

Anaerobic Co-digestion of Fat, Oil and Grease (FOG)/FOG deposits with Sewage sludge

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Significant advantages could be gained by increasing the biogas yield (BY) of sewage sludge anaerobic digestion (AD) by co-digesting sludge with FOG collected from sewers or grease separators at food service establishments (FSEs) or at WWTPs. However, accumulation of long-chain fatty acids (LCFAs) supplied to AD in FOG can cause cell membrane damage, substrate and product transport limitations, sludge flotation, and reduced cell permeability, inhibiting methanogenesis, leading to volatile fatty acid (VFA) accumulation, process acidification and instability, and ultimately a reduction in BY (Usman et al., 2020). FOG deposits form in-sewer through the saponification reaction between Ca and LCFAs (He et al., 2011), indeed, saponification with Ca can reduce the inhibitory effects of LCFAs on the AD process and significantly improve the BY (Wu et al., 2022). Anaerobic co-digestion (ACD) of SS and FOG has been investigated at high addition rates, in the range of 40-60% VS (Chow et al., 2020), but this represents a very significant fraction of the feed to a SS digestion process, which is very unlikely in full-scale operational practice. The effect of saponification with Ca^{2+} ions on AD of FOG has also been studied. However, a comprehensive characterization of FOG deposits is required to provide the fundamental understanding of how saponification reactions could be applied to improve BY and the AD performance of FOG and SS, under representative operational conditions. Here, we discuss results from experiments measuring the effects of different types of FOG and FOG deposit on the BY from ACD with SS.

In this study, two liquid plant-based oils and an animal fat were selected for investigation to provide contrasting patterns of LCFA composition, including: (1) olive oil (OO) with high monounsaturated fatty acid content; (2) sunflower oil (SO), which has a high concentration of polyunsaturated fatty acids; and (3) pork fat (PF), a representative solid animal fat high in saturated fatty acids. Saponification reactions were performed following Poulenat et al. (2003). Batch chemostat experiments were conducted in a temperature-controlled incubator at 35 °C to quantify the effects of FOG and FOG deposits on the BY and AD of SS, prepared from a controlled mixture of thickened primary and secondary sludges in a 50:50 ratio on a VS basis. The rate of FOG/FOG deposit addition was 2, 5 and 10 % on a VS basis. A micro-scale chemostat apparatus was developed to perform the ACD experiments, the reactor volume was 250 ml with a working volume of 200ml. Nitrogen purging was initially conducted for 5 minutes to establish anaerobic conditions. Biogas composition was measured by gas chromatography (Wu et al., 2022). The CH_4 content of biogas collected in the ACD experiments and from the sewage sludge only Control was consistently in the range of approximately 70-75 %.

Figure 1 shows the cumulative specific biogas yield (CSBY) from ACD of FOG/FOG deposits and SS. The results emphasized the highly dynamic effects of relatively small inputs of different types of FOG and FOG deposit, potentially representative of operational SS AD conditions in practice, which were both stimulatory or potentially inhibitory, depending on rate and type. A large increase in BY, equivalent to approximately 40 % compared to the Control, was obtained for OO with high monounsaturated fatty acid content, at the 10 % rate of VS addition. By contrast, the largest increase in CSBY for oil and fat rich in polyunsaturated fatty acids (SO) and saturated fats (PF), occurred at the smallest rate of addition (2%), and was up to 27 % relative to the Control, however, BY declined at higher rates supplied in SS, and, in the case of PF, no effect was observed at 10 % VS compared to the Control, indicating the potential inhibition of the AD process by larger rates of VS addition of fats containing poly and particularly saturated fats.

This behavior could be partly explained by the effect of anaerobic breakdown of polyunsaturated fatty acids (SO) to saturated fatty acids and the solubility of saturated fatty acids (PF), compared to monounsaturated fatty acids (OO). For example, degradation of the representative polyunsaturated fatty acid, linoleic acid, produced saturated fatty acids, palmitic and stearic acids (Lalman and Bagley, 2000), which have higher melting points (e.g., 61-62.5 °C for palmitic acid) compared to monounsaturated forms (e.g., 13-14 °C for oleic acid) (Elsamadony et al., 2021). Thus, the process response to poly and saturated fats could be attributed to their reduced solubility and, consequently, accessibility to LCFA-degrading acetogens under AD operating temperature conditions compared to monounsaturated forms.

Saponification further increased the CSBY of OO, to a maximum value of approximately 47 % at 5 % VS addition, which was optimal for the process, as CSBY decreased at the higher rate of 10 % SOO VS, although this still gave a large improvement in BY compared to the Control, of approximately 40 %. Nevertheless, the potentially supraoptimal response suggested a degree of process inhibition may be apparent at the highest rate of SOO supplied. Cation reaction also significantly mitigated the inhibitory effects of higher rates of PF on AD of SS, removing the lag compared to the Control at 10 % SPF VS and increasing the CSBY by approximately 24 %. However, this response was also supraoptimal as the largest CSBY for SPF was obtained at 5 % VS addition, equivalent to 28 % relative to the SS only Control.

The results showed that large rates of FOG addition to AD SS, suggested by some authors (Luostarinen et al. 2009; Girault et al. 2012), are both undesirable due to their potential inhibitory effects, as well as impractical at an operational level when the main objective is SS treatment. Bearing in mind that raw SS contains 9.6-15.6 % fat in the (Liu and Smith, 2022), the optimum rate of FOG addition in ACD with SS is in the range of 2 – 10 % of VS and is dependent upon the balance of the types of LCFA in FOG and the degree of saponification reactions taking place in sewer, or as a pretreatment for FOG. Further research will be completed to determine the mass balance of VS destruction, and of total fat and LCFA degradation to quantify FOG behavior and how saponification reactions may improve the BY and performance of ACD of FOG and SS. ACD results for saponified SO to be reported.

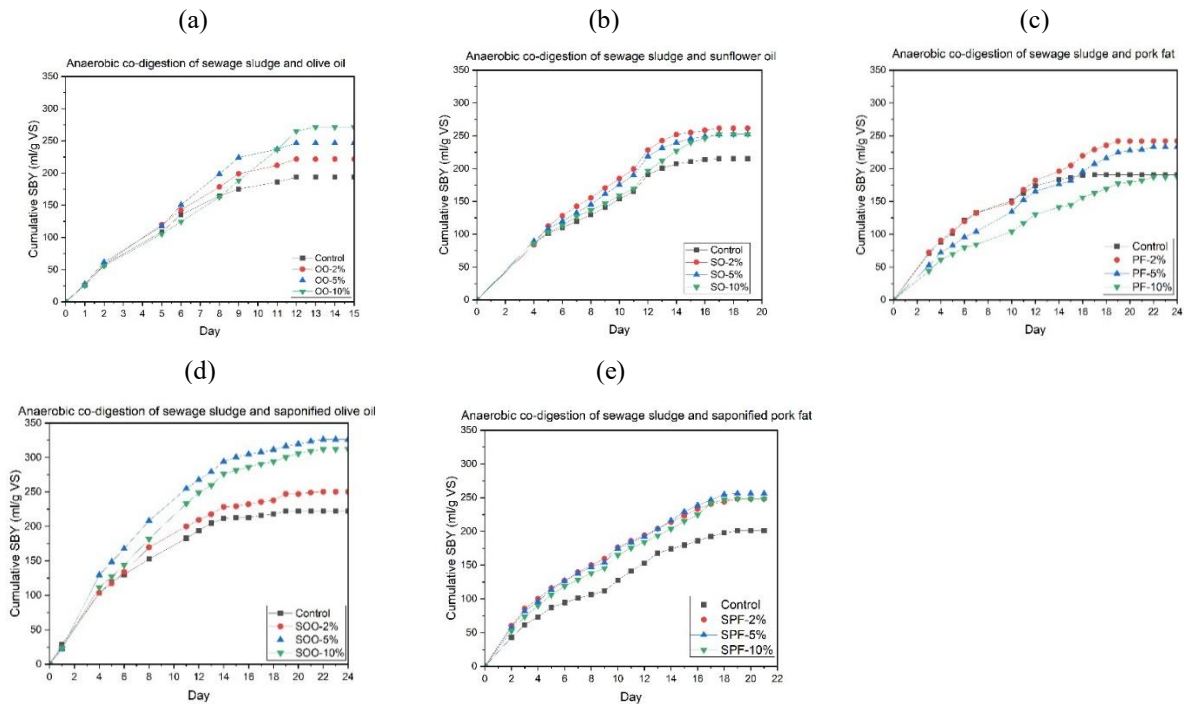


Figure 1. Mean cumulative specific biogas yield (SBY) of ACD of sewage sludge (SS) with (a) olive (OO), (b) sunflower oil (SO) (c) pork fat (PF), (d) saponified olive oil (SOO) and (e) saponified pork fat (SPF), n=3

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