THE EFFECTS OF STEAM EXPLOSION AT DIFFERENT PRESSURE ON DIGESTIBILITY OF SEWAGE SLUDGE IN ANAEROBIC DIGESTION

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Abstract

Thermal hydrolysis process (THP) is a sludge pre-treatment process that provides improved anaerobic digestion performance. THP heats the sludge with steam at high pressure and temperature to produce more digestible sludge by hydrolysis. Currently there is a debate over whether steam explosion or hydrolysis time is the more dominant mechanism. This research paper investigates how steam explosion pressure influences the overall sludge digestion process. Analyses were carried out to ascertain the effects on biogas production, total COD, soluble COD, dry solid and volatile matter contents. The main objective of the project is to identifying the best THP conditions to optimise the performance on the overall anaerobic digestion process.

Keywords

Advanced Anaerobic Digestion, Steam Explosion, Thermal Hydrolysis, Anaerobic Digestion, Hydrolysing Time, Extent of Hydrolysis, Optimising Anaerobic Digestion, Optimising Thermal Hydrolysis Process

Background

This paper presents some preliminary results from the first of a four year collaborative research project between Thames Water and the Centre for Environmental Strategy at the University of Surrey; employing an engineering doctorate student, the primary author of this paper.

Introduction

In order to optimise anaerobic digestion, various methods have been used to pre-treat the sludge. Sludge treatment methods such as pre-treatment and co-treatment usually means processes which are combined with main biological treatment methods such as anaerobic or aerobic digestion. The primary objectives of these treatment methods are usually to increase bio-gas production, pathogen removal, odour removal, reduction in sludge volume and mass and reducing sludge viscosity for easier pumping and handling.

One of the most developed variants of anaerobic digestion process pre-treatment is thermal hydrolysis at high temperature. Generally, in thermal hydrolysis process (THP) sludge is treated with high pressure saturated steam at 7-8 bars followed by sudden pressure release. This causes the sludge at high pressure to undergo an explosive decompression. Generally the THP process runs for 30-40 minutes at temperature around 160-170°C. The most commonly used THP process has been developed by Cambi which uses three stages to hydrolyse sludge. During first stage, the sludge is heated in a pulper. The pre-heated sludge is then introduced in the reactor where it is heated to about 165°C and pressurised at 7bar for 30 minutes.

Hydrolysing at high pressure and temperature disintegrate organic macromolecules and floc particles so the resulting sludge is less viscous, more soluble, easier to pump and degrade in a conventional digester (Veolia 2011).

The higher biodegradability of the thermally hydrolysed sludge results in increased production of biogas. Biogas produced from anaerobic digestion consists of about 65% methane, 25% carbon dioxide, 4% oxygen and 6% other gases. The increase in methane production in anaerobic digestion process is advantageous, since it can be used in a CHP engine to produce energy and lower the operational cost of the plant. The increase of methane production resulting from this process has been linked to sludge COD solubilisation by linear correlations. Which means the more soluble the sludge is, the better it will be in producing methane. But research by Dwyer et al. (2008) has found that while increasing temperature above 150°C increased solubility, no increase in methane production was observed. At excessively high temperature of 170-190 °C the sludge biodegradability decreased, despite of having high solubilisation of sludge. The increased production of non-biodegradable soluble material was responsible for the increase in solubility, which did not result in high gas production. (Dwyer et al., 2008).

It has been also assumed that the THP increases sludge biodegradability due to steam explosion. There is limited amount of published literature addressing the effects of steam explosion on the extent of sewage sludge hydrolysis in THP process. This paper intends to present some preliminary results looking at the effect of how the steam explosion under different pressure conditions can affect the digestion stage of sewage sludge.

Methodology

At this stage of the project the aim was to investigate the effects of flashing pressure (following hydrolysis) on digestibility . Semi-continuous digesters, referred to as chemostats were used in this investigation. The set-up of the chemostats is as follows:

- Chemostats 1 and 2 – ITHP 1 and ITHP 2
- Chemostat 4 and 8 – THP 1 and THP 2
- Chemostat 5 – Conventional mesophilic anaerobic digestion (MAD)
- Chemostat 3 – High load MAD

For the duration of the experiments sludge from two different locations were used. The primary sludge and surplus activated sludge (SAS) for hydrolysis process was collected from Thames Water Sewage Treatment Works (STW) at Reading. From this point onwards we will use the term raw to refer to the mixture of primary sludge and SAS. Raw sludge is a mixture of 60%

primary and 40% SAS by volume. The raw sludge was also used as a control for Conventional Mesophilic Anaerobic Digestion (MAD) and High Load MAD. All this information is summarised in Table 1:

Table 1: Chemostat feed and Type of digestion

Chemostats Name	Types of Sludge	Type of Digestion
ITHP1 , ITHP2	Hydrolysed-digested sludge cake	I THP MAD
THP 1, THP 2	Hydrolysed Raw sludge	THP MAD
Conventional MAD	Raw sludge	Conventional MAD ~5% DS
High Load MAD	Raw Sludge	High Load MAD ~ 10% DS

It is imperative to mention that, digested sludge for the hydrolysis process was collected from Basingstoke STW. Collection of samples from two different STWs may limit the comparison of the results obtained, however, for the purpose of this study; the main objective is to compare the effect of different flashing pressure on the digestion stage for raw and digested sludge.

Thermal Hydrolysis Process (THP):

The methodology of this study was developed to be as representative as a real-life Cambi THP process and to introduce undesired variables that could potentially affect the THP process. A brief description of sludge preparation and hydrolysis procedure is given below.

Sludge Preparation: Raw (mixture of 60% primary and 40% SAS)

Raw sludge was collected from Reading STW was dewatered by squeezing the water out using a fine mesh clothe before hydrolysis by squeezing the water out using a fine mesh cloth. This method was extremely crude and therefore achieving the target sludge by dry solids of 16% was challenging. The average DS of dewatered sludge achieved was between 12 to 14%. The inability to achieve the targeted sludge DS impacted the digestion process. The effect are discussed in the results and discussions section.

Sludge Preparation: Digested

Digested sludge cake collected from Basingstoke STW contained 21-22% DS. The sludge was diluted to 16% DS to ensure the quantity of the feed sludge to the THP process was consistent. This was ensuring variation in sludge DS did not introduce another variable in the hydrolysis process, which might affect the results generated in the digestion process.

Hydrolysis:

In this experiment procedure similar to Cambi's THP process was described in the introduction was followed. In order to reduce the variables that could affect the experiment, various restrictions were introduced. In order to ensure hydrolysis procedure was consistent throughout the investigation period, the following measures were taken:

- The DS of the sludge being hydrolysed was always maintained at about 16% for digested sludge and 16% for raw sludge. The sludge weight was also maintained at 10kg for both types of sludge.
- The hydrolysis reactor was pre-heated for 2 hour before each hydrolysis cycle for ensuring the reactor temperature did not affect the hydrolysis time.
- Following pre-heat, sludge was fed to the reactor as quickly as possible to minimise energy loss through heat to the environment.
- After introducing the steam in the reactor, the pressure in the reactor was allowed to reach 8bar; from which point the time of 30 minutes was counted, before stopping the steam supply.
- After introducing steam to the reactor, the steam valve was kept opened at all times. In a full scale Cambi plant, steam demand is regulated. However, in the pilot scale THP rig this was not possible to follow, thus the steam valve was left opened. By leaving the steam valve opened, the amount of steam in each hydrolysis cycle count be kept consistent.
- The reactor pressure dropped to 7 bar (first study) and 5 bar (second study) before it was flashed to the flash tank.

Digestion stage:

Following hydrolysis the sludge underwent mesophilic anaerobic digestion (MAD) to investigate the impact of flashing pressures on the sludge digestion. The sludge was anaerobically digested using 10 litre chemostats. Working volume of all chemostat was 8 litres, with a hydraulic retention time (HRT) of 10 days. Each chemostat was run for 3 HRT (30 days) at the same flashing pressure. The chemostats were fed the same volume of sludge every day. The following parameters were monitored on a daily basis from all reactors:

- Gas volume
- Gas composition

Feed and digested sludge was analysed twice a week for the following parameters:

- Dry solids (DS%)
- Volatile solids (VS%)
- Alkalinity (mg/L)
- pH
- Volatile fatty acid (VFA) (mg/L)
- Total chemical oxygen demand (TCOD) (mg/L)
- Soluble chemical oxygen demand (SCOD) (mg/L)

The following parameters were calculated to analyse the chemostats performance:

- Organic loading rate (OLR) (kgVS/(m^3 Xday))
- Specific gas production (SGP) (m^3/TDS)
- Volatile solid reduction (VSR) (%) (Calculated using Van Kleeck method)

Results and Discussions

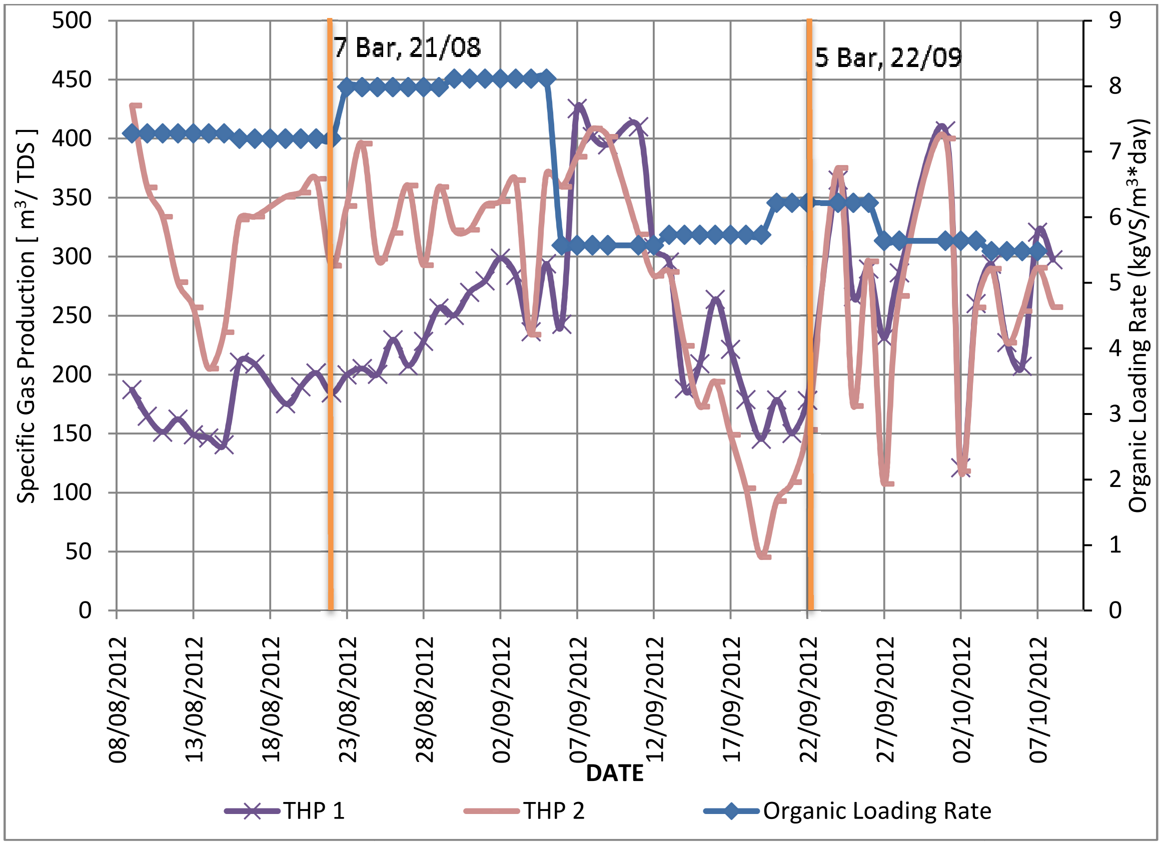

Figure 1: Specific gas production and organic loading rate of Hydrolysis of Raw sludge

Figure 1 shows the specific gas production (SGP) and organic loading rate (OLR) of hydrolysed raw sludge.

As depicted in Figure 1, sudden drop in organic loading rate occurred commencing 06/09/2012. The sudden drop of the organic loading was a result of poor dewatering of the raw sludge prior to hydrolysis. It was stated earlier that targeted dewatered sludge DS was 16%. However, the achieved dewatered sludge DS was around 10-12%. Therefore the feed sludge to the THP process contained more water. As the chemostats were fed volumetrically the dry solids contents dropped, hence causing the organic loading rate to drop.

The effect of this sudden shock to the chemostats was observed until 22/09/2012. Following this, the second stage of the study commenced, whereby hydrolysed sludge was flashed at 5bar.

Commencing 22/09/2012, the chemostats began to show signs of improvement with consistent SGP.

The average SGP of the hydrolysed sludge flashed at 7bar during the period of 21/08 – 22/09 was 251 m^3/TDS and 282 m^3/TDS for THP 1 and THP 2 respectively. Although the experiment is still on-going, but up to date initial results shown that flashing the sludge at 5bar during the hydrolysis process reduced in SGP to 231 m^3/TDS and 214 m^3/TDS for THP 1 and THP 2 respectively.

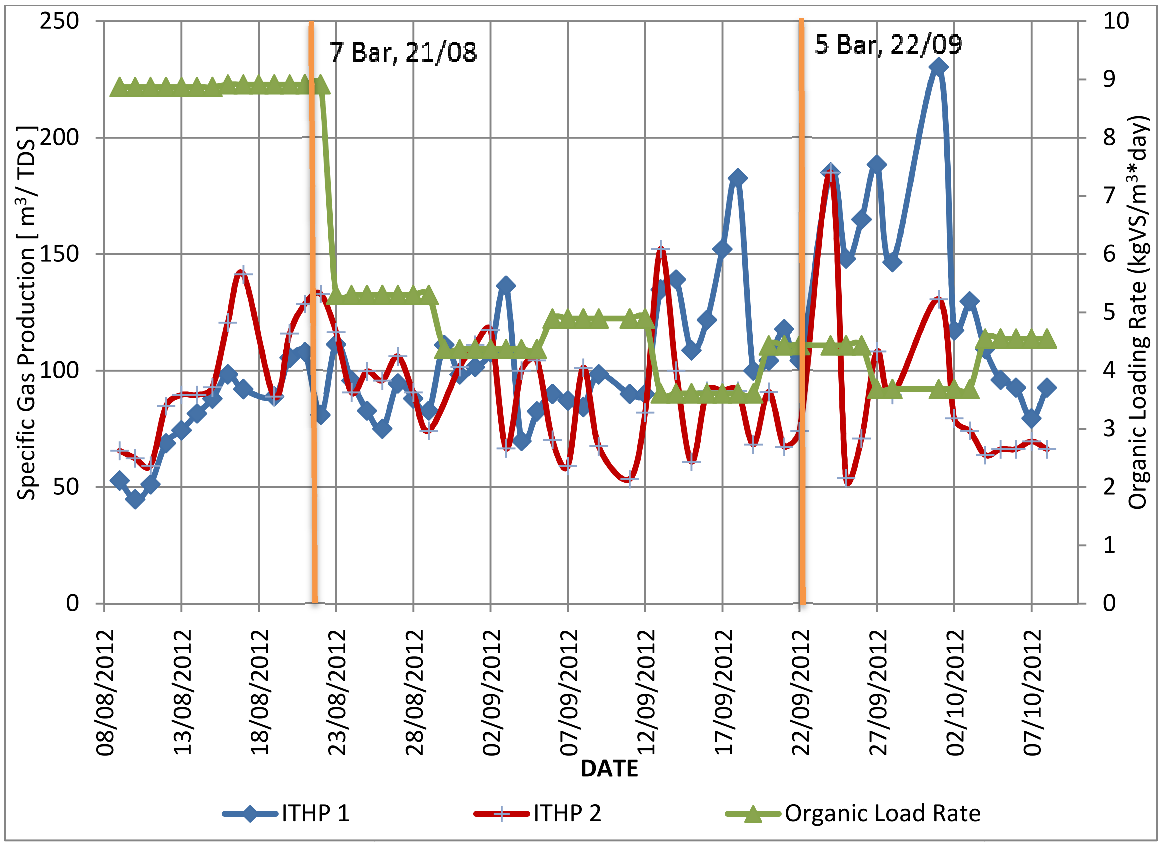

Figure 2: **Specific gas production and organic loading rate of digested hydrolysed sludge**

Figure 2 shows the SGP of the digested hydrolysed sludge of chemostats ITHP1 and ITHP2 versus time. The most notable observation from this graph is the sudden drop in organic loading rate from 9 kgVS/m3*day to 5 kgVS/m3*day. At organic loading of 5 kgVS/m3*day sludge was flashed at 7bar (introduced on 21/08/2012). Given that the HRT of this chemostats was 10 days, it was depicted in Figure 2 that SGP began to destabilised and inconsistent. This occurred from 02/09/2012 and the unstable nature of the SGP becomes more prominent from 07/09/2012.

The initial drop of the OLR (on 21/08/2012) was due to the change in the hydrolysis procedure. As mentioned previously the digested sludge was collected from Basingstoke STW where it is dewatered mechanically to 22% DS. Before the new procedure for this experiment was implemented, that cake at 22% DS was hydrolysed without prior dilution. This produced thicker hydrolysed sludge. Thicker sludge contained more dry solids which resulted in such high organic loading initially.

It is also imperative to mention that prior to hydrolysis and re-digestion, the sludge was anaerobically digested at Basingstoke in order to produce biogas. The SGP reported here was calculated using gas production data from the chemostats only and does not take previous gas production from the plant into account.

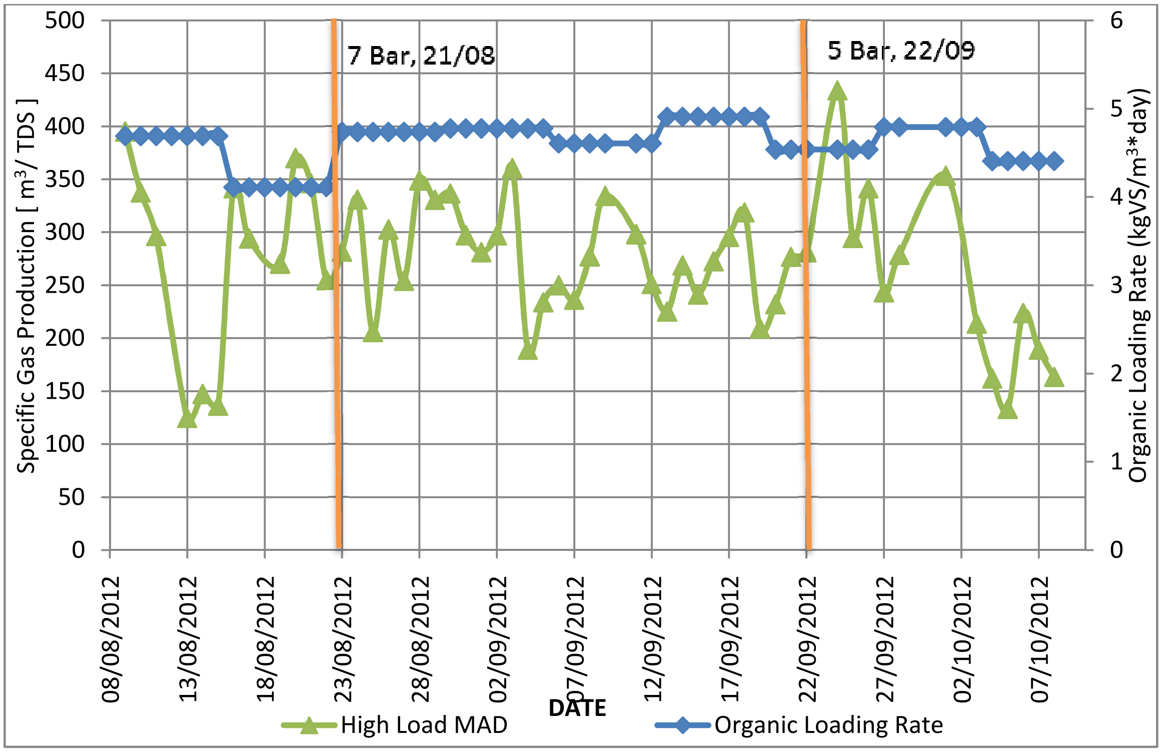

Figure 3: **Specific gas production and organic loading rate for High Load MAD**

Figure 3 depicts the SGP and OLR of high load MAD over time. The SGP values for this chemostat are very stable until 24/09/2012. From that point onwards, the values started to decrease. The same trend can be seen in Figure 4. Given that both Conventional MAD and High Load MAD used the same raw sludge from the Reading STW, it was thought that the sudden reduction was due to low quality raw produced by the wastewater treatment process.

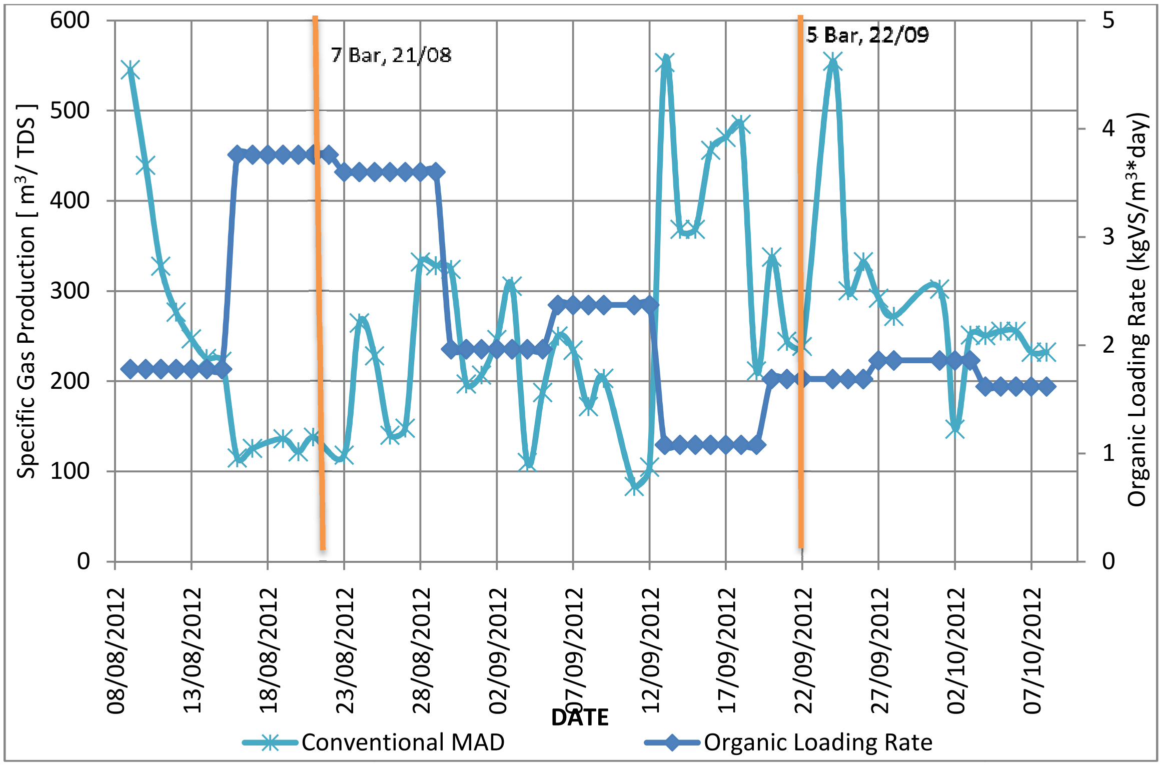

Figure 4: Specific gas production and organic loading rate for Conventional MAD

Figure 4 displays the same parameter for Conventional MAD process. Conventional MAD was the control for this study and was fed with sludge produced from Reading STW without any pre-treatment or dewatering. The OLR of this chemostat was very unsteady and was totally dependent on the STW performance.

Table 2: Average specific gas production and Volatile solid reduction for different types of sludge digestion process

Types	Average Specific Gas Production (m^3/TDS)			Average Volatile Solid Reduction (%)		
	Before*	7 bar	5 bar	Before*	7 bar	5 bar
ITHP 1	76.94	104.12	129.74	17.65	23.67	27.58
ITHP 2	85.60	108.62	123.69	20.18	21.48	31.90
THP 1	171.45	250.51	230.93	39.22	43.90	44.78
THP 2	315.17	281.81	214.00	42.15	44.20	47.17

Before* = SGP and VSR values before the new procedure for this experiment was implemented

Table 2 summarises the average specific gas production and average solid destruction for both ITHP MAD and THP MAD process for the total period at both 5 and 7 bar. The volatile solid reduction (VSR) was calculated using the Van Kleeck method. The values are displayed in Figure 5 and 6.

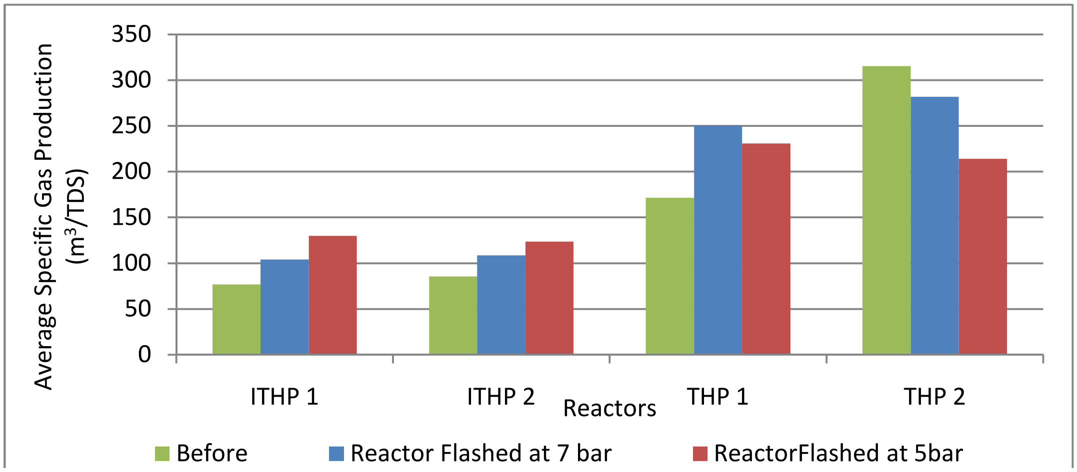

Figure 5: **Overall average specific gas production of different digesters at different flashing pressure**

Figure 5 shows that for the digested hydrolysed sludge flashed at 5 bar increased the overall average specific gas production. However while for the hydrolysed raw sludge showed the contrary. The SGP decreased when flashed at 5 bars compared to flashing at 7 bars. The reasons for this remains to be investigated.

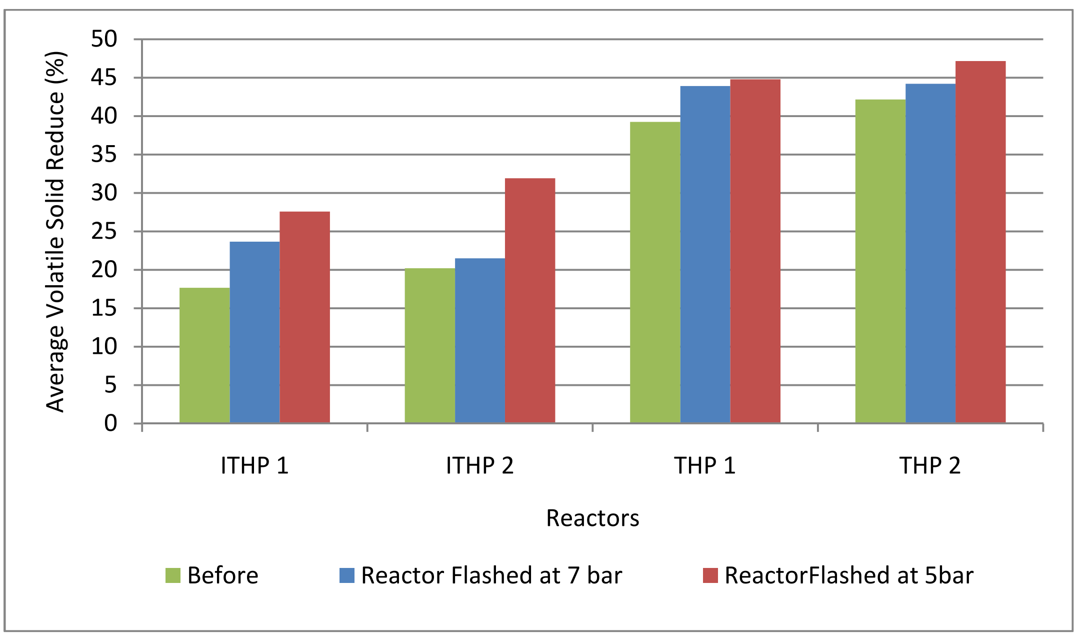

Figure 6: **Overall average specific gas production of different reactors at different flashing pressure**

The change in the hydrolysis procedure and flashing pressure increase the volatile solid reduction rate for both digested and raw hydrolysed sludge. The VSR rate increases even further when the sludge was flashed at 5bar.

The next step of the planned experimental work is to flash the reactor at 3bar.

Conclusion

The preliminary results showed that:

- The average specific gas production for digested hydrolysed sludge increased as the flashing pressure decreased.
- The average specific gas production for the hydrolysed raw sludge decreases as the flashing pressure decreased.
- The volatile solid destruction rate for both digested hydrolysed and raw hydrolysed increases with decreased flashing pressure.

The opinions expressed in this paper are those of the authors and not necessarily those of Thames Water or University of Surrey.

Acknowledgements

The authors would like to thank the following individuals for their support during the project:

Manocher Assadi
Mattew Pook
Stavros Kellari
A. Otto
Liliane Auwerter

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