EXTENDED SLUDGE RETENTION PROCESS WITH SLUDGE RECIRCULATION FOR INCREASING BIOGAS PRODUCTION AT ANAEROBIC DIGESTION

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ABSTRACT

In 2008 IVL Swedish Environmental Research Institute and KTH Royal Institute of Technology jointly took over the responsibility for the R&D facility for wastewater purification Hammarby Sjöstadsverk. The facility consists of different pilot-scale lines for wastewater and sludge treatment/handling.

One of the projects that have been initiated at Sjöstadsverket aims at increasing the biogas production by optimized the digestion process. The overall goal is to increase the degree of digestion to over 60% and reducing the hydraulic retention time from 20 days to 10 days. To achieve this an extended solids retention process with an anaerobic mesophilic digestion combined with a sludge recirculation was used. The effluent from the digester was dewatered with a centrifuge and recirculated to maintain a relatively high solid content within the digester.

The results obtained are very promising. The hydraulic retention time was reduced to 10.6 days while the sludge retention time increased to 218 with 78.7 % reduction of VS, organic content in the sludge. However, OLR, organic load rate to the digester, of 0.69 kg VS/(m^3·day) was relatively low compared to sludge digestion at Henriksdal wastewater treatment plant with 1.5 kg VS/(m^3·day). In order to increase the load external sludge had to be taken from Henriksdal wastewater treatment plant. At increasing the OLR from 2.05 to 3.15 kg VS/(m^3•day) measurement of biogas production indicated that biogas yield was enhanced by 73%, with a maximum production of 14.5 m3/day and methane content was merely promoted by 10.5%, to the highest value of 63%. Specific gas production (SGP), was observed to be 0.65 Nm^3/kg VSin.

BMP, Biochemical Methane Potential tests of gas potential was made to determine the effect of sludge reprocessing on the activity of the methane bacteria. BMP tests are normally used to measure in batch digestion the anaerobic degradability of a given substrate, which are mixed with an inoculum, source for methane bacteria. In this study digested sludge from Sjöstadsverket and Henriksdal was used as inoculum; IS and IH. At BMP tests with an inoculum to substrate ratio of 2:1 based on VS content, production of CH_4 (in NL, Normal Liters) with IS was 0.29 NL/gVS and with IH 0.33 NL/gVS. In a second BMP tests with the same amount of substrate and inoculum for each sample, IS had a higher methane potential than IH, 0.31 NL/gVS and 0.29 NL/gVS respectively. All BMP tests with Sjöstadsverket inoculum produced a larger volume of total accumulated gas. This imply that methane bacteria grown in the digester at Sjöstadsverket can endure a higher OLR and that the digested sludge has high potential to produce biogas.

KEYWORDS

Anaerobic digestion, biogas, BMP biochemical methane potential, methane, mesophilic, OLR organic load rate, specific gas production, total solid and volatile solid. sewage sludge

INTRODUCTION

In 2008 IVL and KTH jointly took over the responsibility for the R&D facility for wastewater purification Hammarby Sjöstadsverk. The facility consists of different pilot-scale lines for wastewater and sludge treatment/handling.

One of the projects that have been initiated at Sjöstadsverket aims at increasing the biogas production by optimized the digestion process. The overall goal is to increase the degree of digestion to over 60% and reducing the hydraulic retention time from 20 days to 10 days. However, for increasing the biogas production the sludge retention time has to be increased. Methane bacteria are slow growing and a too short hydraulic retention time will make the faster growing fermentative bacteria to make an accumulation of volatile fatty acid which will decrease the pH-level and prevent the biogas production. The hydraulic retention time determines the volume needed for digestion and shortening the hydraulic retention time gives that smaller digestion volumes are required.

The extended sludge retention process gives the possibility for separating the hydraulic and solids retention times in anaerobic digester by using recycle of dewatered sludge (Perry, 2004). Figure 1 shows a sketch of process configuration for extended sludge retention process compared to normal digestion. The digested biosolids can be separated by using thickening equipment. The AGF (Anoxic Gas Flotation) process uses biogas to separate and recycle microorganisms, volatile fatty acid to the digester. The material that shall be recycled methane bacteria and degradable organic material has smaller density than water. The separation can also be made with centrifuges.

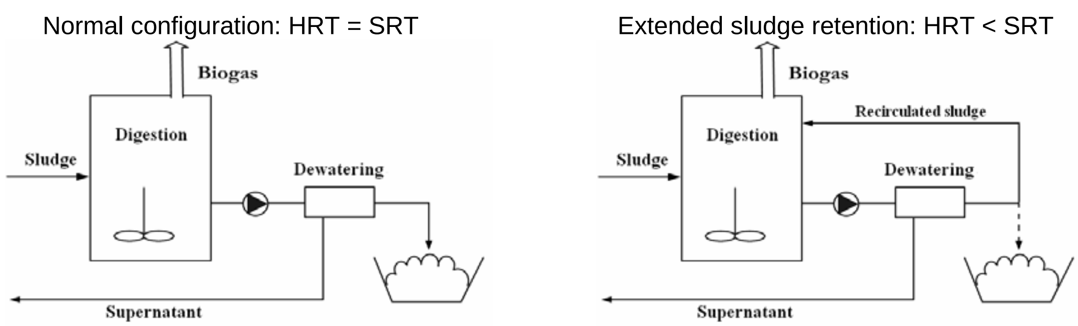

Figure 1. Shows a sketch of process configuration for extended sludge retention compared to normal digestion.

The full-scale test with dewatering with centrifugation and recirculation of dewatered sludge has been made out at a municipal wastewater treatment work in Japan (Yasui et al., 2005). The centrifuge was operated with and without addition of polymer depending on whether the thickened sludge was recycled to the anaerobic digester or discharged for disposal. When thickened sludge was discharged the centrifuge was operated without addition of polymer coagulants. Inorganic solids having higher density were concentrated by the centrifuge to the thickened sludge, leading to withdrawal of an inorganic-rich sludge. The organic-rich decantant having lower density was returned back to the anaerobic digester. When the thickened sludge was returned to the digester, the centrifuge was operated with addition of polymer coagulants.

In the project at Sjöstadsverket centrifugation was chosen as separation method. Centrifuges are equipment that is used at many wastewater treatment plants and introduction of a process with dewatering and recirculation can be made by changing the configuration of the process. Centrifugation of digested sludge is normally made with focus on maximizing the TS, Total Solids, content in the dewatered sludge. However, the main focus at the centrifugation for recycling is to minimize the lost of methane bacteria and degradable organic material with the reject water. That means that types of polymers must be used that binds the organic content to the separated solids and produce a reject water with minimum organic content, VS, Volatily Solids.

Process was run in two phases. During phase 1 is the dewatered sludge recirculated. When too much inert material is accumulated in the digester the reject water can be recirculated and the sludge is taken out as waste sludge. In this phase the centrifugation is to be made with focus on maximizing the TS total solids content in the dewatered sludge.

The work was performed through master thesis and divided in three steps:

- Selection of suitable polymer for dewatering (Forsberg, 2011)
- Test of achieved SRT and HRT in pilot plant (Forsberg, 2011, Huang, 2011)
- BMP, Biochemical Methane Potential tests of gas potential to determine the effect on the activity of the methane bacteria (Rodriguez, 2011).

MATERIAL AND METHODOLOGY

Pilot plant scale anaerobic digestor

Figure 2 shows a sketch of the process configuration. The anaerobic digester tank there the biogas is produced is placed outdoor is cylinder-shaped (Figure 3). This stainless-steel-made tank, with a radius of 1.8 m has a volume of 12m^3. The digester is filled to 3.25 m, which gives an active volume of 8.27 m^3. The digester has an external heater which also improves mixture. Figure 4 shows the decanter centrifuge used for sludge dewatering. The degree of digestion was calculated both on the digestion chamber but also on the whole system (figure 5). The temperature of the reactor is kept between 35-38 °C and the digestion works under mesophilic conditions. At some occasion the temperature became 41 °C higher due to problem with the heater.

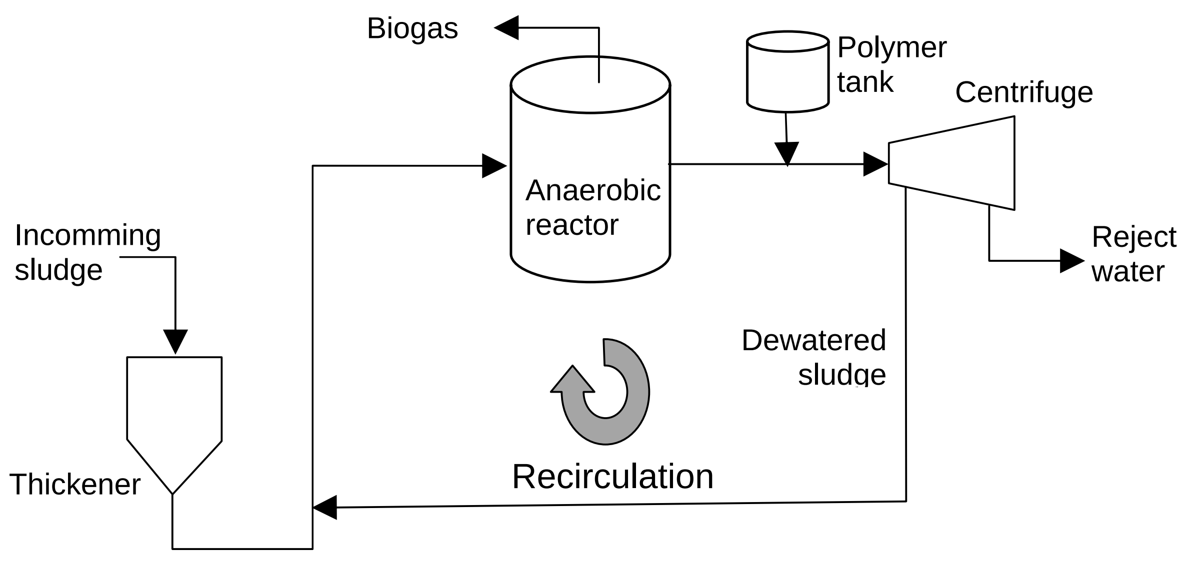

Figure 2. The process configuration.

Figure 3. Anaerobic processes at Hammarby Sjöstadsverk with the sludge digestor chamber.

Figure 4. Decanter centrifuge for sludge dewatering.

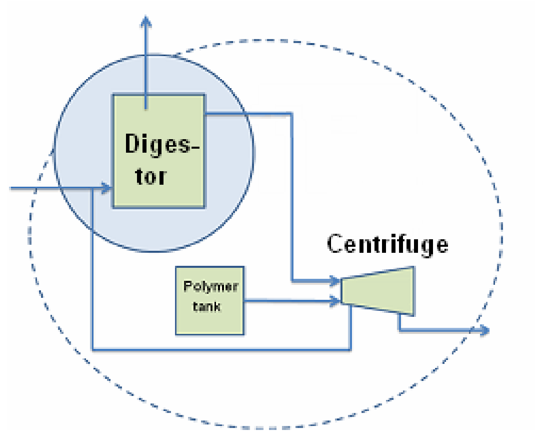

Figure 5. Boarders for the two system on which the degree of digestion was calculated.

BMP, Biochemical Methane Potential test

Figure 6 shows a schematic view of the Biochemical Methane Potential (BMP) test unit. The batch digestion tests for methane potential were using Bioprocess Control's AMPTS equipment. The instrument setup can be divided into four units (Fig. 4). Unit A is a thermostatic water bath with 15 400 ml bottles mixed by a slow rotating agitator, there the biogas is produced. In each reactor substrate is placed together with inoculum. Unit B is a CO_2 fixing step, there biogas produced in each reactor goes through an individual vessel containing an alkali solution (NaOH). Gases such as CO_2 and H_2S are removed by chemical reactions and only CH_4 passes through unchanged. The alkali solution is 3M NaOH solution with a pH indicator (Thymophthalein) added to monitor the sufficient OH- concentration in order to effectively strip CO_2 and H_2S. Unit C is the gas volume measuring device which works by the principle of liquid displacement. When a defined volume of gas is accumulated, the flow cell lifts open and a bubble of gas is emerging through the water. After the flow cell has opened and clicked back down, a digital pulse is generated and recorded in the computer program. Each flow cell is connected to Unit D, this is a data acquisition unit that together with a computer; records, analyzes and displays the resulting methane production.

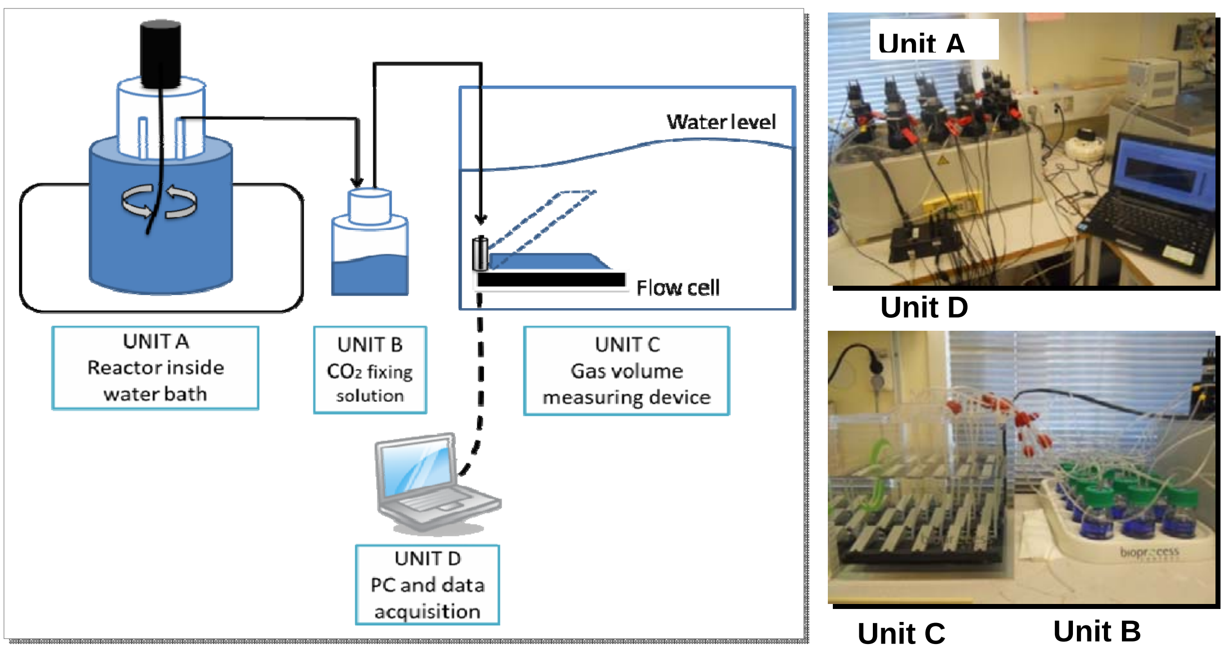

Figure 6. Schematic view of the Biochemical Methane Potential test unit.

RESULTS

Pilot plant scale anaerobic digestor

Flow, TS and VS for the process during 11 weeks test period from week 44 2010 to week 2 2011 is shown by table 1 (Forsberg, 2011). Table 2 shows parameters achieved for the digestion in comparison with Henriksdal WWTP, which is the largest treatment plant in Stockholm situated close to Hammarby Sjöstadsverk. So far the results obtained are very promising. The hydraulic retention time HRT was reduced to 10 days while the sludge retention time SRT increased to 200 days and the degree of digestion was 78.7 %. However the organic loading rate OLR was low compared to a conventional sludge digester at Henriksdal WWTP. Further experiments was therefore made in order to verify the good effect also with increasing load.

Table 1. Flow, TS and VS for the process during 11 weeks (week 44, 2010 to week 2, 2011).

	In to digestor	**Out from digestor**	**Added polymer**	**Dewatered sludge**	**Reject water**	**Unit**
Flow	0.816	0.803	0.150	0.074	0.852	m^3 / day
Total Solids TS	0.86	2.39		23.38	0.11	%
Volatily Solids VS	0.71	1.58		15.68	0.053	%

Table 2. Achieved parameters for the biogas process (Forsberg, 2011) and a comparison with Henriksdals WWTP calculated from Hellström et.al. (2008).

Parameter	**Hammarby Sjöstadsverk**	**Henriksdal WWTP**	**Unit**
Hydraulic retention time HRT	10.6	19.7	Days
Sludge retention time SRT	218	19.7	Days
Degree of digestion	78.7 [1] 21.6 [2]	49.5	%
Methane content	56.1	65.6	%
Specific gas production	0.78	0.47	Nm^3/kg VS
Specific methane production	0.44	0.31	Nm^3/kg VS
Gas production	0.51	0.66	$Nm^3/(m^3 \cdot day)$
Methane production	0.29	0.43	$Nm^3/(m^3 \cdot day)$
Organic loading rate OLR	0.69 [3] 2.08 [4]	1.5	kg $VS/(m^3 \cdot day)$
Total Solids TS in	0.86	4	%
Volatily Solids VS in	0.71	3.32	%

[1] Calculated for entire system.
[2] Calculated for the digestion chamber.
[3] Calculated on incoming sludge
[4] Calculated on incoming and recirculated sludge

In the second 73 day test period in beginning of 2011 efforts was made to increase the load (Huang, 2011). In the beginning of the 70 day test period the OLR was about 1 $kgVS/(m^3 \cdot day)$ and sludge has to be taken from Henriksdals WWTP in order to increase the OLR of the digester to about 3 $kgVS/(m^3 \cdot day)$. The digester succeeded in withstanding an OLR up to 3.15 $kgVS/(m^3 \cdot day)$. Biogas production measurement indicated that gas amount was enhanced to 1.7 $Nm^3/(m^3 \cdot day)$ when OLR was increased from 2.05 to 3.15 $kgVS/(m^3 \cdot day)$. However, the specific gas production was highest wit about 1 Nm^3/kg VS then the OLR was 2 and decreased to 0.5 then the OLR was increased 3.

BMP, Biochemical Methane Potential test

In the BMP tests the activity of the methane bacteria growing in the digester was compared with methane bacteria from Henriksdal WWTP. Outcoming sludge taken from the digester was used as inoculum; IH, digested sludge from Henriksdal and IS, digested sludge from Sjöstadsverket, and incoming sludge used at Sjöstadsverket as substrate. In the first test the ratio of inoculum to substrate was 2:1 based on the VS content of substrate and inoculums. In the second test the same volume of substrate and inoculum was used. Table 3 shows TS total solids and VS volatile solids for inoculum and substrate and table 4 ml used inoculum and substrate. Due to the high VS content of IS compared to IH more inoculum and less substrate was used for IH in test 1 while for IS more substrate and less inoculum was used. Test 1 was made in triplicate and the mean value was calculated while test 2 was made in duplicate. Four bottles was used for blank test with 400 ml inoculum without substrate, 2 with IS and 2 with IH. Blank test are used to measure the methane production from the inoculum, which is subtracted to calculate the methane production potential of the substrate. 6 bottles for test 1, 4 bottles for test 2 and 4 bottles for blank test gives total 14 bottles.

Figure 7 shows the methane potential measured in Normal Liter per gram of VS Volatile Solids in added substrate during the 20 days test period. In test 1 Henriksdal sludge produced more biogas from the substrate than Sjöstadsverket sludge while in test 2 Sjöstadsverket sludge produced more biogas than Henriksdal sludge. The results demonstrated that using IS, Sjöstadsverket sludge as inoculum, produced a larger volume of total accumulated gas (measured in Normal Liters) then IH. However the methane potential which is calculated in Normal Liters per gram of VS added, is higher for sample IH test 1 than IS test 1. This may suggest that inoculum, originating from Sjöstadsverket, can operate at a higher organic load rate and still perform efficient anaerobic digestion of organic material.

Table 3. TS, total solids, and VS, volatile solids, of inoculum and substrate.

	TS (%)	VS (%)
Inocolum		
Sjöstadsv. IS	4.70	3.12
Henriksdal IH	2.32	1.43
Substrate	1.53	1.30

Table 4. Volumes of used inoculum and substrate.

	ml inoc.	ml substr.
Test 1		
Sjöstadsv. IS	182	218
Henriksdal IH	258	142
Test 2	200	200

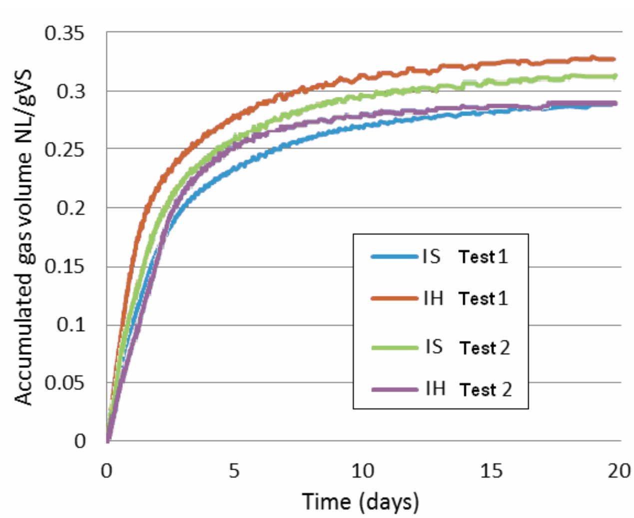

Figure 7. Methane potential measured in Normal Liter per gram of VS Volatile Solids in substrate.

SUMMARY

The results obtained are very promising. The hydraulic retention time was reduced to 10.6 days while the sludge retention time increased to 218 with 78,7 % reduction of VS, organic content in the sludge. At increasing the OLR from 2.05 to 3.15 kg VS/(m^3·day) measurement of biogas production indicated that biogas yield was enhanced by 73%, with a maximum production of 14.5 m^3/day and methane content was merely promoted by 10.5%, to the highest value of 63%. Specific gas production (SGP), was observed to be 0.65 Nm^3/kg VS_{in}. All BMP tests with IS produced a larger volume of total accumulated gas. This imply that methane bacteria grown in the digester at Sjöstadsverket can endure a higher OLR and that the digested sludge has high potential to produce biogas.

Independently of the trial outcomes will the project result imply a change in the future sludge digestion process! If a high degree of digestion is obtained at a higher load, the implication is that the digestion process can be optimized while at the same time the reactor volume can be reduced. However, if a high degree of digestion is obtained only at low loads, which is indicated by the results from increased OLR, the digestion process can be designed so that traditional pretreatment processes with dewatering can be replaced with the ones tested in the project and by that increasing the biogas production.

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