A STUDY OF THE IMPACT OF AN INNOVATIVE INTERMEDIATE THERMAL HYDROLYSIS PROCESS ON THE PERFORMANCE OF ANAEROBIC SEWAGE SLUDGE DIGESTION PROCESS

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Abstract - Over the last 16 years, different sludge pre-treatment processes have been retrofitted to existing sewage sludge treatment plants in order to improve the sludge treatment process efficiency. Some of these pre-treatment technologies, notably the thermal hydrolysis process (THP), have greatly increased the sludge throughput and allowed more efficient utilisation of treatment assets without adversely impacting on the biology of sewage sludge anaerobic digestion process. Whilst the digester throughput is increased by utilising the THP process, the biogas yield has not increased significantly or the expected increase in volatile solid reduction (VSR) has not been realised. A novel sludge treatment process configuration was developed which consists of an intermediate step of thermal hydrolysis (ITHP), to study the reasons for this lack of expected performance. The results obtained from laboratory scale investigations showed that the ITHP process has resulted in an overall volatile solids reduction (VSR) of 66 - 68% in comparison with 55 - 60% VSR from the THP process. The overall biogas production from the ITHP process was found to be in excess of 450 m³/tonne dry solids (TDS) fed, compared with 350 and 387 m³/tds feed achieved from the conventional mesophilic anaerobic digestion (CMAD) and THP digestion configuration processes respectively.

Keywords: Anaerobic digestion; double digestion; Intermediate thermal hydrolysis process (ITHP); Sewage sludge

Introduction
The treatment and disposal of sludge is a problem of growing importance, representing up to 50% of the current operating cost of a wastewater treatment plant (Appeles et al, 2008; Spinosa et al, 2011). This cost could be offset and savings could be made by one or a combination of several measures including optimising the sludge treatment processes, investing in novel treatment technologies or changing existing process configurations. These steps should lead to more sustainable overall sludge treatment process.

Water companies in the UK utilise anaerobic sludge digestion assets in most of their Sludge Treatment Centres (STC); most of which were built during the 1940s through to 1990s (Noone G. P., 2006). Since then, the quantity of sludge has increased due to population growth, and improved treatment standards due to tightening of wastewater treatment consents as a result of increasing legislation. To deal with the ever
increasing amount of sludge and effectively use the assets available, a more effective way of sludge treatment is required.

The sludge recycled to land often contains about 60 – 66 % organic matter (Neutralac® Solution, 2011; Deryck H., 2005; Shana et al., 2011). This remaining quantity of energy rich sludge could be further subjected to anaerobic digestion using alternative technologies with the view of obtaining additional biogas and reducing the sludge volume for tankering, hence reducing the carbon footprint (Shana et al., 2011).

Existing sludge digestion technologies are not as efficient as they should be in reducing sludge organic matter and enhancing biogas production. In the CMAD process, between 35 – 45 % of the initial biodegradable organic matter in the sludge feed is converted to biogas (Hobson J. and Doorn M., 1999).

Even with more advanced anaerobic digestion technologies, such as the Thermal Hydrolysis Process (THP), around 50% of the initial biodegradable organic matter is recycled to land (Shana et al, 2011).

This lack of efficient sludge digestion technology warrants this present study which aims to investigate the concept of ITHP. The ITHP consists of a conventional MAD followed by THP and a second stage of MAD of the resulting sludge. According to Bougrier et al. (2007), there is no gain if high organic matter content sludge and easily biodegradable sludge is thermally pre-treated, but there is benefit to be gained if difficult to biodegrade sludge was thermally pre-treated and digested.

Throughout the 1970s and 1980s, numerous studies were conducted to determine the effects of thermal treatment on sludge digestion process as a way of enhancing the process efficiency. During this period, reducing digester volume and sludge Hydraulic Retention Time (HRT) were the drivers for further improvement in sludge treatment which later resulted in the development of processes such as the thermal hydrolysis process (Asaadi M., 2005; Riches et al., 2010; Panter K., 2008).

A review of the literature shows that up to the late seventies improved sludge dewaterability was the major emphasis for the use of thermal treatment (Camacho et al., 2008, Shana et al, 2011) and was the main reason for building hydrolysis plants. The review of historical developments in thermal treatment processes also indicates a change of emphasis from improved dewaterability to digestibility in terms of process and goals through time (Piat et al, 2007).

However, very limited information exists on the pre-treatment or co treatment of digested sludge and the re-digestion of already digested sludge. Burke D. A., (2000) conducted a study on pasteurisation and re-digestion of sludge using a process called anoxic gas floatation (AGF) unit. The process stabilised the digestion process and eliminated digester foaming. Volatile solid conversion increased from 57 to 73%.

Sundin A. M., (2008) conducted work using mechanical disintegration of digested sludge to investigate whether the disintegration process could increase the anaerobic volatile solid degradability. The author reported that a mechanical disintegration of the digested sludge achieved a 9% increase in the total gas production and recommended that disintegration of digested sludge could be applied in the recirculation flow of the second digester.

The present work, a novel laboratory scale sludge treatment process configuration was proposed and tested based on the concept of the THP process by utilising it as an intermediate step of thermal hydrolysis process (ITHP). This experimental work was conducted over last two and halve years, but this report contains the experimental data collected over a period of last 12 months.
Experimental Methods
The sludge feed used from this experimental work was collected from one of Thames utilities Waste Water Treatment Plant. Eight Mesophilic Anaerobic Digesters with a working volume of 8 litre capacity were used. Four types of digestion technologies were tested utilising duplicate digesters.

The purpose of this duplication was for performance check-up and to make sure the continuity of the experiment in case the digestion process goes wrong in one of the digesters. The following experimental set up was used:

- Control: re-digestion of diluted digested sludge cake (double digestion, i.e. MAD + MAD),
- Mesophilic anaerobic digestion of thermally hydrolysed raw sludge (conventional THP, i.e. THP + MAD),
- Conventional mesophilic anaerobic digestion of raw sludge (conventional MAD, i.e. CMAD) and
- Intermediate thermal hydrolysis process (ITHP) i.e. CMAD + THP + MAD

The feed for the THP and conventional MAD was prepared using 60% primary and 40% biological Surplus activated sludge (SAS) blend on weight by weight basis. The feed for THP was dewatered to a minimum of 16% dry solid.

The feed to the double MAD and ITHP was already site digested sludge and was also dewatered to a minimum of 16% dry solid.

The dewatered cake for both THP and ITHP configurations were separately hydrolysed using a laboratory scale THP. The laboratory scale reactor was run in the following order: (1) steam was introduced to a reactor containing sludge cake, 8 bar pressure and 170°C temperature was maintained and the cake was pressure cooked for an extended period of 15-20 minutes in order to elevate its temperature. After this initial period of heating, the reactor was locked for further 30 minutes. The hydrolysed sludge was flashed out into the flash tank. It was allowed to cool down to below 100°C and discharged in a container.

In addition the WRc Standard Biodegradability Test rig was used to assessing the VFA degradation potential, COD removal rate and sludge constituents’ degradation kinetics (Fernandes and Kimber, 1990). Batch digested sewage sludge composition in terms of total carbohydrates, proteins, lipids and ash was determined using the Weende Proximate Analysis, following the standard methods (British Standard, 1999). Detailed experimental methods and set ups used in this work were reported in a paper by Shana et al., (2011).

Results and Discussion
The results obtained from semi-continuous and batch laboratory digestion processes conducted for over 35 weeks are presented. The first part of this paper looked at the effect of digester HRT and organic load rate on the sludge digestion efficiency. In the second part, the sludge digestion kinetics assessed using sludge parameters, namely, COD, sludge VFA, carbohydrates and proteins are reported.

Effects of Hydraulic Retention Time (HRT) and Volatile Solid Load on sludge digestion process efficiency
In order to assess the effect of HRT on digestion process efficiency, initially all the digesters were run on 18 days HRT. After 17 weeks of the experiment, the digesters were controlled on VS load basis in order to provide all digesters except conventional MAD, with a similar amount of VS load.
Figures 1, 2, 3 and 4 show the variations in the HRT and volatile solid loads maintained during the experimental runs for conventional MAD, double MAD control digester, THP, and ITHP configurations.

Due to low VS content in ITHP and double MAD control digesters sludge feed, the HRT of these digesters were reduced to 16 days at the end of two weeks of digestion period. The aim of this reduction was to increase the digester volatile solid load in these two digesters to the level of CMAD and gradually to that of THP digester.

The HRT of THP and CMAD were kept at 18 days (figure 1). For the first 18 weeks of the experiments, the VS load for all digesters except CMAD was maintained between 2 to 4 Kg VS/m³/d; that of CMAD VS load was kept between 2-2.5 kg VS/m³/d (Figure 2). After 18 weeks of digestion period, the digester organic matter load of all digesters, except CMAD was gradually increased to 6 kg VS m⁻³ digester capacity in order to assess the impact of increased organic load on the digestion process.

After a number of weeks of digestion period, it was decided that the amount of sludge volatile solid fed to the first stage CMAD in the ITHP configuration required further increase and optimisation. The aim of this was to increase the amount of volatile solid load in the first stage MAD of ITHP configuration and double the organic loading rate of the CMAD. As a result, a high rate/high primary sludge digestion experiment was set up. The digester organic matter load of 2.5 kg VS per m³ used for the CMAD was gradually increased to 3.98 kg
The load was further progressively increased to 7 kg VS m$^3$ digester capacity (Figure 3). At this loading rate the digester did not switch to acid phase mode or foam. The hypothesis is that the remaining VS content of digested sludge from this high rate digester will be further effectively digested during the subsequent ITHP process. The ITHP configuration sustainably produced an overall VSR ranging from 60 - 68% against 40 - 55 % and 50 – 62% from CMAD and double control MAD digesters respectively (Figure 4). Abraham et al., (2003) further reported that during commissioning, the CAMBI$^\text{TM}$ process achieved an average of 60 -70 % VS reduction. It is important to note that the 70% VS destruction reported here was achieved when the sludge solid load was low. This finding is corroborated with what was noted during this work. The overall volatile solid destruction achieved from ITHP configuration was close to this maximum theoretical volatile reduction as reported by Li and Noike 1992, in Abraham et al., (2003). This finding clearly illustrates the benefit of using IHTP compared to conventional methods. During this trail, it was discovered, that the volatile solid destruction of THP was in the range of 57 - 60% when the volatile solid load of the digester was between 2 – 4 kg VS per m$^3$ digester capacity and was progressively reduced to a CMAD level of performance when the volatile solid load was increased to 5 – 6 kg VS per m$^3$ digester capacity. The VSR achieved from each digestion stage varied with increased volatile solid load. This finding was in line with published work of Abraham et al., (2003), where increased solid load reduced the digester VSR. Norli (2006) reported that the Cambi THP treated sludge volatile solid reduction in various sites and countries ranging from 54 – 62%; as reported in Table 1 below.

<table>
<thead>
<tr>
<th>Site</th>
<th>HRT (days)</th>
<th>VS (%)</th>
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<tbody>
<tr>
<td>Aberdeen, Scotland 2001</td>
<td>17.5</td>
<td>57.5</td>
</tr>
<tr>
<td>Dublin, Ireland 2002</td>
<td>15</td>
<td>62</td>
</tr>
<tr>
<td>Vaestved, Denmark 2000</td>
<td>-</td>
<td>54 - 62</td>
</tr>
<tr>
<td>ITHP, 2011 (this work)</td>
<td>16</td>
<td>60 - 68</td>
</tr>
</tbody>
</table>

Problems experienced in measuring %VS reduction in sludge in general and in hydrolysed sludge in particular were reported for instance by Panter (2008). It was stated that dissolved organics are lost during dry solids determination process at 105$^0$C and accurate measurement of volatile solid content was difficult. However, in this experiment it was then decided to use the volatile matter content of the reactor fed (raw cake) and assess the volatile solid reduction in the ITHP and THP digestion processes. This was latter found to be the best sampling option for assessing the performance of THP related sludge digestion processes. Another issue raised was that ash deposition in the digester during the digestion process makes the measurement of sludge dry solids content even less reliable (Panter K., 2008). The author then recommended that COD should be used as a good performance measure for THP pre-treated sludge. During this work, it was identified that measuring COD on a thick hydrolysed sludge and digested sludge carries similar limitations and difficulties. Figure 5 shows the weekly cumulative specific gas production per tonne of solid sludge fed to the digesters.
Figure 5: Specific gas production from ITHP treated digested sludge in comparison with THP and full scales conventional MAD

Average specific gas production rates of 490, 386, 350 and 360 m3/TDS fed were achieved from ITHP, THP, CMAD and double MAD digestion processes respectively. The use of HRT as a control parameter often caused the under or over feeding of digesters, therefore, causing variation in digestion process performance. Whereas, when the digesters were controlled by organic matter load a stable digestion process was obtained. Table 2 shows VFA, alkalinity and pH data collected from the digestion technologies assessed. The pH range of all digesters involved was within expected level (7.4–7.9).

Table 2. Results of VFA (mg/l), pH and alkalinity (mg/l) in raw sludge feed and all the digestion modes involved (N= 30 samples).

<table>
<thead>
<tr>
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<th>pH</th>
<th>Alkalinity (mg/l)</th>
<th>VFA (mg/l)</th>
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<tbody>
<tr>
<td><strong>Conventional MAD</strong></td>
<td>7.4 - 7.8</td>
<td>5500 - 6624</td>
<td>80 - 123.39</td>
</tr>
<tr>
<td><strong>THP Control MAD</strong></td>
<td>7.6 - 7.8</td>
<td>6800 - 7683</td>
<td>500 - 1194</td>
</tr>
<tr>
<td></td>
<td>7.7 - 7.8</td>
<td>5680 - 67447</td>
<td>60 - 113</td>
</tr>
<tr>
<td><strong>ITHP</strong></td>
<td>7.7 - 7.9</td>
<td>5400 - 6658</td>
<td>85 - 129</td>
</tr>
<tr>
<td><strong>Digester feed</strong></td>
<td>6.0 - 6.6</td>
<td>3500 - 5000</td>
<td>3800 - 6857</td>
</tr>
</tbody>
</table>

The pH range in well functioning low organic load CMAD suggested by Gerardi H M., (2003), was 6.8 – 7.2. The finding from this work showed that almost all of the digestion technologies used in this experiment produced higher pH values than the suggested range above.

Based on the data in table 2, it is clear that the higher pH range in the digesters was caused by the high alkalinity content of the digesting sludge. As the data from this work showed, that high organic load in a high rate digestion process could record an excess pH, but still function well given the fact that there was a sufficient VFA in the system to neutralise and maintain the digester environment close to neutral or low alkaline condition. This experimental work indicated that high pH of 7.6 – 7.9 do not always generate ammonia toxicity.

This work suggested that the stability of the digestion process can only be correctly assessed if all the data for pH, alkalinity and VFA are available. In the case of THP, the spot sampling of pH and alkalinity would only have caused undue concern due to high pH and alkalinity. This would have forced one to think that ammonia toxicity may be taking place in these digesters and would have prompted one to take an unnecessary corrective action plan or led one to a time consuming and costly digester reseeding procedure.

As a general rule of thumb, for high solid load digesters, high alkalinity, high VFA and pH should be expected and no action should be taken until the pH value goes beyond 9.2 when the ammonia goes from a liquid phase to a gas phase (Sjoholm O., 2003; Pearce P. 2006).
Conclusions
The ITHP digestion configuration achieved 6 – 8 percentage point more volatile solid reduction compared to standard THP digestion configuration and increased biogas production per tonne dry solid of sludge fed (16% additional biogas). The increased volatile solid reduction and biogas generation from the ITHP configuration was sustainable compared with the performance of the other digestion configurations tested. ITHP dealt well with an already digested sludge feed organic matter content, which is the hard to digest part and achieved enhanced overall sludge digestion process efficiency.

Future work strategy
Based on the results obtained to date, the following future tasks are proposed: Investigate the limits of ITHP process by undertaking targeted changes in digestion process parameters, continue the optimisation of the ITHP configuration process and consolidate the results obtained to date and investigate the kinetics of the processes involved to establish a better understanding of the mechanisms involved in improved sludge digestion process performance.

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