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### Citation for published version:

Kanu, IR, Aspray, TJ, Arthur, S & Adeloje, A 2015, Laboratory experiment to select variables for predicting foaming in anaerobic digester. in *Proceedings of the Infrastructure and Environment Scotland 3rd Postgraduate Conference*. Heriot-Watt University, Edinburgh, pp. 77-83.

### Link:

[Link to publication record in Heriot-Watt Research Portal](#)

### Document Version:

Publisher's PDF, also known as Version of record

### Published In:

Proceedings of the Infrastructure and Environment Scotland 3rd Postgraduate Conference

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## Laboratory experiment to select variables for predicting foaming in anaerobic digester

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### ABSTRACT

Foaming has been a persistent problem for the operators of anaerobic digesters. Efforts from various researchers have been channeled towards understanding the mechanism of foaming in anaerobic digester however; there has not been an explicit explanation for this phenomenon due to insufficient data on anaerobic digester foaming episodes. In this study, extensive literature review was followed by laboratory set up to monitor foaming in anaerobic digester. Secondary data collected from full scale wastewater treatment plant in combination with preliminary data obtained during the experiment were helpful in widening understanding on the mechanism of foaming in anaerobic digester. This informed the basis for variable selection to be used in developing a predictive model of anaerobic digester foaming. Using a semi-batch laboratory anaerobic digester, organic loading rate, surfactant concentration and biogas production rate were selected as the most sensitive variables as they correlate with anaerobic digester foaming

### 1. INTRODUCTION

Energy in sewage sludge (thermal, chemical and mechanical) has been estimated to about 2-4 times the amount of energy employed in wastewater treatment (Banfield & Littlejohn, 2013). Sludge production during wastewater treatment process occurs mainly in the course of primary treatment and secondary treatment thus they are usually known as primary sludge (PS) and secondary sludge (SS). An activated sludge (AS) wastewater treatment plant in Scotland with a population equivalent of 806,883 and inflow rate of 335,226m<sup>3</sup>/d generates sludge in the range of 640m<sup>3</sup>/d and 360m<sup>3</sup>/d of 5% thickened PS and SS respectively (Sourced data\_Seafield performance log). In United Kingdom, 1.1 Million tonnes of sludge is generated per annum with possible production of up to 110MW of electricity per annum through anaerobic digestion (WRAP & NNFC, 2015).

Though anaerobic digestion has been a well-established technology that has gone through a lot of development, nevertheless, foaming continues to pose a significant challenge to its operation. AD foaming is highly unpleasant with potential loss of active digester volume, structural damage, spillage, damage to the gas-handling system and subsequent reduction in biogas production (Kanu et al., 2015). When foaming occurs in an anaerobic digester (AD), it tends to reduce the production of gas by up to 40% (Moeller, et al., 2010). Issues relating to AD foaming date as far back as 1985 when a survey by the American Society of Civil Engineers reported half of the AD to have experienced foaming once during their operating

lives (Filbert, 1985). Attempts have been made by several researchers to resolve AD foaming without success as most remedies proposed are either site specific or not impracticable at a full scale AD (Niekerk et al., 1987; Barjebruch et al., 2000; Barber, 2005; Dalmau, et al., 2009; Ganidi et al., (2009); Moeller, et al., 2010; Subramanian, et al., 2012; Rodríguez-Roda et al., 2013; etc.). The complications encountered in solving the problem of foaming in AD stems from the fact that it is occurring in an environment of microbiological complexity requiring adherence to some specific operating conditions such as temperature, pH, organic loading rate, volatile fatty acid (VFA) to alkalinity ratio, etc to function optimally. However, in practice, it is difficult to consistently maintain such operating conditions and in some instances, it is not easy to ascertain deviations from the optimal operating conditions until the system has gone bad such as the occurrence of AD foaming. Thus, major deficiencies exist in the present knowledge of efficient remedial actions for mitigating foaming in anaerobic digesters (Subramanian et al, 2012). On this premise, modelling becomes a useful tool for monitoring treatment plants and is technically the most feasible and probably the least costly way of attaining a sustainable improvement in performance (Dalmau, et al., 2009; Rustum & Adeloye, 2012).

Modelling AD foaming has faced its own challenges over time. With regards to mechanistic model, there has been lack of basic knowledge on the mechanism of foaming in AD. Thus it is hard developing a kinetic relationship to explain foaming occurrence. On the other hand, modelling AD foaming using knowledge based techniques has faced the challenge of non-existing record of

foaming which was observed during the process of collecting data from AD operators. When foaming occurs, it cause so much nuisance that the operators are keen to resolve the foaming issue rather to measure and record the extent of foaming. Consequently, the only available AD foaming model faced this challenge. Dalmau et al., (2010) tried developing a knowledge based model of foaming in AD based on heuristic knowledge which on validation exhibited discrepancies such that the model showed relatively high foaming risk compared to the real data. To avert such circumstance in this study, an experiment was set up to monitor anaerobic digester foaming based on knowledge derived from existing literature on possible causes of foaming in anaerobic digester.

The aim of this initial phase of the experiment was to develop a better understanding of the mechanism of anaerobic digester foam and the link between the feed sludge characteristics and the operating conditions. This result will be crucial in selecting variables needed to develop a model to predict foaming in anaerobic digester. These variables will be used to calibrate and test the predictive model which will then form the basis of operating anaerobic digesters in a mode that reduces foaming.

**2. Existing knowledge in the literature**

There has been conflicting ideas on the factors that cause foaming in anaerobic digester with the deduction that some of these factors are site specific. Ganidi et al., (2009) noted that filamentous microorganisms were present in sludge and foam samples during bench scale batch digestion but their contribution to foaming was considered insignificant. Heard et al., (2007) suggested that the filamentous microorganism cells themselves do not cause foaming but they do produce biosurfactant that aids foam formation while they stabilise the foam by reducing the rate of drainage from the foam lamellae. Based on a survey carried out by Subramanian, et al., (2012) and Rodríguez-Roda et al. (2013) in U.S.A and Spain respectively, they concluded that the presence of foam causing filaments is the most common cause of foaming. In a survey and laboratory study carried out by van Niekerk et al. (1987), high ratio of waste activated sludge (WAS) to primary sludge (PS) was identified as one of the causes of foaming in AD. On the contrary a laboratory scale investigation of foaming in AD conducted by Ross and Ellis (1992) reported thickest foam in digesters receiving a low WAS to PS ration. They related foaming to high organic loading ratio (ORL), hydraulic retention time (HRT), high total volatile acid: total alkalinity ratios (TVA: TA), low volatile solids reductions and low pH.

Digester configuration	Digester operation	Digester feed quality
<ul style="list-style-type: none"> <li>• Digester shape</li> <li>• Sludge withdrawal and gas piping (Subramanian et al., 2012)</li> </ul>	<ul style="list-style-type: none"> <li>• Temperature (Barber, 2005)</li> <li>• pH (Kouglas et al., 2014)</li> <li>• Mixing intensity (Kouglas et al., 2014)</li> <li>• Volatile Fatty Acid (VFA) production (Ross and Ellis, 1992)</li> <li>• Organic Loading rate (Nafiska G., 2009)</li> <li>• Gas production rate</li> </ul>	<ul style="list-style-type: none"> <li>• Surface active agents in feed (Proteins, Lipids, Fat, Oil and Grease, detergents) (Nafiska G., 2009)</li> <li>• Foam causing filamentous microorganism in feed (Heard et al., 2008)</li> </ul>

**Figure 1: Factors contributing to foaming in anaerobic digester**

Notwithstanding the contradictions existing in the literature as regards the factors causing AD foaming, some of these factors were consistently present such as surface active agents, organic loading rate (OLR), VFA concentration, rate of biogas production, temperature, pH and mixing. Based on these consistent factors, an experiment was set up to monitor their influence in anaerobic digester foaming.

**3.0 Methodology**

**3.1 Description of the full scale sewage treatment works and sample collection**

Sludge samples used for the experiment were collected from a wastewater treatment plants (WWTP) in Scotland with features as shown in table 1. The WWTP had experienced series of foaming in the past. The level of foam is visually checked sporadically through a sight glass on top of digesters and monitoring the pressure relief valve. Since there is no means of measuring foam, continuous dosing of Antifoam(BURST) in the heating recirculation circuit has been the practice as it is deemed expedient for the efficient running of the digester. Nevertheless, the operators were not certain that the antifoam dose was the major reason for not witnessing foaming over the time as some other operational conditions such as reduction in organic loading rate had been adjusted within the time to curb the foaming incidence.

A plastic container was used to collect sludge samples daily from the digester feed tank and store them in a cold room at 4 °C until when needed.

**Table 1 : Features of field scale wastewater treatment plant**

<b>Inflow to WWTP</b>	
PE	806883
Flow rate to the works (m <sup>3</sup> /d)	335226
Chemical oxygen demand (mg/l)	297
Total suspended solid (mg/l)	168
Ammonia-nitrogen (mg/l)	17
Biological oxygen demand (mg/l)	116
<b>Digester configuration</b>	
No of cylinders	6
Diameter (m)	15
Height (m)	13.84
Volume (m <sup>3</sup> )	2446
<b>Digester feeding</b>	
Proportion of feed to Digester	36% thickened at 5.72% DS secondary sludge + import (Gravity belt thickener) and 64% thickened at 4.28% DS primary sludge (Picked fence thickener)
Frequency of feeding	20 min / 2 hours
Organic loading rate	2.8 kgVS/m <sup>3</sup> .d
<b>Digester operation</b>	
Temperature	35
pH	7.2, (5.7 feed)
VFA/Alkalinity	0.1 to 0.3
Organic loading rate	2.8 kgVS/m <sup>3</sup> .d
Mixing	Sludge recycling
Biogas (m <sup>3</sup> /d)	23255
Biogas (methane)%	63

### 3.2 Laboratory semi-batch anaerobic digester

Three semi batch reactors run in duplicate duplicates were fed with glucose and sludge sample using seed sludge from a non-foaming AD (Figure 2). One digester fed with glucose functioned as the control which is essential to ensure that the inoculum contain sufficient biomass to carry on the digestion process as well as an evidence to prove that the setup and procedure is suitable for anaerobic digestion and production of biogas.

Based on available literature for the onset of AD foaming, and the operating condition of the field scale AD, the organic loading rate (OLR) for the

digesters were varied from an initial start-up of 0.16kgVS/m<sup>3</sup>d to 2.8kgVS/m<sup>3</sup>d provided that the digester process-control parameters (pH, tVFA and Alkalinity) are within the desired limits. The temperature of the digester was maintained at 35°C using a thermostatically set water bath. A thermometer was placed in the water bath to monitor and ensure that the set temperature was maintained during the period of the experiment. Sample withdrawal will be followed by digester feed and manual mixing to be done once in a day.



**Figure 2: Semi-batch anaerobic digester set up**

### 3.3 Data collection

#### 3.3.1 Surfactants

Anionic, cationic and non-ionic surfactant were determined using Hach cuvettes; LCK 433\_Anionic Surfactants, 0.05-2.0 mg/l, LCK331\_Cationic surfactants, 0.2-2.0 mg/l and LCK 332\_Non-ionic surfactants, 0.2-6.0 mg/l. Total surfactant concentration was determined as the sum of the three. The procedure as applied in this experiment was carried out as per manufacturer's instructions after centrifugation of samples at 6000 rpm for 10 minutes.

#### 3.3.2 Organic loading rate

This was determined based on the volatile solid concentration of the feed sludge. Volatile solids and total solids were determined as stipulated in (APHA, 2012)

#### 3.3.3 Volatile fatty acid (VFA)

Montgomery et al., (1962) proposed an empirical method of determining organic acids based on colorimetric ferric hydroxamate. The method was carried out as per procedure stated in Montgomery et al., (1962) after centrifugation of the samples at 6000 rpm for 10 minutes.

### 3.3.4 Biogas production rate

Biogas was collected in a cylindrical glass as shown in figure 3. The difference in height is recorded on daily basis as well as the daily room temperature and atmospheric pressure. The volume of biogas taking measures to offset the effect of atmospheric pressure.

### 3.3.5 pH

Anaerobic digester can operate within pH range of 6.0 to 8.0. However, the ideal range should be within 6.8 to 7.2 for maximum biogas production. Unionised volatile acid at pH below 6.0 or unionised aqueous ammonia at pH above 8.0 becomes toxic to methane forming bacteria (WEF, 2007). The pH reading was taken immediately the samples were collected from the digester using a pH probe.

### 3.3.6 Foaming

The highest volume of foam observed in the digester was recorded. On collecting the feed sludge sample from WWTP, Alka-Seltzer © foaming potential test (Fryer, et al., 2011) was carried out to estimate the foaming propensity. This was recorded as the highest volume of foam observed.

### 4.0 Statistical analysis

Calculation of mean values, standard deviations and standard errors were carried out for all data obtained during the experiment.

### 5.0 Results and discussions

The experiment was scheduled to be repeated three times, however, as at the time of this report it was only the first set of the experiment that has been carried out for the period of 25/11/2015 to 03/11/2015.

During the period of the experiment, the digester was monitored and VFA to alkalinity ratio was in the range of 0.1 and 0.2. The pH range varied between 6.0 and 8.0. Thus based on these conditions, the digesters are considered to be operating at optimal conditions (Metcalf and Eddy, 2012).

It was observed that foaming occur within 1 hour of introducing the feed sample. This has been considered to be as a result of the increase in surfactant concentration in the digester from the feed sludge. The increase in biogas production due to methanogenesis taking place at the same time as increment in surfactant concentration results in emulsification of the gas bubbles by the surfactants thereby producing lots of foam. The observed foam lasted for some time and then starts to collapse.

As already illustrated by Ganidi et al (2011), it was observed in this experiment that organic loading rates below 2.5kgVS/m<sup>3</sup> did not result in foaming, while an initial increase in OLR results in a

significant increase in foaming but not subsequently. This could be attributed to the fact that microorganisms have the ability to adjust easily to their environment. Thus an initial increase affects the foaming potential but when maintained does not have much influence.

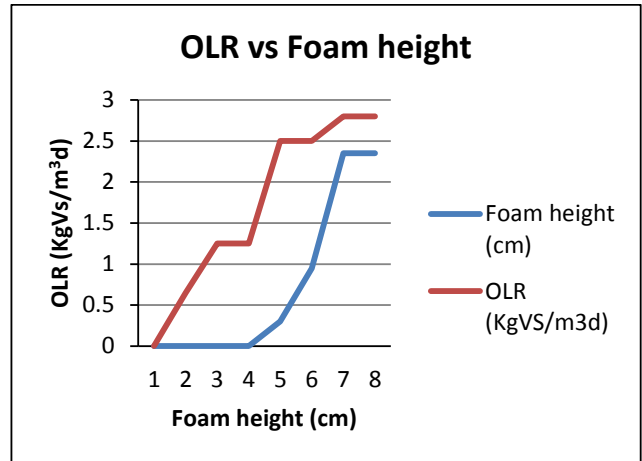


Figure 3: OLR Foam height

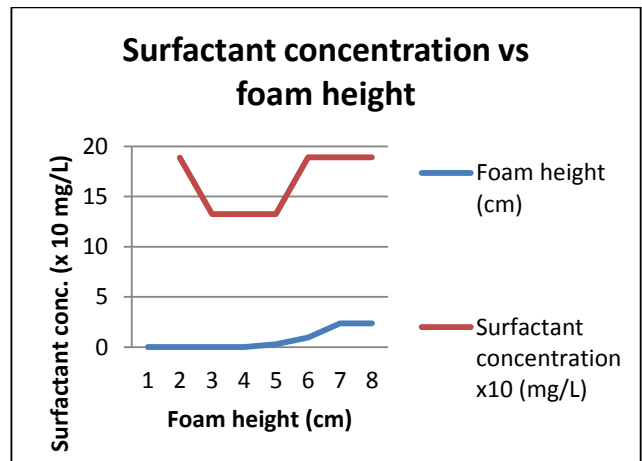
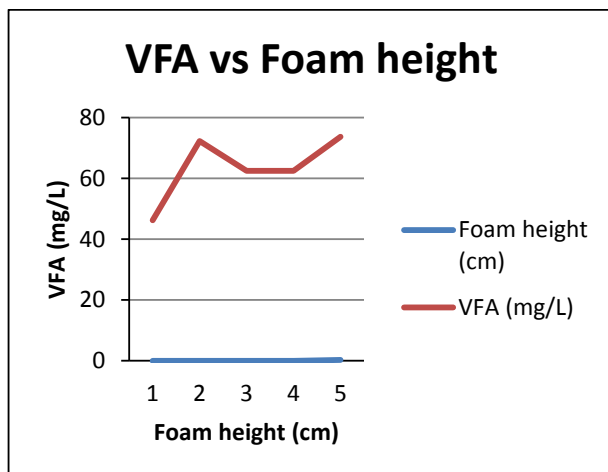


Figure 4: Surfactant concentration versus foam height

The surfactant concentration of the feed sludge was taken when collected from the WWTP. It was observed that an increase in surfactant concentration result to an increase in the foaming potential. Another observation was an increase in surfactant and soluble protein concentration with storage time. It is thought that as the sludge is kept for a longer time, digestion progresses thus the increase in protein and surfactant concentration which is supposedly a result hydrolysis.



**Figure 5: VFA versus foam height**

VFA concentration did not seem to have any significant influence on foaming as variations in the volatile acid concentration did not concur with variations in foaming as shown in figure.

Digester fed with glucose did not foam even when fed with a higher organic loading rate this is supposedly attributed to the absence of surfactant in the fed glucose. In addition, glucose is not a complex particle that needs to undergo hydrolysis thus there is no secretion of extracellular substance necessary for hydrolysis (Metcalf and Eddy, 2010).

## 8.0 Conclusion

In conclusion, the experiment was useful in developing a better understanding of foaming in anaerobic digester. Based on the preliminary data collected, surfactant concentration, percentage variation in organic loading rate, rate of biogas production and percentage of digester volume covered with foam were viewed as the significant variables necessary for a proper modelling of anaerobic digester foaming.

## 9.0 Future work

The next step will be to select a suitable model and carry on with laboratory experiment as to generate sufficient data to fit into the model. The model when developed will be useful in predicting anaerobic digester foaming such that dosing of antifoam will only be done when necessary

## Acknowledgement

I sincerely appreciate all the assistance from Veolia Water Uk for all their contribution in terms of providing sludge samples and historical data.

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