ATBEST

Viscosity characteristics of CSTR biogas processes as affected by substrate composition

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INTRODUCTION

Changes in substrate composition as a means to achieve a more efficient utilization of existing biogas facilities may induce shifts in viscosity of the process liquid and, consequently, problems with inadequate mixing, heat transfer, breakdown of stirrers, or foaming, leading to deteriorations in overall process performance (Nordberg and Edström, 2005; Lindmark et al., 2014).

Currently the total solids (TS) content is considered to be the most important process parameter affecting viscosity and is also used to predict it (Tang & Zhang, 2014). Despite this, there have been some indications that the relationship between TS and viscosity cannot be applied generally (Björn et al., 2012b). This study was carried out in order to evaluate the effects of several commonly monitored operational and process parameters as well as to elucidate the potential effects of different substrate types on anaerobic sludge viscosity.

METHODS

The viscosities of reactor fluids sampled from 28 mesophilic 5L laboratory-scale semi-continuous stirred tank reactors (CSTRs; 4 L working volume) for biogas production were investigated. The reactors were grouped into six categories based on their feedstock (Table 1), covering sewage sludge (SS), agricultural waste (AW), co-digestion (CD), forestry waste (F), food waste (FW), and paper mill waste (PM). Process performance of the reactors was monitored on a regular basis by measuring biogas production and methane content, volatile fatty acid (VFA) concentrations, pH, total solids (TS), and volatile solids (VS).

At the time of sampling for viscosity analysis, the studied CSTRs were operating at stable conditions to ensure that no potentially adverse effects on viscosity were caused by process disturbances, which might override its relationships with the examined process and operational parameters. A rotational rheometer was used for apparent viscosity analyses in accordance with the three-step protocol described by Björn et al. (2012a). The obtained viscosity values at shear rates of 20 s^{-1}, 100 s^{-1}, 300 s^{-1}, and 800 s^{-1} in interval 1 were selected for further analyses.

28 Mesophilic 5 L CSTR

Grouping based on substrate type

Table 1. Type of feedstocks and operational conditions of sampled mesophilic (37°C) laboratory-scale biogas reactors. OLR = organic loading rate; HRT = hydraulic retention time; TS = total solids; VS = volatile solids.

| Group	No. of reactors	OLR range (gVS/l/day)	HRT range (days)	TS range (%)	VS range (% of TS)	pH range
Agricultural waste (AW)	8	2.5 – 7.0	10 – 20	1.6 – 7.7	76 – 84	7.2 – 7-9
Co-digestion (CD)	10	2.1 – 6.7	16 – 31	2.4 – 12	41 – 83	7.1 – 8.0
Forestry waste (F)	2	3.5 – 4.5	20	6.7 – 7.7	87 – 93	7.2 – 7.6
Food waste (FW)	4	5.5 – 8.2	10 – 20	3.7 – 5.3	59 – 80	6.7 – 8.0
Paper mill waste (PM)	3	3.0 – 3.7	6 – 11	2.6 – 11	54 – 62	7.3 – 7.6
Sewage sludge (SS)	1	2.0	23	2.6	70	7.4
Total:	**28**	**2.0 – 8.2**	**6 –31**	**1.6 – 12**	**41 – 93**	**6.7 – 8.0**

Viscosity analyses
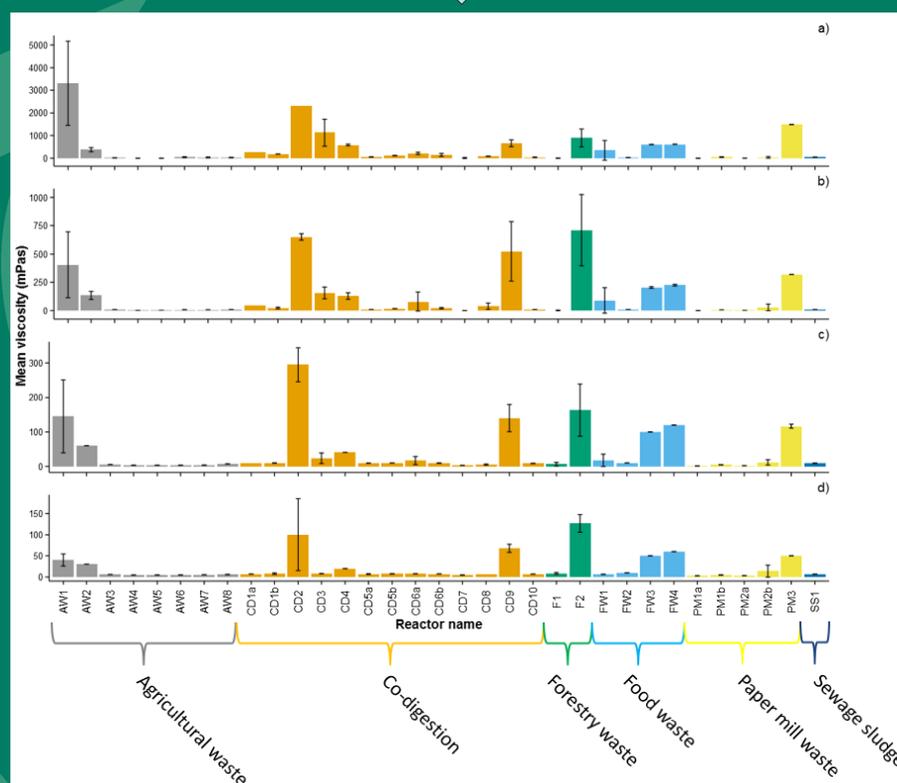
Figure 1. Viscosity values for the studied biogas reactors at shear rate 20 s^{-1} (a), 100 s^{-1} (b), 300 s^{-1} (c), and 800 s^{-1} (d). Cases where data was available for more than one point in time for the same reactor are marked with lowercase letters in the order of sampling. Note: Y axis scales were adjusted in relation to the maximum values and are thus different for each plot.
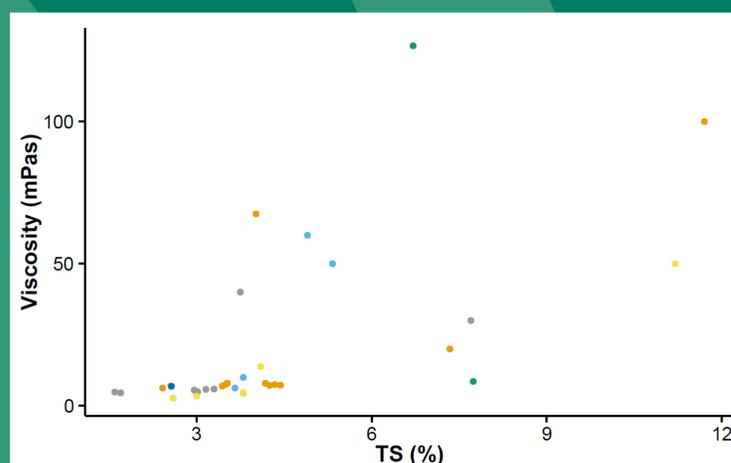

Figure 2. Relationship between limit viscosities (shear rate 800 s^{-1}) of the studied biogas reactor fluids and TS. The colours correspond to those on Figure 1 (grey = agricultural waste, orange = co-digestion, green = forestry waste, light blue = food waste, yellow = paper mill waste, dark blue = sewage sludge).

RESULTS

The results show that viscosities of reactors digesting different substrates may differ considerably but the variation within each group tends to be higher than between groups. The reactors exhibiting the highest limit viscosities were F2 (spruce-based waste; 125 ± 21 mPas), CD9 (food waste + glycerol + frying oil + fatty acids; 68 ± 10 mPas) and FW4 (milled cereal; 60 ± 0 mPas), while the ones exhibiting the lowest limit viscosities were PM1a (fiber sludge + biosludge; 3±0), PM2a (fiber sludge + biosludge; 3±0), and CD7 (fish sillage + soap + glycerol + bleaching clay; 5±0 mPas) (Fig. 1c) .

TS was the only parameter among those monitored in this study which was significantly correlated to viscosity at all selected shear rates (Pearson correlation coefficients of 0.5 – 0.7, p <0.01). Differences in TS could thus partially explain the observed differences among the majority of the reactors. Nevertheless, for several cases no such relationship was found: for example the F1 reactor, digesting forestry waste residue, had a substantially lower viscosity than F2 (just 9±2 mPas), although it had a slightly higher TS content (Figure 2). Thus, in cases like this TS cannot be seen as the driving force behind the observed differences in viscosity.

CONCLUSIONS

TS concentration is currently considered to be the key performance parameter affecting viscosity in CSTR biogas reactors. Our results suggest that in addition to TS, other factors affecting the viscosity of sludge in anaerobic digesters should be identified and taken into account when designing reactors for biogas production from organic wastes. This will in turn allow for development of more accurate models for viscosity prediction and their further implication for reactor design and operation. Thus, our next step will be to investigate the specific characteristics of individual substrates used during AD, as well as parameters, which are known to influence the viscosity in biogas reactors, e.g. nutrient deficiency and reactions by the microorganisms leading to changes in the amount and characteristics of extra polymeric substances and soluble microbial products.

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