration, shape and physical features	Digester shape and configuration Sludge withdrawal and gas piping