PARALLEL DIGESTION OF SECONDARY AND PRIMARY SLUDGE

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Abstract

It is common practice in the UK Water Industry to blend surplus activated sludge (SAS) and primary sludge prior to conventional digestion. Within Thames Water, the majority of the anaerobic digestion plants operate with a blended feed sludge. The problematic of processing these two very different types of sludge is understood however little scientific information is available considering parallel digestion of SAS and primary sludge. The paper is a continuation of research, which suggested that digestion of SAS and primary together potentially compromise biogas production. The paper discusses digester performance criteria and reviews recent literature. Data derived from an improved research digestion facility that was operated with a pumped feed and on-line monitoring of operational parameters are reviewed. Two anaerobic digesters (60 litre volume) were operated in parallel and fed with SAS and primary sludge respectively. The results show that a SAS only digester could produce stable digestion performance with a relatively low biogas yield. Digestion of primary sludge may produce more biogas in comparison; however a primary digester may require close monitoring for early recognition of acidification.

Keywords

Surplus Activated Sludge, Primary Sludge, Anaerobic Digestion

Introduction

It is common practice in the UK Water Industry to blend surplus activated sludge (SAS) and primary sludge prior to conventional digestion. Within Thames Water, approximately 60% of the 180,000t/ds of SAS produced in 2007 were processed at anaerobic digestion plants that operate with a blended feed sludge of SAS and primary. Recent research suggests that digestion of SAS and primary together potentially compromises gas production and that gas production could be increased if SAS and primary were digested separately (Winter et al., 2009). Mininni et al. (2009) suggested that separate treatment of primary and secondary sludge could facilitate sustainable sludge management. Primary sludge accumulates pollutants and could therefore be considered for thermal treatment post digestion, whereas SAS contains the majority of the nitrogen and could be considered for land application.
**Surplus Activated Sludge (SAS)**

Surplus activated sludge has relatively low degradability, especially that resulting from the operation of activated sludge plants at long sludge ages (Carrrere et al., 2010). Winter et al. (2009) demonstrated this through the potential to produce Volatile Fatty Acids (VFA) from SAS derived from various sludge ages. Bolzonella et al. (2004) suggested a clear relationship between gas production during anaerobic digestion and solid retention time in the activated sludge process. The composition of SAS is fundamentally different to that of primary sludge because the activated sludge process results in biomass composed of microbial and extracellular polymeric substances (EPS). These are a complex mixture of biopolymers comprising polysaccharides, proteins, nucleic acids, uronic acids, humic substances, and lipids, amongst others. EPS is relatively recalcitrant to anaerobic digestion by nature (Carrrere et al., 2010). SAS has a low C:N ratio and may contain 40% protein (Gonzales, 2006). The theoretical gas production from SAS can be assessed based on elemental constituents. Various authors (Mininni et al., 2004; Horan and Lowe, 2008) showed that the biogas potential from SAS is relatively high, between 0.767 – 0.868 Nm³/kg VS, considering that the digestibility of SAS is commonly perceived as poor.

**Primary Sludge**

Primary sludge comprises of settleable solids derived from primary settlement tanks. It is mostly organic matter that is highly putrescible. Typically, primary sludge has a higher C:N ratio than secondary sludge. Gonzales (2006) showed that a primary sludge studied contained 17% protein but 27% carbohydrates. Biogas production from primary sludge could be between 0.842 – 0.968 Nm³/kg VS (Mininni et al., 2004; Horan & Lowe, 2008). However, Horan & Lowe (2008) suggest that sewage sludges are in general a poor feedstock for anaerobic digestion because it contains insufficient carbon and too much nitrogen. Barber & Lancaster (2009) calculated a theoretical gas yield from sewage sludge at 35°C as 1.07 m³/kg VS destroyed.

**Methodology**

The project was carried out using automated anaerobic digestion rigs developed by Glamorgan University. The design was adapted to enable robust data collation on a representative scale (60 litre reactor). Two anaerobic digesters, one fed with SAS, one with primary sludge were operated. The digesters were pump-fed several times per day without compromising the anaerobic environment. On-line monitoring of biogas was conducted through infrared gas cards for CO₂ and CH₄ followed by gas flow measurement through pressure differential mass flowmeter. The accuracy of the gas cards was confirmed with calibration gas at regular intervals and small adjustments were made if required. The mass flowmeter was calibrated with 100% CH₄ calibration gas and a factor of 0.848 was applied to correct for a typical biogas composition of 65% CH₄/35% CO₂. Gas flow calibration was carried out through a rotameter (100% CH₄) to avoid systematic errors in pressure differential through serial application of the on-line gas...
monitors. Digester temperature was controlled at 35°C ± 2°C. Digestion sequence and on-line monitoring was controlled through LabView 8.6 Graphical Programming (National Instruments, 2008) with bespoke Virtual Instruments written by Glamorgan University.

Figure 1 shows the digestion rig comprising of chilled feed tank, digester with external heating jacket and waste tank based on scales. Mechanical stirrers are used for digester mixing and to ensure homogenous sludge feed. The biogas line contains gas cleaning through H₂S scrubbing and gas drying to protect the on-line instruments.

![Image of automated anaerobic digestion rig](image)

**Figure 1:** One of the automated anaerobic digestion rigs

**Digester Feed**

SAS originated from a biological nutrient plant with a sludge age of 12 – 14 days. Thickened SAS was sampled once a week and transferred into the feed tank. To avoid blockages, thickened SAS was at times diluted with unthickened SAS to achieve a target DS of approximately 4%. Primary sludge originated from lamella primary thickeners. However at the time of the project, the site received significant amounts of primary sludge imports from various works. This resulted in inconsistent feedstock for the primary digester as discussed in subsequent sections. Primary sludge was gravity thickened once a week and transferred into the feed tank.

**Sampling and monitoring**

Feed sludge was sampled once a week for DS and VS. Digested sludge was sampled three times a week. On-line monitoring included digester temperature and pH. Gas monitoring comprised of
percentage CO₂ and CH₄ and gas flow (ml min⁻¹). On-line readings were taken every three minutes.

Results and Discussion

Table 1 gives an overview of digester performance data. SAS digestion data were collated after 3 HRT. The data of the primary digester were collated after the digester was re-commissioned following digester failure as illustrated in figure 5. The data of the primary digester can therefore not be seen as derived from a steady state digester. Table 1 indicates that the SAS digester performed steadily with an average VS destruction of 33% and a relatively low gas yield. Notable is the good gas quality with a higher percentage CH₄ than that from primary digestion. The primary digester, in comparison, produced more biogas however VS destruction and gas quality were relatively low considering primary sludge is perceived as a readily digestible feedstock.

Table 1: Average digester performance data

<table>
<thead>
<tr>
<th>Unit</th>
<th>SAS Digester</th>
<th>Primary Digester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °C</td>
<td>35.6</td>
<td>35.2</td>
</tr>
<tr>
<td>Operational Period Days</td>
<td>150</td>
<td>70</td>
</tr>
<tr>
<td>HRT Days</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Load KgVS/m³/d</td>
<td>1.67</td>
<td>1.48</td>
</tr>
<tr>
<td>VS destroyed %</td>
<td>33</td>
<td>41</td>
</tr>
<tr>
<td>CH₄ %</td>
<td>66.6</td>
<td>62.6</td>
</tr>
<tr>
<td>Gas flow Litre/day</td>
<td>17.9</td>
<td>40</td>
</tr>
<tr>
<td>m³/t DS fed</td>
<td>160</td>
<td>420</td>
</tr>
<tr>
<td>m³/t VS fed</td>
<td>210</td>
<td>540</td>
</tr>
<tr>
<td>m³/t VS dest.</td>
<td>660</td>
<td>1340</td>
</tr>
</tbody>
</table>

Digester Feed

Figure 2 shows the digester feed characteristics. It can be seen that the SAS feed was relatively consistent in VS content with some low DS due to thickening problems. The average DS was 3.5% and the average VS was 73%. In contrast, the primary sludge feed was more variable in VS and DS content. The average DS of primary sludge was 4% and the average VS 75% (second period of monitoring). The inconsistency of the primary feed contributed to the erratic volatile solids destruction of the primary digester (Figure 3).
SAS – digester feed

Primary – digester feed

Figure 2: Volatile solids and dry solids in the digester feed

Digester Performance

Both digesters showed high variability in VS destruction throughout the monitoring period. Figure 3 shows a three point rolling average of the VS destruction. The variability can partly be explained through the variability in feed VS that result in marked differences in the VS destruction calculated through the Van Kleeck method. The variability in the VS destruction from primary sludge digestion should be interpreted with caution as the digester failed (reduced pH, high VFA) after about 60 days and was then re-commissioned i.e. the primary digester never reached steady state.

SAS Digestion

Primary Digestion

Figure 3: Volatile solids destruction

The specific gas production is shown in Figure 4. It illustrates the relatively low but robust gas yield from SAS digestion. Figure 4 indicates an acclimatisation process throughout the initial three retention times (45 days) with an increasing gas yield from SAS digestion. The yield from primary digestion, not being in steady state conditions, is significantly higher but variable. It is obvious that the gas yield from primary digestion exceeds at times the theoretical maximum. However, a digestion system that has not achieved stable conditions may show artificially high specific gas production, because the decoupling between gas production and solids destruction is not compensated through long term stable conditions. The quantitative interpretation of the digester performance from primary sludge digestion should therefore be treated with caution.
Figure 4: Specific gas production in m$^3$/kg VS fed

Figure 5 shows notable data as the methane content of the biogas from SAS digestion was consistently higher than that from primary digestion. The average 67% CH$_4$ from SAS digestion indicates good gas quality. The curve for primary digestion shows that the digester commenced losing methanogenesis after about 30 days of operation and methane content in the gas dropped to less than 50% after 50 days. This was associated with a drop in pH in the digested sludge.

Figure 5: Percentage CH$_4$ in biogas

Gas flow profiles

To improve understanding of digestibility of SAS and primary sludge it may help to further analyse the gas flow profiles of the respective digesters. Figure 6 shows typical gas flow profiles from SAS and primary sludge digestion. SAS digestion results in a sharp initial decline of gas.
production after feeding (6hrs feed cycle), whereas primary digestion shows a greater volume of gas produced and a steady slow decline throughout a 8hrs feed cycle. The SAS digester received on that day a higher VS load (1.9kgVS/m$^3$) than the primary digester (1.6kgVS/m$^3$). The daily gas profiles should not be analysed in isolation however they confirm that, in general, the gas yield from primary digestion was higher than that from SAS digestion.

Figure 7 demonstrates how the gas yield from SAS digestion increased during the initial phase of the project. Two daily profiles from the beginning of the project (April) and after three further retention times (June), where the SAS digester received a similar load of approximately 1.9kgVS/m$^3$, show that the magnitude of gas produced increased during the project. The increase in yield at a similar load suggests that the micro-organisms adapted to the feedstock of SAS. Anaerobic digestion of sludge is a multi stage process consisting of hydrolysis, acidogenesis, acetogenesis and methanogenesis. The hydrolysis stage is the rate limiting step in the degradation of particulate organic compounds whilst methanogenesis is the rate limiting step for fermentation of soluble organics (Asaadi, 2008). However it cannot be seen from this analysis if the adaptation was caused through improved hydrolysis, or a combination of improved steps of anaerobic digestion.

![Figure 6: Typical daily gas flow profiles from SAS and primary sludge digestion](image1)

![Figure 7: Comparison of daily gas flow profiles from SAS digestion](image2)
Conclusion

Anaerobic digestion of SAS resulted in a stable digestion process with a relatively low gas yield. Digestion of primary sludge in comparison resulted in a higher gas yield however the digestion process was not stable partly because of an inconsistent feedstock. Digestion of SAS resulted in gas quality that is comparable with that from conventional digestion of mixed sludge. The gas yield from SAS digestion increased during the duration of the project, notably during the initial three hydraulic retention times, indicating that the microbial environment adapted to the SAS feedstock. The findings give confidence to operators and decision makers that conventional digestion of SAS is a feasible process route for sludge management.

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References


