Optimisation Activities at Stockholm Site - Status of Biogas Production at Henriksdal Plant 2000 - 2005

Daniel Hellström, Stockholm Vatten VA AB
Lena Jonsson, Stockholm Vatten VA AB
Lina Vallin, Svensk Biogas

R nr 6, augusti 2009

STOCKHOLM Vatten

Biogas as vehicle fuel - **Ma**rket E**x**pansion to 2020 Air Quality

Contract Number: 019795

OPTIMISATION ACTIVITIES AT STOCKHOLM SITE - STATUS OF BIOGAS PRODUCTION AT HENRIKSDAL PLANT 2000 - 2005

Deliverable D2.15 – Report

Work Package 2 – Production

		Approved by the
Author(s):	*Daniel HELLSTRÖM (SVAB)* *Lena JONSSON (SVAB)* *Lina VALLIN (SB)*	☒ External reviewer ☒ Work Package Leader ☒ Project Coordinator ☐ European Commission
Reviewer(s):	*Björn HUGOSSON (STO)*	
WP/Task No:	*WP2/Task 2.5*	
WP Leader:	*Mats RYDEHELL (BRG)*	

Keywords: Biogas, production, digestion, biomethane, wastewater treatment, sewage, optimization, Henriksdal, Stockholm Water Company

Abstract: Anaerobic digestion at Henriksdal's wastewater treatment plant has been evaluated over a 6-year period. The evaluation has identified a number of measures that can be undertaken to utilise the potential better and ensure a stable process. Changing to serial operation should increase biogas production by 5 - 7%. A longer solids retention time as a result of thickening of sludge gives slightly increased biogas production, but mainly a substantial reduction in the heating requirement. Another advantage of a reduced sludge flow is that volume is released to receive more external organic matter. A combination of an extended retention time and a transition to serial operation should yield an increase of just below 10% with the organic load unchanged. The greatest potential for increased biogas production lies, however, in increasing the organic load on the anaerobic digesters. The introduction of various lysis methods may possibly lead to an increased degree of degradation and increased biogas production. Besides the above measures, present and planned measures also need to be conducted to reduce the leakage of methane from digested sludge and biogas handling. Such measures mean that an even greater proportion of the energy content of the biogas produced is utilised.

		Date of Delivery to the EC	
Document Identifier:	del_2.15_SVAB_v1	**Contractual:**	30/06/2009
Status:	Version 1 – Draft		
Number of pages:	81		
Dissemination Level:	PU	**Actual:**	30/08/09

Document history

When	Who	Comments
02-06-2009	SVAB	Swedish version presented to Site Leader
03-07-2009	SVAB	English draft completed and sent to Work Package Leader
	SVAB	Updated draft
07-2009	ACIES	Review and minor changes
08-2009	SVAB	Complete data analysis
08-2009	LMCU	Final review before sending

Review

Questions	Answer	Comments
(i) Accordance of the deliverable with the Description of Work	☐ Yes ☐ No	
(ii) Readability of the deliverable	☐ Yes ☐ No	
(iii) Overall project deliverable consistency	☐ Yes ☐ No	

Table of Contents

1. Glossary

AD – anaerobic digester

BOD – biochemical oxygen demand [mg/l]

CH_4 – methane

COD – chemical oxygen demand [mg/l]

CSTR – continuously stirred tank reactor

DM – dry matter [%]

EAS – excess activated sludge

EOM – external organic matter

FS/ROI – fixed solids/residue of ignition [% of DM]

GC – gas chromatography

HRT – hydraulic retention time [d]

Kjel-N – Kjeldahl nitrogen [mg/l]

LNG – liquefied natural gas

LOI/VS – loss of ignition/volatile solids [% of DM]

NH_4-N – ammonium nitrogen [mg/l]

Ntot – total nitrogen [mg/l]

Nm^3 – normal cubic metre, see definition below [Nm^3]

pe – population equivalents

PS – primary sludge

PW – presedimented wastewater

ROI/FS – residue of ignition/fixed solids [% of DM]

SRT – solid retention time [d]

SS – suspended solids [mg/l]

VFA – volatile fatty acids [mg/l]

VS/LOI – volatile solids/loss of ignition [% of DM]

WWTP – wastewater treatment plant

Biogas/Raw biogas	Gas produced by anaerobic degradation i.e. digestion of organic matter. The methane concentration of this raw biogas is 50-75%.
Biomethane	The raw biogas that has been purified to a methane concentration of 95-98 %.
Biomethane filling station	The gas station where vehicles are filled with biomethane.
Compressed natural gas	Upgraded raw biogas for use in vehicles, also called biomethane. The raw biogas has been purified to a methane content of 95-98%.
Digested sludge	Sludge leaving the anaerobic digesters.
Excess activated sludge	Sludge removed from the biological treatment.
Fermentation	Energy-producing metabolism involving a sequence of oxidation/reduction reactions to break down organic matter.
Gas production	The biogas production calculated per time. Unit in this report: [Nm^3/d].
Hydrolysis	The biochemical process with degradation involving the breaking of a chemical bond and the addition of water.

Mesophilic temperature	The temperature (37°C) at which mesophilic organisms have their most favourable growth rate. The interval for growth could be set to 20°C - 45°C.
Methane gas	Gas with 100% methane concentration.
Normal cubic metre	The quantity of gas that takes up the volume of one cubic metre at a pressure of 1 atm and a temperature of 0°C.
Organic load	The quantity of organic matter supplied to the anaerobic digesters per time. Unit in this report: [kg VS/d].
Primary sludge	Sedimented sludge, in the pre-sedimentation tanks, from incoming water at the wastewater treatment plant.
Retention time	The mean time for which a material is in a reactor.
Specific gas production	Gas production calculated per charged quantity of VS to the anaerobic digesters. Unit in this report: [Nm^3/kg VS].
Specific organic load	The quantity of organic matter supplied to the anaerobic digesters per reactor volume and time. Unit in this report: [kg VS/($m^3 \cdot$ d)].
Thermophilic temperature	The temperature (55°C) at which thermophilic organisms have their most favourable growth rate. The interval for growth could be set to 45°C - 67°C.

2. Introduction

The comprehensive aim of the BIOGASMAX project is to reduce the use of fossil fuels for transport in Europe by increasing the use of biogas. The project is to proceed for nearly five years and show that biogas is a technically, economically and environmentally sound alternative as a fuel for vehicles. By providing good examples and devising solutions for switching to biogas, the project is to increase the use of biogas. In addition, the total production and use of biogas for operation of vehicles is to increase.

The project comprises eight different work packages: management, production, upgrading, distribution, use, evaluation, implementation and dissemination of results. The project is conducted in seven urban regions in Europe (Lille, Stockholm, Bern, Gothenburg, Rome, Torun and Lombardy) and includes 32 participating organisations from 8 countries (FR, SE, DE, NL, IT, CH, UK and PL). The project total budget is approximately 17 million EUR with a contribution of just under 7.5 million EUR from the EC.

This subpackage forms part of "work package 2", referred to below as WP 2, which specifically aims to optimise the production of biogas. This is, among other things, intended to be achieved through increased use of various substrate mixtures, by increasing the efficiency of and developing the operation of existing facilities and by drawing up guidelines and instructions for biogas plants. Stockholm Water Company's (named Stockholm Vatten) role in the project is, in conjunction with Svensk Biogas, to devise and apply tools for increased biogas production at Stockholm Water Company's Henriksdal plant. This subproject will therefore investigate the efficiency improvement potential offered by existing plants and possibility to influence biogas production through the selection of substrate composition. In addition, innovative methods for better substrate use, and thus increased specific biogas production, will be investigated.

3. Aim

The demand for biomethane as vehicle fuel has increased considerably during the last years. It is therefore important that the producers of biomethane respond to this increased interest and try to scale up the production. A cost-effective way is to make use of the existing plants and optimise the process to produce more biogas.

The main aim of the project is to show how biogas production at Henriksdal can increase by ten per cent at the existing plant through process optimisation, the use of innovative methods or the addition of external material. This is done via collaboration between Svensk Biogas and Stockholm Water Company. In this part of WP2, a description of the current situation for biogas production and proposals for efficiency improvement measures for Henriksdal will be provided. This covers:

- A survey of the anaerobic digesters (retention time, operation and maintenance of stirrers, review of checklists).

- A survey of sludge handling from the biogas production perspective.

- Identification of other factors which are important for biogas production.

In parallel with the description of the current situation, a number of innovative methods, such as pre-treatment of the sludge with cell lysis, enzyme addition, mechanical processing, pressure changes and/or use of membrane technology, will be investigated.

The report aims to document and investigate biogas production at Henriksdal's wastewater treatment plant in Stockholm. Through this investigation, further knowledge about the process is expected to be gained and passed on to internal and external interested parties. The report is expected to investigate results from production during the period from 2000 to 2005 inclusive, and to discuss operating scenarios on the basis of results achieved. In addition, the aim of the report is to share operating experience with various operators within the biogas arena and members of the Biogasmax project.

4. Henriksdal's wastewater treatment plant

Stockholm is the capital of Sweden and the country's largest municipality with 760 000 inhabitants; if the whole of Stockholm county is included, the number of inhabitants is 1 900 000. Stockholm Water Company AB is a municipally owned company whish is owned by Stockholm Stadshus AB (98%) and by Huddinge municipality (2 %). Stockholm Water Company produces and supplies drinking water for just over 1 million people in Stockholm and Huddinge and a further nine neighbouring municipalities. Wastewater from Stockholm, Huddinge and six neighbouring municipalities is treated by the two plants operated by Stockholm Water Company (Henriksdal and Bromma), in which a total of approximately 135 million cubic metres of wastewater are treated each year.

Henriksdal's wastewater treatment plant (WWTP) is the largest treatment plant in the city of Stockholm. The load to the WWTP is just under 800 000 pe (calculated on the basis of BOD_7) with a mean flow of approximately 240 000 m³/day (Environmental report 2005). The wastewater is treated in three stages before finally being released into the receiving water the Baltic Sea (Figure 1).

The treatment consists of screening, grit chamber, chemical precipitation, pre-sedimentation, activated sludge process (including secondary sedimentation) and filtration with additional chemical precipitation. The sludge from the waste treatment is reused for landfill site coverage or as soil improver. The raw biogas formed in the digestion process is collected in an equalisation and storage gas tank (Figure 1). It is upgraded to compressed natural gas (vehicle fuel), or used as fuel in the treatment plant's heating boilers and for electricity production in gas engines.

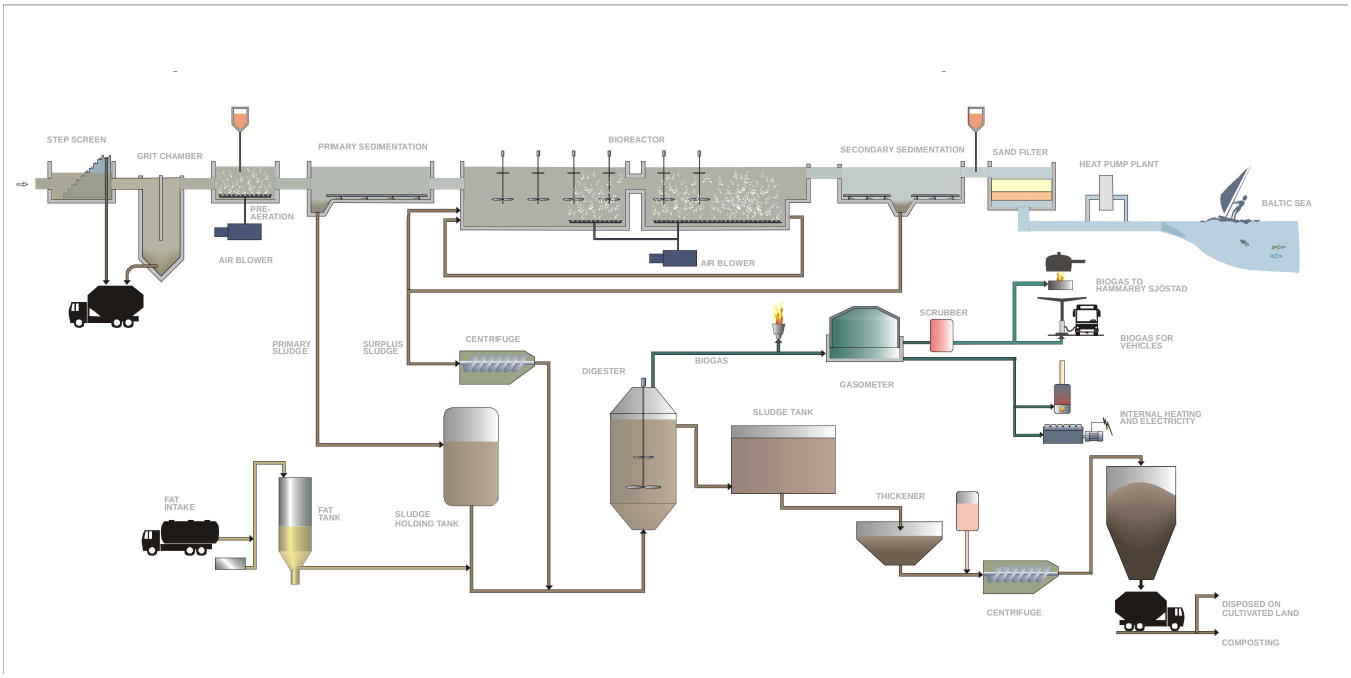

Figure 1. Overview of the wastewater treatment process at Henriksdal. The diagram has been obtained and modified on the basis of information material belonging to Stockholm Water Company AB[1].

[1] Gasometer = equalisation and storage gas tank

The main function of a wastewater treatment plant is of course to treat wastewater. When investigating the digestion process, the main focus is utilisation of organic matter. However, one must have an understanding of the entire treatment system to put the digestion process in the right context.

Incoming amount of organic matter to the wastewater treatment plant (WWTP) are relatively constant. The factor that has the greatest impact on variations in the incoming flow is quantities of precipitation. 2003 was a year with a dry, hot summer with low flows in to the WWTP (Table 1). On the other hand, the concentration of COD in incoming water was slightly enhanced then. The amount of organic matter to the anaerobic digesters will therefore be not much lower than normal despite the lower flow of wastewater to the WWTP.

Table 1. Incoming flows affecting the quantity of organic material for the digestion process.

Year	Hydraulic load to WWTP [m^3/day]	Influent concentration of COD to WWTP[2] [kg/m^3]	Organic load of COD to WWTP [tonne COD/d]	Hydraulic load to digesters [m^3/day]	Organic load of VS to digesters[3] [tonne VS/year]
2000	260 900	0.44	111	1896	19 200
2001	240 100	0.45	105	1867	19 300
2002	241 400	0.47	110	1852	21 500
2003	211 200	0.51	106	1856	18 800
2004	236 900	0.53	122	2030	21 300
2005	237 200	0.49	113	1958	20 000
Mean	**237 800**	**0.48**	**112**	**1910**	**20 000**

4.1. Mechanical treatment

The first stage in the wastewater treatment process is mechanical treatment, which consists of screens and a grit chamber. This is designed to remove solid contaminants from the incoming water. The quantity of screenings received by the plant varies with the incoming flow and the prevailing weather. Traditional coarse screens had a grating gap width of 20 mm, and the newer finer screens have a grating gap width of 3 mm. However, some rags and similar matter will pass through the screens and be removed in the main wastewater treatment process. Thus, rags and similar matter will be found in the sludge and can cause disturbances in the digesters, e.g. they can be entrapped on the stirrer blades and thus reducing the effectiveness of the stirrer. With a reduced size of screen opening, the quantity of rags should have decreased, but this has not been verified. Long periods of fine weather and low flows mean that screenings accumulate in sewers, tunnels, pipes and pumping stations. During these periods, smaller quantities of screenings than normal are received by the plant. However, when the flow to the plant increases again, the collected screenings will accompany the wastewater to the WWTP.

The grit chamber is intended to separate particles, having the density of sand, with a diameter of more than approximately 0.15 mm. This means that sand, seed and coffee grounds will be separated in the grit chamber, but not smaller particles and sludge. The purpose of the grit chamber is to reduce the wearing of equipment, e.g. pumps, and the deposition of sand in sedimentation and aeration tanks.

[2] As from 2004, the analysis method for the organic concentration of incoming wastewater was changed from COD to TOC. During an introduction and reference period for the new method, the ratio (COD/TOC) was 3.53. The TOC value analysed has been multiplied by this factor in order to be able to compare with data from 2004 and 2005.

[3] Includes sludge separated in the wastewater treatment and external organic matter.

4.2. Chemical treatment

Pre-aeration fulfils a number of functions; including aeration of the incoming wastewater to avoid unpleasant odours, and the oxidation and mixing of added precipitation chemicals. In this plant, chemical precipitation is achieved with ferrous sulphate, which is added in the pre-aeration tank, and phosphorus compounds and suspended organic matter will be precipitated. In the case of salts of divalent iron, iron ions first need to be oxidised (at the pre-aeration stage) to trivalent ions, which have the capacity to form a gelatinous hydroxide precipitate. Divalent iron ions also precipitate phosphorus, but these flocks are smaller and lack gelatinous iron hydroxide precipitation.

The precipitated phosphorus and the organic matter are removed in the pre-sedimentation tanks. This relieves the organic load to the biological stage and leads to a reduction in excess activated sludge production, allowing a higher sludge age. The use of precipitants will increase the amount of primary sludge, which will result in an increased organic load to the anaerobic digesters. Thus, effective pre-precipitation can have a positive effect throughout the plant, both on the water treatment and on production of biogas. The total retention time in the pre-treatment process (mechanical and chemical treatment including the pre-sedimentation tanks) is around 2 - 6 hours.

The incoming quantity of organic matter, COD (chemical oxygen demand), to the WWTP exists in two forms, namely dissolved and unsolved. A minor part of particulate COD is removed by screening and in the grit chambers. The major part of particulate COD is removed in the pre-sedimentation tanks as primary sludge. However, dissolved COD and a significant part of particulate COD is not removed in the pre-sedimentation step but will pass to the biological treatment.

4.3. Biological treatment

The nitrogen treatment takes place in the biological stage in tanks with various micro-organisms, chiefly bacteria that form an active sludge.

In the first part of the tank, the water does not contain any free oxygen and an anoxic process (denitrification) takes place there. In denitrification, nitrate is converted to nitrogen gas by heterotrophic micro-organisms, with simultaneous consumption of organic matter. The nitrogen gas rises into the air and is returned to the atmosphere (which already contains 79% nitrogen gas). The wastewater then flows into the next part of the tank, where the water is aerated (oxygenated) and an aerobic process takes place (nitrification). The nitrification is carried out by two chemical reactions with the help of different groups of micro-organisms. First, ammonium is oxidised to nitrite by Nitrosomonas and, afterwards, nitrite is oxidised further to nitrate by Nitrobacter.

After that, the water is passed to secondary sedimentation tanks in which the sludge sinks to the bottom. Most of the sludge is recirculated to the aeration tanks and the remaining sludge, excess activated sludge (approximately 400 m^3/d after thickening), goes to digestion. The excess activated sludge has a DM concentration of 0.5% when it is pumped from the biological stage. To increase the concentration of DM, the sludge is thickened with 5 decanter centrifuges (Alfa Laval XMNX 4565) to an average of 4.6% for the entire evaluation period (Figure 13). [4]

4.4. The digestion system

Primary sludge (PS), thickened excess activated sludge (EAS) and external organic matter (EOM) are treated in the anaerobic digesters. The primary sludge is pumped from the pre-sedimentation process to two sludge silos (2 x 175 m^3, communicating vessels). From these, the respective anaerobic digester is distributed in a rolling sequence via a distribution pipe system to the bottom of the respective anaerobic digester (AD). The EAS is pumped from the centrifuges to the sludge distribution system and mixed with the PS and the EOM. All sludge and EOM is treated in seven anaerobic digesters with a total volume of approximately 39 000 m^3. AD1-AD4 and AD7 each has a volume of approximately 5 000 m^3, while AD5 and AD6 each has a volume of just under 7 000 m^3 (see Table 2). AD1-AD4 and AD7 are normally charged with the same quantity of material while AD5 and AD6 are charged with more material but deliberately with a slightly smaller quantity of material relative to its liquid volumes. The anaerobic digesters are situated below ground level, incorporated in the rock with the rock sides as walls. The pumping of material into the digesters takes place in the bottom and the discharge of digester material (digested sludge) takes place via a weir in the form of a vertically situated pipe at the top of the anaerobic digesters.

Stirring takes place mainly with the aid of stirrers consisting of three blades in AD5 and AD6, a larger one at the bottom and two smaller ones in the middle and at the top, on a long stirrer shaft. AD1-AD4 and AD7 do not have the central blade, see Figure 2. In addition, there is a separate top stirrer installed which hopefully beats down any foam in the anaerobic digester. The stirrer output supplied is 28 kW for the central stirrers and 20.3 kW for the foam stirrers, i.e. in total 48.3 kW. Reversal of the stirrers takes place 3 times a day for approximately 3 minutes each time. Some stirring is also achieved through circulation of sludge via the externally located heat exchangers. The sludge circulated via the heat exchangers is removed at the upper part of the lower cone (on the right of Figure 2) and is returned at the bottom together with incoming, untreated sludge which is supplied to the pipe after the heat exchanger.

On average, an anaerobic digester is emptied every year in turn or according to the circumstances for inspection and cleaning. The history for the emptying operation has been evaluated by examining the temperature curves and biogas production for the respective anaerobic digester. The emptying history during the evaluation period (2000-2005) can be seen in Table 3. Any normal emptying has resulted in approximately 10 weeks' shutdown of an anaerobic digester. In calculations in which the anaerobic digester volume is a parameter, the volume is corrected to the total volume of anaerobic digesters that is still in operation (active volume).

The overpressure in the anaerobic digesters is approximately 35 mbar (359 mm water column)[5]. All anaerobic digesters have a diameter of 21.0 metres. Table 2 and Figure 2 indicate the dimensions of the anaerobic digesters up to the liquid surface. Above the liquid surface, the raw biogas is collected in a volume equivalent to 1.0 - 2.4 m vertically. The depth of liquid is approximately 22 metres in AD1 - AD4 and approximately 21 metres in AD7, while it is just over 26 metres in AD5 - AD6, see Table 2.

[4] DM concentration of EAS is based on the manual sludge samples taken on working days between 07:00 and 08:00. Further investigations conducted in autumn 2007 of variations of the DM concentration over a longer period of the day showed that these samples probably provide an underestimate of the DM concentration and thus the amount of DM (Åkerlund, 2008).

[5] The outlet pipes were lowered in AD3 - AD7 in 1996, see section 5.4.b.

Table 2. Dimensions and liquid volume for the respective anaerobic digester.

Anaerobic digester	a (m)	b (m)	c (m)	d (m)	e (m)	f (m)	g (m)	h (m)	Volume (m³)
1	11.37	20.0	21.0	1.167	4.71	1.0	8.0	8.5	5070
2	11.41	20.0	21.0	1.167	4.69	1.0	8.0	8.5	5068
3	12.06	19.99	21.0	1.167	4.37	1.0	8.0	8.5	5036
4	12.08	19.99	21.0	1.167	4.36	1.0	8.0	8.5	5035
5	12.83	19.3	21.0	1.400	3.27	1.6	12.9	8.4	6687
6	12.81	19.3	21.0	1.400	3.28	1.6	12.9	8.4	6688
7	12.66	19.3	21.0	1.400	3.32	1.6	7.6	8.4	4855

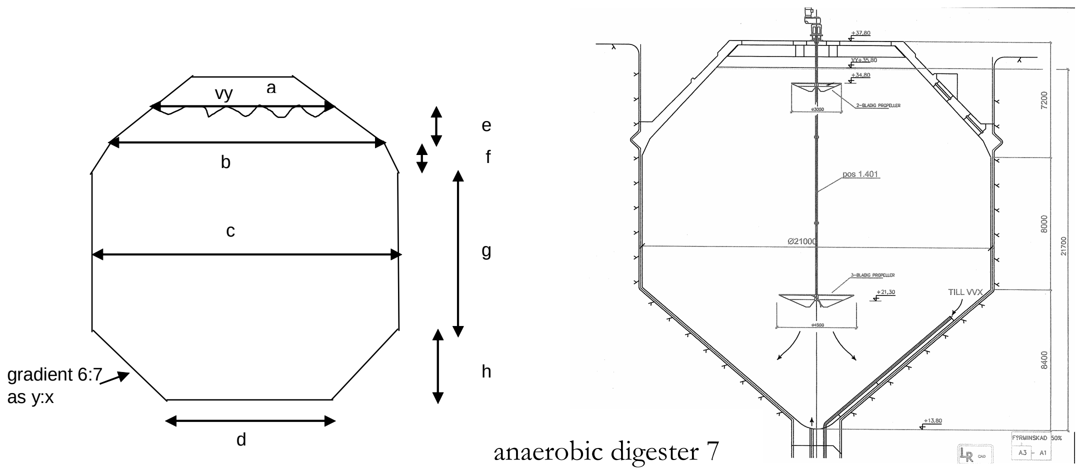

Figure 2. Diagram of an anaerobic digester (not proportional) with dimensions according to Table 2 (on the left), and scale drawing of AD7 (on the right). The top stirrer is not included in this drawing.

Table 3. History of anaerobic digester emptying operations during the evaluation period.

2000	2001	2002	2003	2004	2005
AD2	AD3		AD7	AD1	
AD4	AD5			AD2	
	AD6				

When AD2 was emptied and cleaned in summer 2006 due to a poor function of its heat exchanger, an inspection and documentation of the anaerobic digester was performed internally. Very little clogging with rags and other items was found, and no reeds, etc. were present in the anaerobic digester which impeded the sludge flow. In view of the fact that this anaerobic digester has not been in operation for more than two years since the previous emptying, this is not surprising. A list of observations is provided in Appendix I.

4.5. Digested sludge handling

The digested sludge is pumped to the sludge dewatering stage, which is geographically situated 2 kilometres from Henriksdal (the Sickla plant). The sludge passes through two equalisation and storage tanks (2 x 5000 m^3) in Henriksdal, and two under-sized gravimetric thickeners (2 x 660 m^3) in Sickla, and is then passed to centrifugation. The dewatered sludge, DM concentration approximately 28%, is stored in two dry sludge silos with a total volume of 800 m^3, of which no more than approximately 250 m^3 is normally used. The dewatered sludge is currently (2009) used for establishing areas of vegetation on waste rock dumps and sand stores at quarries in northern Sweden. The reject water from the sludge dewatering contains, in addition to suspended solids, a high concentration of ammonium, very approximately around 800 mg NH_4-N/l. This recirculation of ammonium accounts for 10 - 15% of incoming amount of ammonium to the WWTP. By recirculating this ammonium to the process when the nitrogen load to the WWTP and the biological stage is low (e.g. at the time of day when the nocturnal dip affects the treatment plant, with a time shift owing to long tunnels), a more uniform nitrogen load to the biological stage should be achieved and the process improved. Another way of reducing this load is to have an extra treatment stage for the reject water before it is returned to the nitrogen treatment process in the WWTP. Another attractive alternative is to conduct the digestion process in such a way that most of the nitrogen is bound in the biomass and is not present as ammonium in the reject water. This can be done by planning what EOM is to be received for the digestion process. EOM that does not contain high concentrations of nitrogen will contribute to the production of biomass in the anaerobic digesters without supplying nitrogen. This means that the nitrogen already in the anaerobic digesters will be utilised in connection with the formation of the biomass and in this way more nitrogen is incorporated in an organically bound form.

4.6. Gas handling

The biogas produced during the digestion process has until April 2003 entirely been used for electricity production and heating in 4 gas engines and 3 gas boilers. The biogas that cannot be dealt with is passed to a torch for disposal. In January 2004, an agreement was concluded with Storstockholms Lokaltrafik concerning the supply of compressed natural gas (biomethane) for buses. A public biomethane filling station for vehicles has also been in operation since the summer of 2005. In the long term, all raw biogas produced at the WWTP will in principle be sold as compressed natural gas for vehicles. The first biogas upgrading plant was taken into operation in April 2003, and another plant was taken into operation in April 2006. The total biogas treatment capacity accordingly totals 1400 Nm^3 raw biogas/h. The biogas treatment is conducted by a recirculating water scrubber, in which the raw biogas is cleaned from carbon dioxide, hydrogen sulphide and ammonia via pressurised water absorption. The treated gas contains approximately 96-98% methane with a set point of 97%.

5. The digestion process

The primary sludge removed in the pre-sedimentation tanks and the sludge removed as excess activated sludge in the biological treatment is treated in the anaerobic digesters. Chemical sludge is incorporated in primary sludge via pre-precipitation and also in the EAS via simultaneous precipitation which takes place when unprecipitated divalent iron passes to the aeration tanks and is oxidised there to trivalent iron. Henriksdal's WWTP also receives external organic matter (EOM) in the form of sludge from grease separators and food waste from markets which are pumped direct to the anaerobic digesters. A more detailed description of this sludge is presented below in section 5.4. The digestion process is an anaerobic biological process which requires certain conditions to function optimally. The anaerobic process can be divided into three steps.

- Hydrolysis of complex organic compounds
- Formation of volatile organic acids
- Formation of biogas

These three stages all take place in the anaerobic digester, but are carried out by different groups of micro-organisms. The stages have different optimums for their processes. For the entire chain to function synergistically, the process must be operated in a stable fashion under conditions that function for all groups of micro-organisms involved.

The digestion process is affected by factors such as temperature, retention time and substrate addition. If the digestion functions well, it will result in a stabilised sludge with a reduction in the concentration of organic material of 45-55%. The dewatering properties for the sludge are improved and the odour problems associated with sludge handling are reduced. In addition, a biogas with a high energy content (methane gas) is produced. The following paragraphs describe the most important of the factors that affect digestion processes (Gerardi, 2003).

5.1. <u>Temperature</u>

Micro-organisms can be classified according to the temperature range in which they live and grow (Figure 3). It should be noted that the quoted ranges in the Figure provide an indication of how temperature affects the growth rate and that the boundaries between the groups of micro-organisms are not distinctive. If the temperature in a microbiological process decreases, the activity will decline. A rapid increase of the temperature can cause an imbalance in the process, i.e. accumulation of organic acids, since this step responds faster to an increased temperature than the gas production step. If the temperature is too high, the organisms will die mainly due to destruction of protein structures in the exposed organisms.

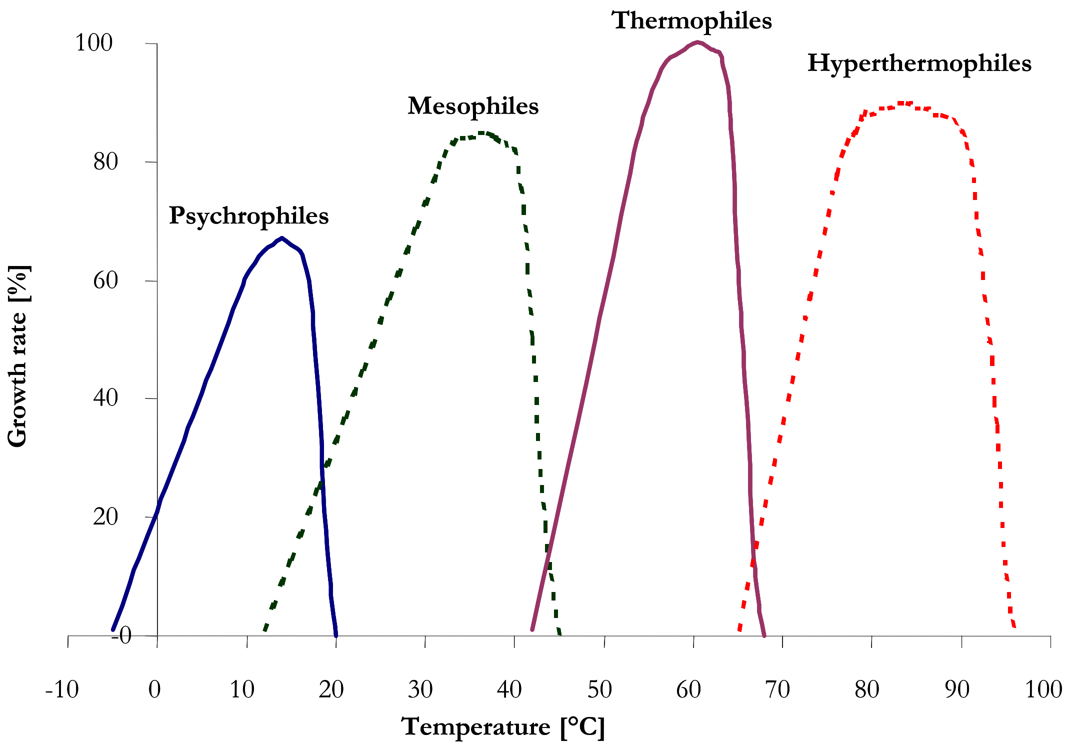

Figure 3. Micro-organisms' growth rate and classification based on temperature (modified according to Brook (1999)).

Conventional anaerobic digesters at wastewater treatment plants are mostly operated at the temperature considered optimal for mesophilic organisms, i.e. at 33 – 38°C. However, a number of anaerobic digesters are also operated thermophilically (approximately at 50 – 55°C). Furthermore, a number of different substrates, such as fertiliser and various types of organic waste are today anaerobically degraded to produce biogas in digesters at different temperatures. With a thermophilic temperature, a higher degradation rate and a shorter treatment time for the organic material are achieved than with degradation at mesophilic temperature. A more effective process may in some cases compensate for the higher temperature and energy supply when thermophilic digestion is applied. The mesophilic process is usually less vulnerable to process disturbances due to a more diverse microbiological culture. The process can thus handle process changes better and potential risks for process disruption are reduced. A known problem with thermophilic digestion is that there is greater vulnerability to ammonium toxicity, which can develop with high concentrations of nitrogen in the case of protein degradation.

The temperature has not been optimal for the digestion process at Henriksdal throughout the studied period. The set point for temperature was 35°C until October 2001. This value was then increased to 37°C to achieve higher biogas production. The temperatures in the anaerobic digesters have fluctuated over the years; for example, the variation during 2002 is illustrated in Figure 4. In 2002, none of the anaerobic digesters was emptied for cleaning and inspection, and thus Figure 4 presents the average temperature for all anaerobic digesters during that year. The capacity of the heating system was under-sized during periods with increased sludge flows with relatively low temperatures that normally occur during snow melting periods, e.g. March 2002. During such periods, the temperature in the anaerobic digesters can decrease to 30-31°C. Appendix II illustrates the temperature history for all anaerobic digesters separately, while Table 13 in Appendix IV shows the annual mean values for the temperature in active anaerobic digesters. At the lower set point, it was easier to maintain a uniform and desirable temperature, while the seasonal variations are more clearly apparent at the higher set point.

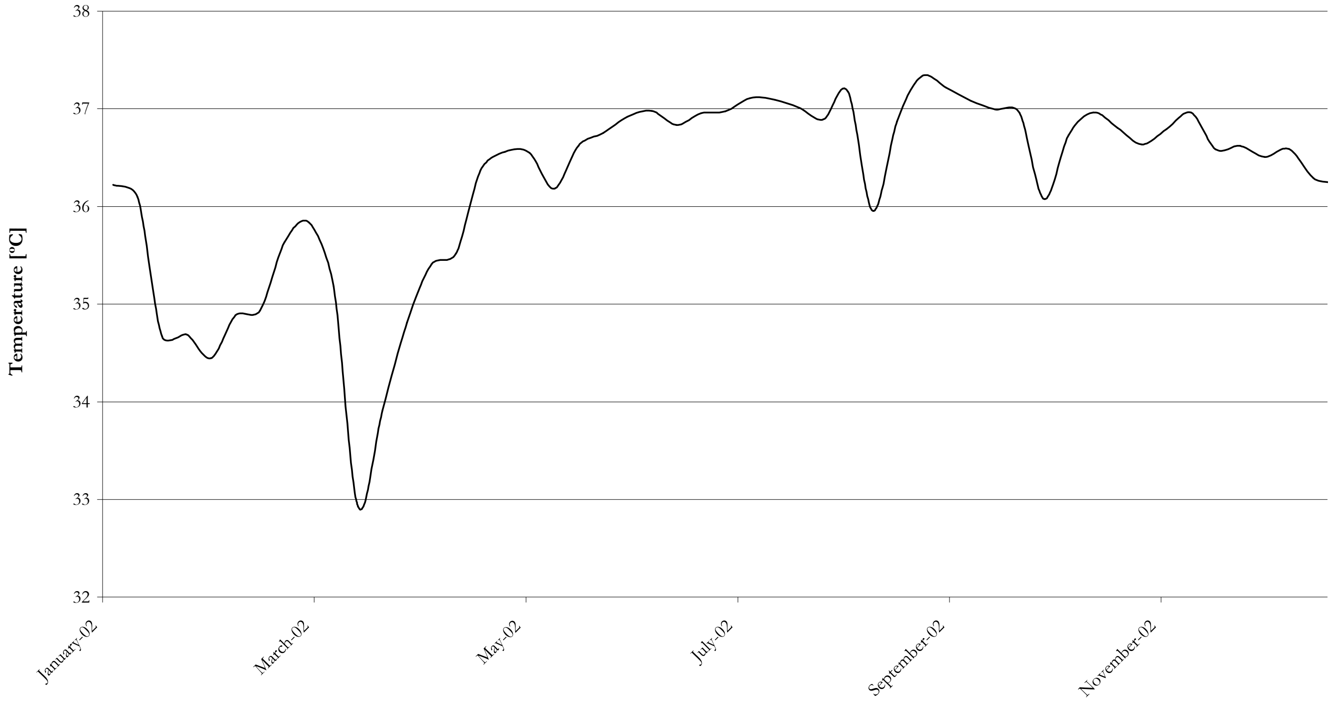

Figure 4. Temperature variation in all anaerobic digesters during 2002. The temperature is a mean value of the temperatures in all anaerobic digesters over the period.

The temperature in the digestion process at Henriksdal during 2000 - 2005 is illustrated in Figure 5 as an average temperature for actual volume of digesters in operation at each specific week. That is, the mean value was calculated by dividing the total heat content of the sludge expressed as temperature multiplied by active volume for each digester in operation divided by the total active sludge volume in the digesters.

During the evaluation period, temperature increased slightly in the form of annual means. A trend for increased gas production can also be seen, although there are many variables that affect the result.

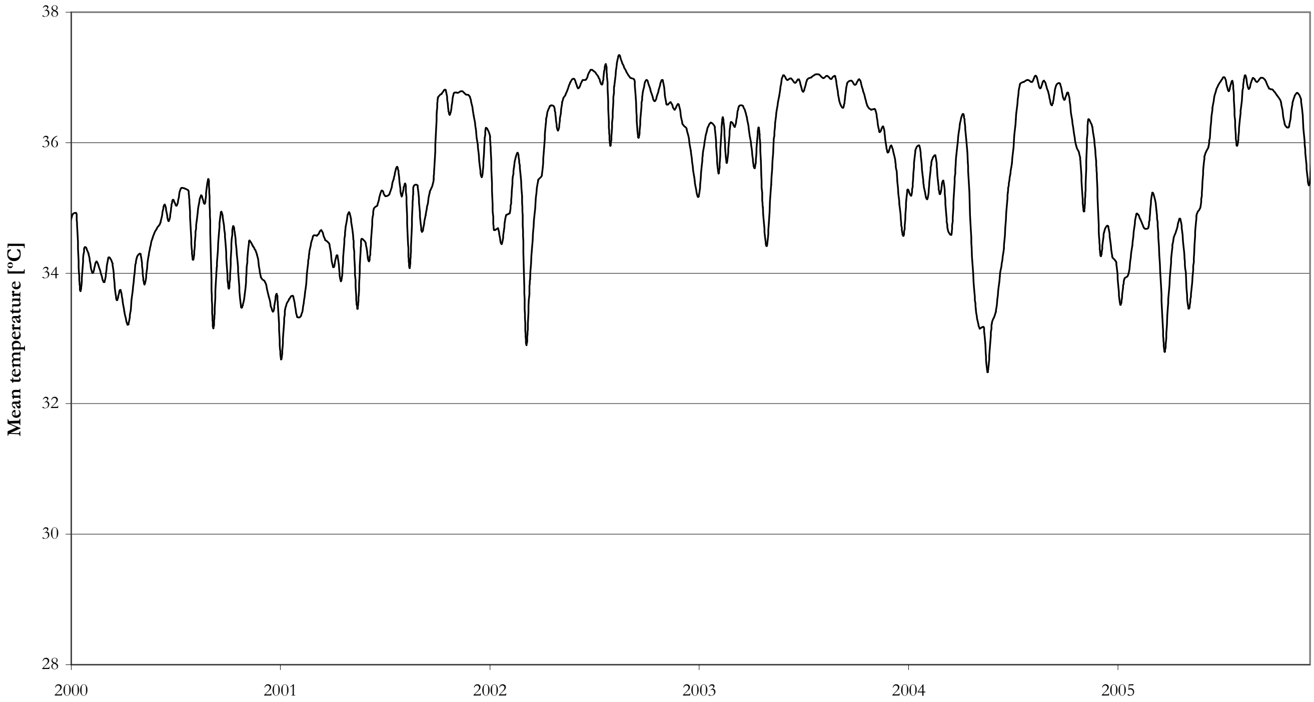

Figure 5. Mean temperature in active anaerobic digesters during the evaluation period.

5.2. Retention time

The term 'retention time' is a common operation parameter in digestion. There are two measures of retention time, namely SRT (solids retention time) and HRT (hydraulic retention time). SRT, see Formula 1, is the mean time for which biomass and other solid material is retained in the reactor. SRT is of great importance for the growth of micro-organisms in an anaerobic digester. The great majority of digestion plants in Sweden at the present time are based on continuously totally stirred processes (CSTR = continuously stirred tank reactor), in which the biomass is not separated from the aqueous phase and HRT = SRT. There are digestion techniques in which the biomass is separated from the liquid phase and then returned to the anaerobic digester. Such a technique has been tested at the Sjöstad plant in Stockholm (Negre, 2007). In this way, SRT and HRT can be controlled independently of each other. The hydraulic retention time can then be kept short in the reactor with continuously retained good microbiological growth. Under these conditions, HRT can be determined with reference to the substrate to be digested and SRT can ensure sufficient microbiological growth. These techniques are well suited to anaerobically treating large volumes of process water containing COD. A process with a long SRT and short HRT is advantageous in many respects. A long SRT leads to a reduced anaerobic digester volume and better buffer capacity for variations in load. In a CSTR, about 95% of the material in the reactor has been replaced after three SRTs.

Formula 1. Calculation of retention time (HRT).

$$Retention\ time\,[d] = \frac{Anaerobic\ digester\ tank\ volume}{Volume\ of\ incoming\ flow\ per\ day}$$

The retention time is important for microbiological growth. The material must be allowed to remain in the anaerobic digester for a sufficient time for the micro-organisms to grow and multiply. The methane-forming micro-organisms are the ones which grow most slowly. The doubling time varies considerably according to the organism, from 3 to 30 days in mesophilic processes. It is therefore recommended that the retention time in the anaerobic digester should exceed 12 d and preferably 15 d (Gerardi, 2003). If the retention time is too short and the micro-organisms are diluted at a higher rate than they can multiply, this is called "wash out".

During the evaluation period, HRT in the digestion process at Henriksdal has varied between 19 and 21 days as an annual mean. This is probably a rather representative value for Swedish WWTP.

The retention time in the anaerobic digesters has fluctuated and has during shorter periods occasionally been as low as 10 days and sometimes above 25 d (Figure 6). The retention time is, as described by Formula 1, dependent on the sludge flow and the actual anaerobic digester volume in operation. Variations in sludge flow are mainly due to the quality and quantity of primary sludge, i.e. the sedimentation characteristics of the primary sludge is an important parameter but also the hydraulic load to the pre-sedimentation step. Furthermore, different operation strategies can influence the SRT in the anaerobic digesters. To increase SRT, the flow of primary sludge removed from the pre-sedimentation tanks should be minimised, i.e. the primary sludge should have a high DM concentration. However, such a strategy will also result in an increased solid retention time in the pre-sedimentation tanks and increase the anaerobic degradation of organic material in the pre-sedimentation step. The result will be less material available for production of biogas in the anaerobic digesters and also an increased risk for production of gas that might cause flotation of the sludge in the pre-sedimentation tanks. Thus, it is important that the sludge thickening within the pre-sedimentation tanks is effective to facilitate removal of sludge with a relatively high concentration of DM and with a low solid retention time within the pre-sedimentation tanks.

During periods when one or more anaerobic digesters are closed for inspection, the total digestion volume will decrease and so will the retention time. During the summer of 2004, two anaerobic digesters were taken out of operation for cleaning at the same time and the result of this is shown clearly in Figure 6. The retention time was very short and the biogas production per kg VS decreased slightly during the period when the two anaerobic digesters were out of operation. The retention time had a mean of 14 days and on certain weeks it was down to only 12 days. A rapid decrease of SRT, e.g. caused by the anaerobic digesters taking out of operation, results in an instantaneous and disadvantageous change in the microbiological process. This might cause disturbances such as foaming problems, increase of the organic acids concentration, reduced biogas production etc. However, in this case the initial retention time was relatively long and that is probably the main explanation why the registered effect of the rapid decrease of SRT was small.

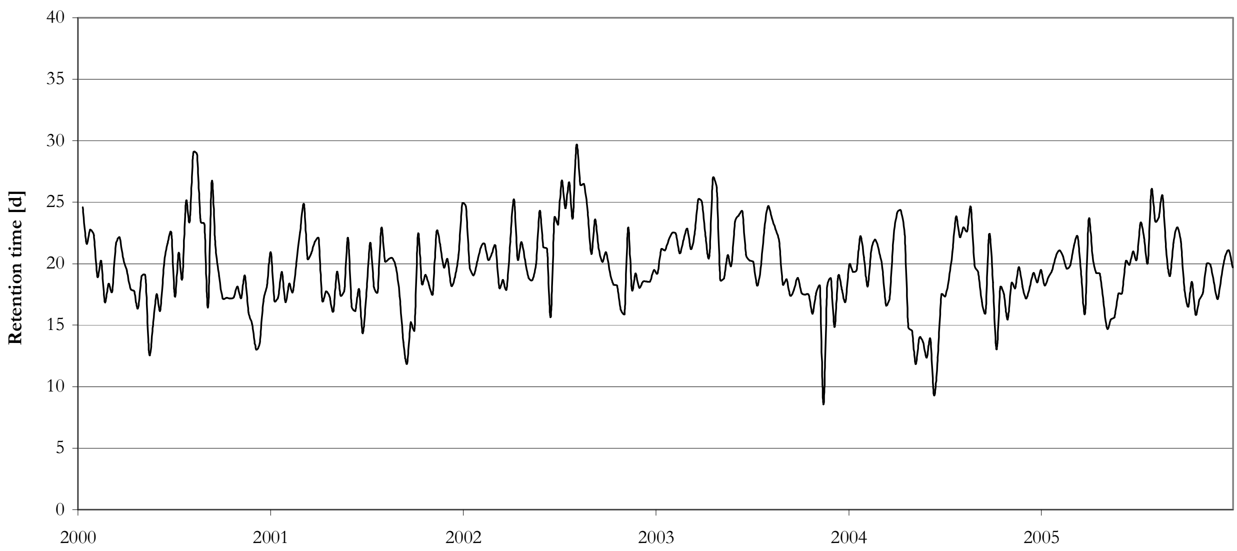

Figure 6. The retention time in the digestion process at Henriksdal calculated from the total volume of all seven anaerobic digesters. Only the volumes of digesters in operation have been considered in the calculation of SRT.

5.2.a. Trace element experiments

Complete stirring is important to utilise the entire anaerobic digester volume effectively and also to obtain a uniform temperature throughout the anaerobic digester. New stirrers were installed in all anaerobic digesters in 1994 to achieve complete stirring. A trace element study was conducted in September 1994 and another in April 1995 in AD5 with the addition of lithium to verify the mixing efficiency, and it was then found that 100% of the anaerobic digester volume was utilised and that the mixing was effective. Cleaning of AD5 took place last time in summer 2001. A further trace element study was conducted in May 2007.

By monitoring the changes in the lithium concentration in the outlet of the anaerobic digester directly after dosing (impulse response) and then monitoring how the concentration decreases in the following weeks, mixing efficiency and the occurrence of dead volumes or short-circuit streams in the anaerobic digester can be revealed.

The volume of the anaerobic digester 5 is 6687 m^3. The lithium chloride solution contained 100 kg (99.5% by weight) LiCl (16.3 kg Li) and was diluted with approximately 250 litres of water. The mean flow during the trace element experiment was 478 m^3/d and the retention time, calculated as V/Q, was 14.0 d. Dosing of lithium chloride took place on 09/05/2007 immediately before the heat exchanger below AD5 (see Figure 7) with a progressive cavity pump with a capacity of 25 l/min. The maximum concentration of Li in the anaerobic digester that could be achieved, if the entire anaerobic digester volume was utilised and if it was totally mixed, was then 2.44 mg Li/l.

Figure 7. On the left – the heat exchanger coil below anaerobic digester 5 at Henriksdal. On the right – the dosing point (at the bottom on the right) for the LiCl solution.

The sampling took place in the outlet pipe from AD5. The sampling started approximately 50 minutes before the lithium dosage started. The pumping of Li into AD5 started at 10^{10} and went on for 17 minutes and 45 seconds. Samples were taken from the outlet weir pipe at intervals of 10 minutes starting at 09^{18} on the first day. On the following days, one sample was taken in the morning and one in the afternoon, after which a sample was taken each day. Figure 8 and Figure 9 below show the result of the experiment. 30 minutes after the start of dosing, the Li concentration of the outflow started to increase and after 1 h and 20 min peaked at a stable concentration of 3.3 mg Li/l. If this concentration, which is thus considerably higher than expected for a continuously ideal stirred tank reactor with a volume of 6,687 m^3, is assumed to be the expected initial concentration C_0, the decrease in effluent concentration almost completely follows the pattern for a continuously ideal stirred tank reactor.

An unexplained inaccuracy in the trace element test is that there was considerably more lithium in the effluent from the anaerobic digester than was added. Even if the reason for this not has been established, the relative decrease of the Li concentration strongly suggests that the anaerobic digester was completely mixed and that the anaerobic digester volume was effectively used.

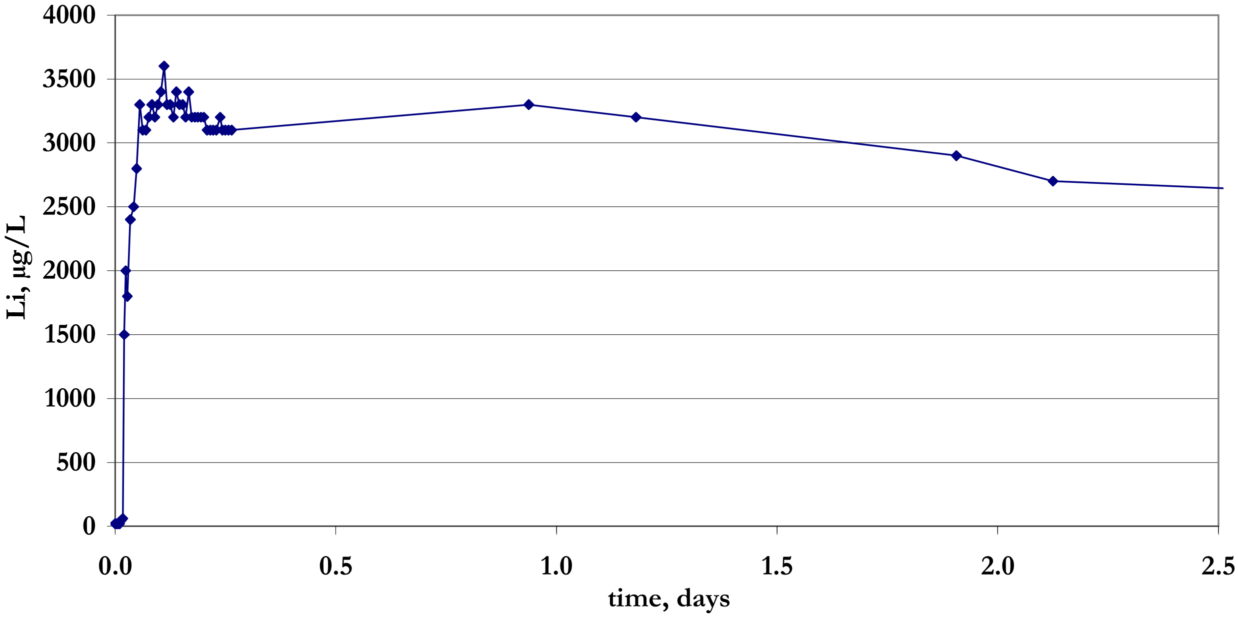

Figure 8. Li concentration in the effluent from the anaerobic digester 5 as a function of the sampling time.

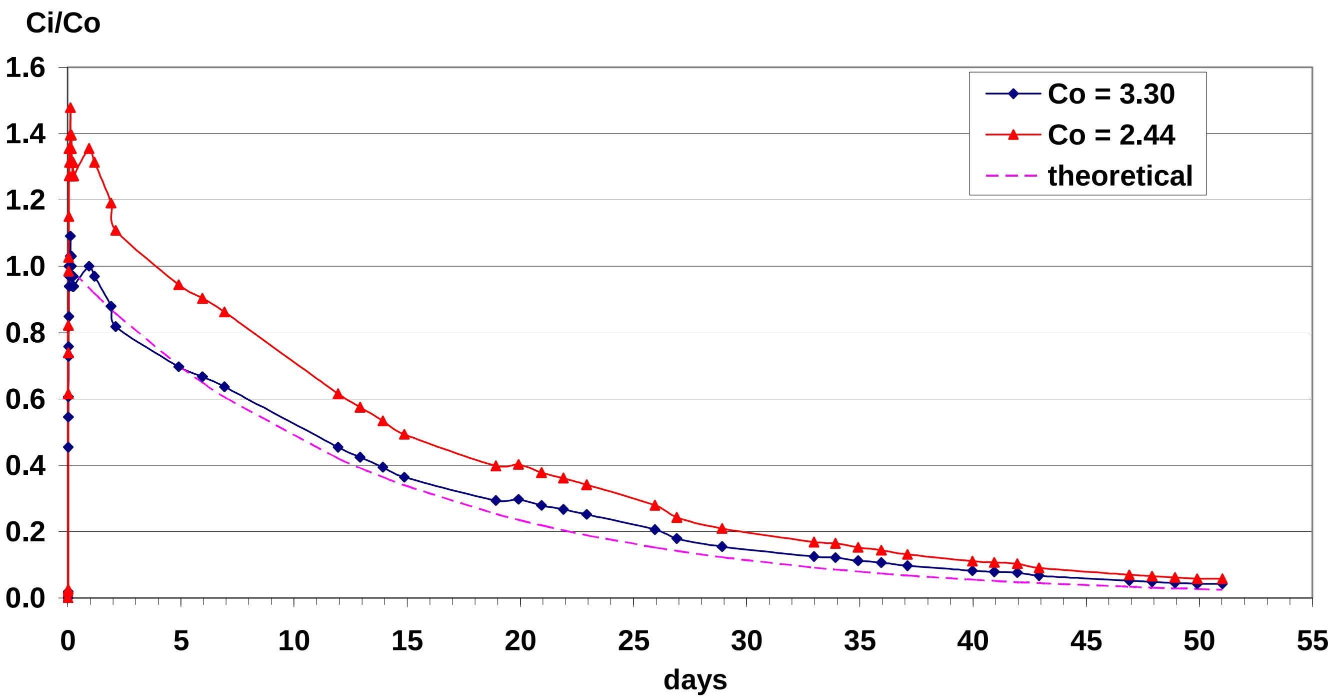

Figure 9. Normalized Li concentration in the effluent from the anaerobic digester 5 as a function of the number of days after dosing of LiCl.

5.3. DM, VS and organic load

In this report "substrate" is the flow of a certain material, e.g. primary sludge, which enters the anaerobic digesters. A substrate consists of two fractions, water and dry matter (DM). DM consists in turn of two components, an inorganic component (residue of ignition, ROI) and an organic component (loss of ignition, LOI). DM is analysed by the sample being weighed and placed in a heating cabinet at 105˚C for at least 12 h so that the water in the sample evaporates. The sample is then weighed again and DM is calculated with the aid of Formula 2:

Formula 2. Calculation of the proportion of dry matter (DM) in a material.

$$DM\ (\%\ \text{by}\ weight) = \frac{weight\ after\ heating\ at\ 105°C}{weight\ before\ heating} * 100\%$$

The two fractions in DM are analysed by the dry sample being heated at 550˚C for 2 h. The organic component is thermally oxidised and the ash, the residue of ignition, remains in the sample. The sample is weighed again and the concentration of inorganic matter can then be calculated in accordance with Formula 3:

Formula 3. Calculation of the proportion of residue of ignition (ROI) of the quantity of DM.

$$ROI\ (\%\ of\ DM) = \frac{weight\ after\ heating\ at\ 550°C}{weight\ after\ heating\ at\ 105°C} * 100\%$$

The proportion of DM that is not present as residue of ignition is LOI or, as it is often called, Volatile Solids (VS) and is calculated in accordance with Formula 4:

Formula 4. Calculation of the proportion of volatile solids (VS) in the quantity of DM.

$$VS\ (\%\ of\ DM) = 100 - ROI$$

The specific organic load from the substrate which is important for the degradation process is calculated in accordance with Formula 5:

Formula 5. Calculation of specific organic load per volume of anaerobic digester and day.

$$Load\ \left[kg\ VS/(m^3 \cdot d)\right] = \frac{kg\ VS\ pumped\ in}{m^3\ anaerobic\ digester\ volume\ and\ day}$$

It is important to be aware of the organic content of the substrate. In a WWTP, the sludge that is digested has been thickened prior to charging. The thickening process (usually via sedimentation, though centrifugation also occurs) yields a sludge with relatively stable concentrations of DM and VS. The variations in load are then mostly dependent on the volume of sludge pumped to the anaerobic digester. If different substrates are mixed, it is important to have knowledge about the organic concentrations and the characteristics of the different substrates to obtain a good substrate mix and a uniform organic load to the anaerobic digesters.

It is important to analyse the concentrations of DM and VS for all significant quantities of EOM in order to calculate the contribution to the total load of organic matter. The concentration of DM for various substrates is difficult to estimate by ocular observations and the difference is mostly apparent merely from conducting analyses. An example is the comparison between a rice pudding containing 21% dry organic matter and cream containing nearly 60%, despite the fact that the rice pudding has a more solid consistency and thus is apparently "drier". By loading an anaerobic digester with material with an unknown concentration of DM, uneven loads can be obtained, which may lead to process disturbances. A sedimented sludge at a WWTP is relatively stable in terms of the concentrations of DM and VS, and variations in the organic load normally follow variations in the hydraulic load (Figure 10).

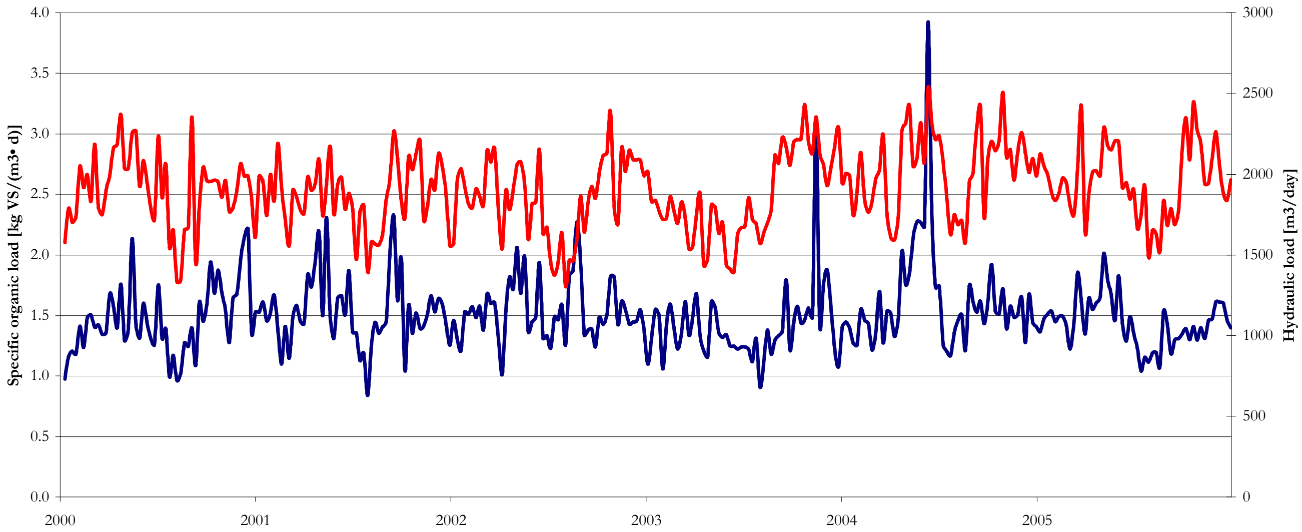

Figure 10. The specific organic load (——) and the hydraulic load (——) on the digestion tanks.

The organic load to the anaerobic digesters was relatively high (Table 13 in Appendix IV) and stable in 2002. The separation of organic matter in the pre-sedimentation tanks was also relatively high (Appendix III). The mean for the concentration of DM in the primary sludge was 3.8% (Table 5). However, the specific organic load was not unusually high since all anaerobic digesters were continuously in operation. In the middle of 2004, there is a period of very high specific organic load to the anaerobic digesters (Figure 10). This is due to the fact that 2 out of 7 anaerobic digesters were not in operation for supervision at the same time. The mean values for the organic load to the digestion process are presented in Table 13, Appendix IV.

DM and VS are the main analyses conducted on the digestion process. The information required for planning the load and monitoring degraded material is obtained with analyses of these parameters at various stages of the process, together with flow measurements. Some examples of DM and VS analyses and their significance follow:

- Incoming substrate – DM and VS is a measure of the concentration of organic matter in the substrate. The main information that DM and VS provide, in the analysis of the substrate in the influent, is the total organic load to the anaerobic digesters. DM can be measured online, but online measurement of sludge is difficult and parallel analyses are often conducted on samples taken manually. Depending on the variations of the substrate in the influent, the recommended frequency for sampling differs.[6] For primary and excess activated sludge, it is recommended that the sampling schedule is adapted to the variations in the DM and VS that normally occur. As EOM can vary in nature, and as the proportion of the amount of EOM in the total amount of organic matter varies, no general frequency can be recommended. Analyses should, however, be carried out so that knowledge of the respective EOM's concentration and variation is obtained.
- Digested sludge – DM and VS analyses is conducted on samples taken from the anaerobic digester circulation or on the outlet from the anaerobic digesters. The DM and VS analysed consist of

[6] Monitoring of DM in excess activated sludge shows that the time of sampling is critical for obtaining representative samples.

microbiological biomass and organic matter not degraded. Analysis of the respective anaerobic digester is carried out at least once a week.

- Dewatered digested sludge – DM and VS are analysed in the dewatered digested sludge and the concentrations of metals and nutrients in relation to organic matter are calculated. The frequency of analyses is determined by applicable demands for the dewatered digested sludge.

5.4. Incoming substrate for the digestion process

The incoming substrate to the digestion process consisted of three fractions: primary sludge, thickened excess activated sludge and external organic matter. A specification of hydraulic loads and organic concentrations is provided in Table 5 (section 5.4.d.).

5.4.a. Primary sludge (PS)

Sludge that has sedimented in the pre-sedimentation tanks, including sludge that has precipitated chemically, is called primary sludge (PS). It is pumped, intermittently throughout the entire day, from the bottom of the sludge collection pockets in the pre-sedimentation tanks. Control of the withdrawal sequence of PS is carried out by measurement of the sludge DM concentration. The sludge is thickest, i.e. has the highest concentration of DM, at the start of the pumping of a new pocket. A minimum desired concentration of DM is set and the pumping takes place until the concentration of the sludge DM has decreased to this concentration level. The control also involves a preset time parameter, where the shortest time in the pumping sequence is approximately 5 - 11 minutes per sludge pocket. The pumping always continue for at least this time, and if the sludge has still not decreased to the desired DM, the pumping of sludge continues until the set maximum time has been achieved. If DM has still not reached the set point, the sequence is incorporated in a new pumping phase after all the sludge pockets have first been pumped a first time.

Primary sludge production totals approximately 1450 m^3/day and the organic concentration of the sludge was relatively constant at DM = 3.6 ± 0.6 % and VS = 74 ± 4% of DM. The flow of primary sludge varies over the year, see Figure 11. During the summer months, when a large proportion of the population are not in the city and many industries reduce production, the organic load to the WWTP is reduced.

During the period from 09/07/2003 until 21/11/2003, the flow meter for primary sludge was out of order. To capture the seasonal variations, flow values were extrapolated from the same period in 2002 and 2004. A mean value from the weekly means in 2002 and 2004 was calculated and used as a flow value corresponding to the same week in 2003. These calculated values have been used throughout the study.

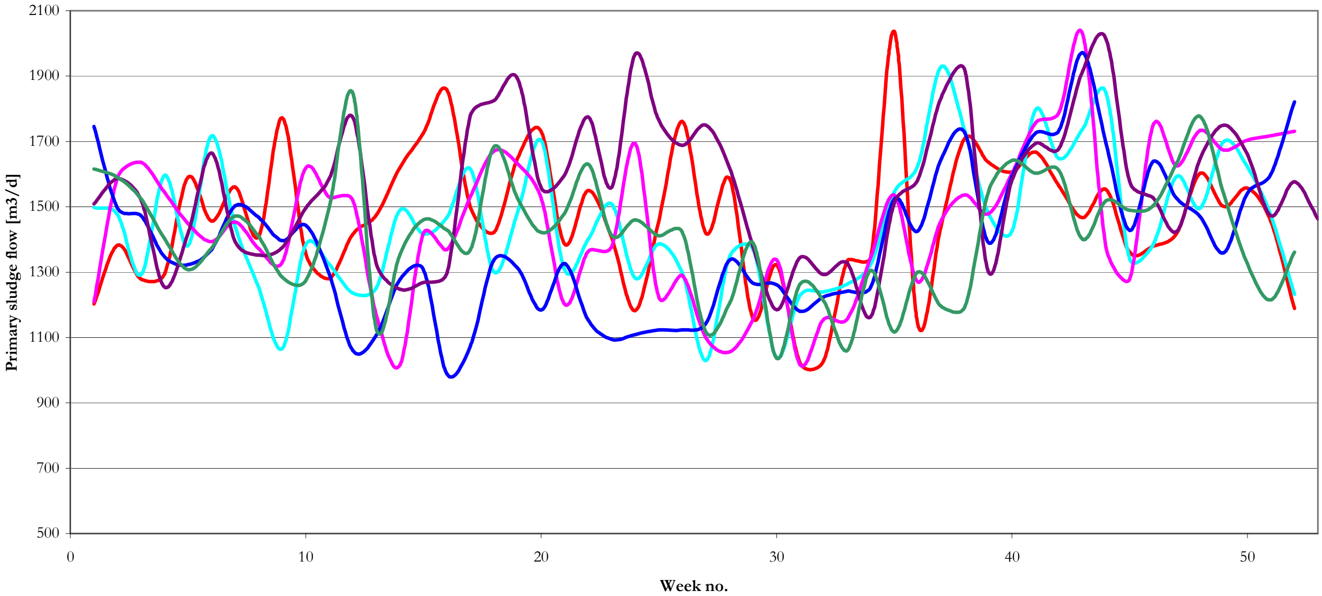

Figure 11. Primary sludge flow for the digestion process during 2000 - 2005 varies with the season. The values are floating means for four weeks so as to identify annual variations more clearly. Years 2000 (—), 2001 (—), 2002 (—), 2003 (—), 2004 (—) and 2005 (—).

The separation of sludge in the pre-sedimentation tanks has been calculated via a COD balance for the tanks. COD values and flows used are mean values for the relevant year, and the results can be seen in Appendix III. The mean for the removed organic matter in PS via the pre-sedimentation process has been 53 ± 3%. 2003 has been chosen as an example of the variation of the separation process over a year, see Figure 12. Much of the potential for high biogas production lies in having effective separation of the primary sludge in the pre-sedimentation stage. If more sludge can be removed at this stage of the process, biogas production in total will increase. One should also be aware of, however, that COD is also needed as a carbon source for the denitrification in the biological stage.

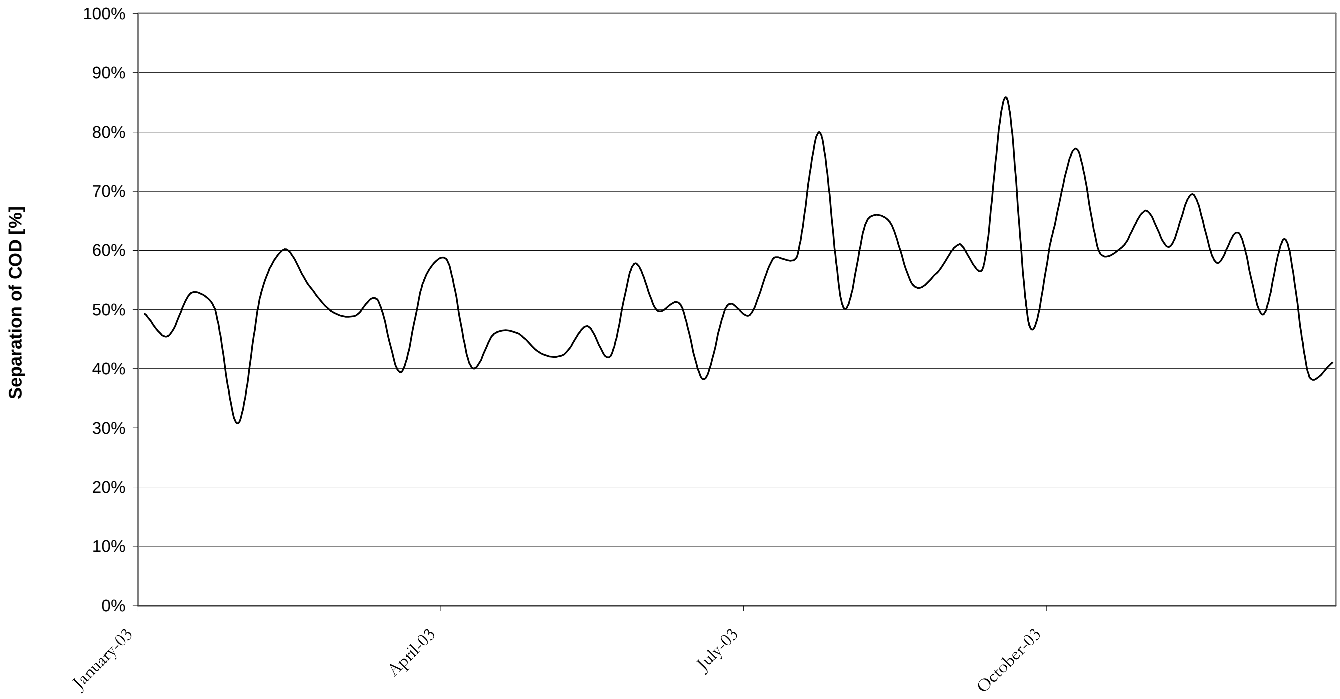

Figure 12. Separation via the pre-sedimentation process during 2003.

5.4.b. Excess activated sludge (EAS)

Excess activated sludge (EAS) is the sludge removed from the biological treatment (section 4.3). The biomass in this sludge is, unlike "fresh" primary sludge, a sludge which is relatively difficult to degrade. The organic material in the decantate from the pre-sedimentation tanks is to a large extent consumed by the bacteria in the biological treatment and incorporated in cell structures. Thus, the specific biogas production from this sludge is therefore not so high.

It is desirable to reduce the amount of water pumped into the anaerobic digesters. With a reduced amount of water, the retention time in the anaerobic digesters increases or generates volumes for receiving additional external organic matter (EOM). The EAS is thickened before being taken into the anaerobic digesters. In the past, the sludge was thickened in gravitation thickeners, but in 1999/2000 five EAS centrifuges were installed with a capacity for thickening the sludge to a DM concentration of 6-8%. As early as 1982/1983, two older EAS centrifuges were installed. However, these did not have the capacity for handling the entire flow of EAS. Before the centrifuges, the EAS has a DM concentration of approximately 0.5%. However, the thickening potential of the centrifuges have not been possible to fully utilise. At higher DM concentrations the sludge became almost impossible to pump due to a very high viscosity in thickened sludge. Thus, due to problems with pumping thickened EAS, the DM concentration of thickened EAS has periodically been relatively low (e.g. only 2.7% during the second half of 2003), see Figure 13.[7]

[7] There are strong indications that recorded DM concentrations in EAS may diverge sharply from actual mean quantities in the case of low concentrations of DM. This is due to the fact that samples were taken most often between 07:00 and 08:00. At this time of day, however, the concentrations of SS in the EAS and thus usually in the thickened EAS are lower than for the rest of the day. This is apparent from "on-line" SS meters for EAS, but which, owing to great measurement uncertainty, only can be used to see qualitative changes over time.

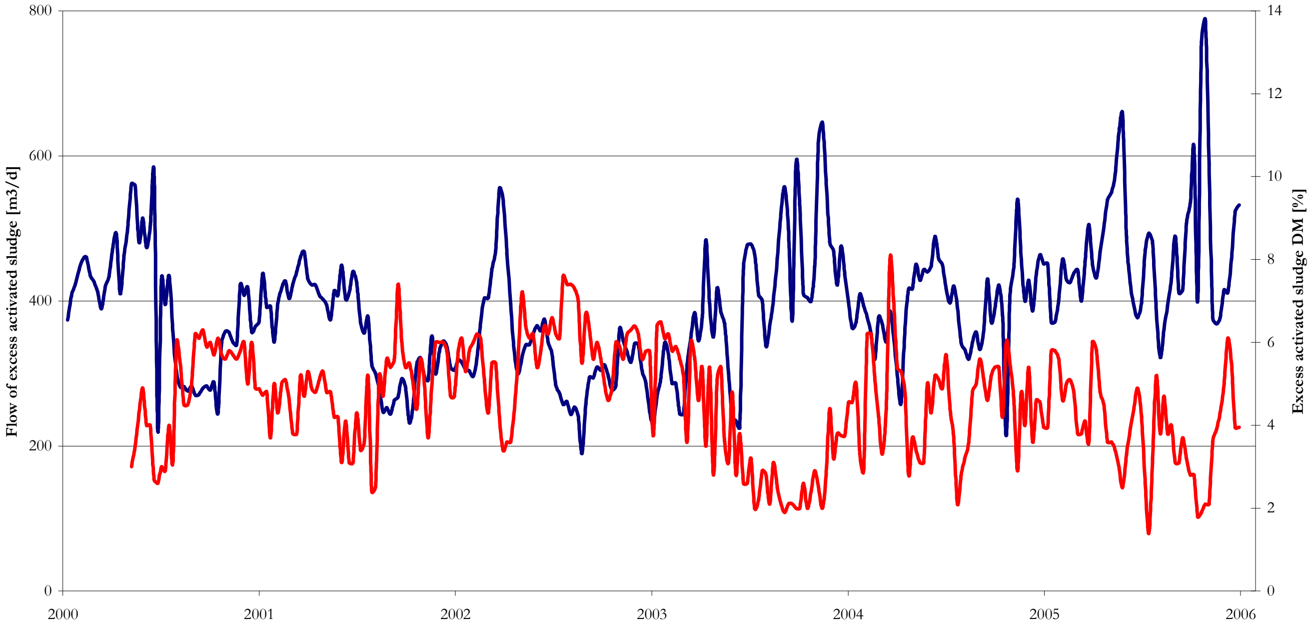

Figure 13. Flow (—) and DM concentration (—) of thickened excess activated sludge pumped to the digestion process.

During 1996, foam problems were detected in the digestion process at Henriksdal. The foaming was caused by the filament-forming bacterium Microthrix parvicellae entrapping produced biogas. Microthrix is not uncommon in municipal wastewater treatment plants and grows mainly in the biological stage at a high sludge age, and reaches the anaerobic digesters via the EAS. (Foam was detected in the inlet to the secondary sedimentation tanks but, surprisingly, not in the aeration tanks.) The measures taken were to increase the withdrawal of EAS to reduce the sludge age and thus limit the prevalence of Microthrix. However, this led to reduced nitrification in the biological stage. The digestion of EAS and PS was separated for a very short while and the digestion of EAS could then take place in AD1 and AD2 only, while longer retention time and better digestion of the sludge was achieved. To prevent sludge entering the biogas pipe system, the levels of fluid were reduced by approximately 0.3 m in AD3 and AD4, and by approximately 1.3 m in AD5 - AD7. The internal flows at the treatment plant were rearranged so that as little filament-containing sludge as possible was recirculated back to the anaerobic digesters. The measures taken resulted in reduced occurrence of Microthrix, the foaming in the anaerobic digesters decreased and the EAS could be charged to all anaerobic digesters again. Furthermore, top stirrers were installed in all anaerobic digesters to reduce the risk of operational problems due to foaming. During the early spring of 2008, foam was again detected in the anaerobic digesters.

5.4.c. External organic matter (EOM)

In March 2000, Henriksdal WWTP began to receive EOM. EOM is taken in via a separate tank (13 m^3) and pumped into the charging sludge pipe which passes from the primary sludge silos to the anaerobic digesters. To avoid clogging of the pipe owing to the fat content of EOM, sludge is always pumped from the sludge silo together with EOM to maintain a higher flow in the pipe. EOM is received throughout the year, with slightly lower amounts in the third quarter of each year (Figure 14).

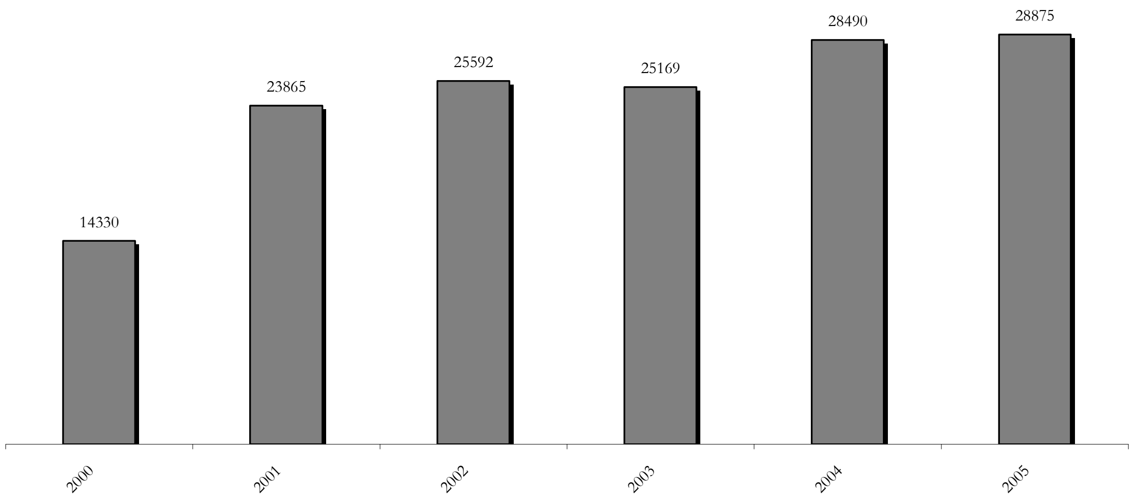

Figure 14. Quantity of EOM [m³] received by Henriksdal during the evaluation period.

96% of the EOM fraction consists of grease separator sludge from food production and restaurants. The annual mean for the quantities has been calculated for the entire evaluation period. Some materials have been received only during certain times of the year, but the proportion of such materials is very small and they are therefore included as a mean value for the entire period. Analyses of the concentrations of DM and ROI have been carried out on a number of occasions (35) on grease separator sludge and only on a few occasions on other organic matter.

The result in Figure 15 shows the DM concentration of grease separator sludge varies between 0.3 and 38.6%. The mean value from these measurements is 9.7% and the median value is 5.2%. The value of VS is more constant and the mean is 94.6% of DM. In calculations, the value 9.9%[8] is used as the DM concentration in EOM, although a recent investigation has pointed to 5.2 % as a more accurate value. The variation in the concentration of DM is considerable and may depend on a number of factors:

- Emptying interval of the grease separators in question.
- Sampling procedure – as grease accumulates in the vehicle; the sample may vary according to whether it is taken at the beginning or end of the pumping of the grease sludge from the vehicle to the receiving tank. At the start of the pumping, the aqueous phase comes first, and at the end of the pumping the sample comprises more grease.
- Sample handling – the grease will also separate from the water phase in the sample, and to obtain a representative sample for analysis, a well mixed sample and if possible also a larger amount of sample is required.

[8] Calculated mean of the analysis response that was available when the calculations were performed. As the actual mean diverges only marginally from this and as there is a high standard deviation, no recalculation has been carried out.

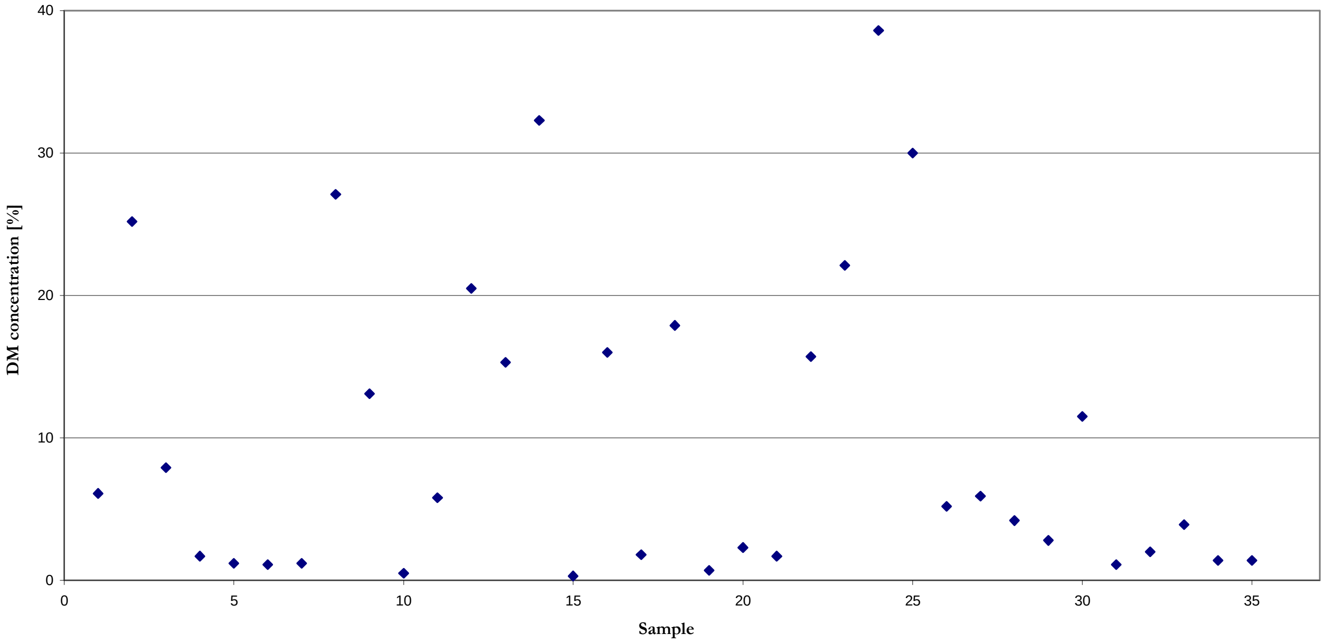

Figure 15. Analysis of the concentration of the DM [%] in grease separator sludge.

The sampling of the material takes place on delivery and the sample is taken in the pipe when the vehicle is emptied. Where large quantities of EOM are received, it is very important that the concentration of organic matter in EOM is known as this may vary a great deal and make a major contribution to the total organic load to the anaerobic digesters, see Figure 15, Table 4 and Table 5. At Henriksdal, the quantity of EOM corresponds to only 4% of the influent flow to the anaerobic digesters. The concentration of organic matter in EOM, where the above mean (a concentration of 9.9% DM) is assumed, accounts for 11% of the total organic load to the anaerobic digesters, see Table 4. An analysis of the sensitivity in the concentration of EOM shows that with a DM concentration of 0.3%, the quantity of EOM will correspond to 0.4% of the total load of organic matter to the anaerobic digesters and with a DM concentration of 38.6%, the quantity of organic matter will correspond to 33% of the organic load, see Table 4. The organic concentration of EOM is thus very important for small flows as well. It is therefore important that the knowledge of EOM is as great as possible and so representative and accurate conditions should exist for sampling and analysis. Samples should be taken more often if the values from the analyses have a high standard deviation.

It is possible that the results in Figure 15 describe reality, and that the variation in the concentration of DM depends on the operation and handling of the grease removal equipment. However, the dispersion in the results requires extra investigation of sampling and sample handling. To gain an idea of the separation of grease from the water phase in the vehicle and to investigate how the sampling procedure affects the results, a number of samples should be taken during an emptying operation. It is recommended that a number of samples, e.g. five, are taken at regular intervals throughout the emptying process. The samples should be analysed individually and also as a composite sample in which all samples have been mixed properly. To also see the variations in the method of analysis, a sample should be analysed (preferably the composite sample above) in five replicas. The deviation in the analysis response is calculated. Based on results obtained, a sampling routine is formulated and the persons who take samples are informed.

Table 4. Sensitivity analysis of the organic concentration of EOM with reference to the total organic load to the anaerobic digesters.

	DM [%]	*VS* [% of DM]	*Quantity of VS* [tonne/d]	*Proportion of organic load to AD* [%]
Lowest value	*0.3*	*94.6*	*0.2*	*0.4*
Mean value	*9.9*	*94.6*	*6.3*	*11*
Highest value	*38.6*	*94.6*	*24.4*	*33*

5.4.d. Summary of sludge flows and sludge quality

A summary of flows and concentration of organic matter in the various sludge streams is presented in Table 5. During 2002, the DM concentration of the PS and the EAS was higher than the mean value, Table 5. For example, the organic load during 2002 and 2004 was slightly higher than normal (Table 13 in Appendix IV) with very high values, including for weeks 32 - 35 of 2002. During this period, the flows were not higher than normal. The high load was instead a result of a high DM concentration in the primary sludge (Table 5). In 2004 the flow of PS was higher than normal (Table 5) which increased the organic load.

Table 5. Summary of substrates for digestion. The values for PS and EAS are calculated annual means, and values for EOM have been calculated from the mean of all analyses (n=35) conducted on grease during the investigation.

Year	Primary sludge (PS)			Excess activated sludge (EAS)			External organic matter (EOM)		
	Quantity	DM	VS	Quantity	DM	VS	Quantity	DM	VS
	[m³/d]	[%]	[% of DM]	[m³/d]	[%]	[% of DM]	[m³/d]	[%]	[% of DM]
2000	1 466	3.4	75.5	391	4.9	62.1	39	9.9	94.6
2001	1 443	3.3	75.0	358	4.7	62.1	65	9.9	94.6
2002	1 452	3.8	75.2	330	5.8	62.2	70	9.9	94.6
2003	1 388	3.6	75.6	400	3.7	62.5	69	9.9	94.6
2004	1 560	3.6	72.5	393	4.6	61.7	78	9.9	94.6
2005	1 411	3.6	72.6	468	4.0	62.6	79	9.9	94.6
Mean±SD	**1453±214**	**3.6±0.6**	**74.4±4.4**	**390±92**	**4.6±1.3**	**62.2±2.0**	**67±21**	**9.9**	**94.6**

In 2003, there was a low hydraulic load to the WWTP, and also a low flow of primary sludge with a normal DM concentration. This resulted in a low organic load to AD (Table 13 in Appendix IV and Table 5). The flow of thickened excess activated sludge was slightly higher than normal, but the concentration of DM after the centrifugation was low[9], (Table 5). The degree of degradation during the year was normal (Table 8). With a long retention time and a low organic load, the degree of degradation is expected to increase. A low flow of primary sludge means that the retention time of the sludge in the pre-sedimentation tanks increases and the sludge is not

[9] DM concentration of EAS is based on the manual sludge samples taken on working-days between 07:00 and 08:00. Follow-up carried out in autumn 2007 concerning the variation in concentrations of DM over a longer period during the day showed that these samples probably give an underestimate of the quantities of DM (Åkerlund, 2008).

as "fresh" as it usually is when it reaches the anaerobic digesters. There is a great difference in the biogas potential of "fresh" sludge and a sludge that has been in a pre-sedimentation tank for a long time. A possible reason for the slightly lower degree of degradation during the summer of 2003 is that the flow meter for the primary sludge does not show a correct value. As many calculations are carried out on the basis of the flow of primary sludge (during July - October 2003, the average flow of the corresponding week in 2002 and 2004 were used), this presumably gives a major influence on the result if the calculated reference flow is too low.

6. Monitoring of process and production

Monitoring of the digestion process takes place via a number of parameters. These tools consist of monitoring of operation via daily work in the plant, chemical analyses of the sludge in laboratory and calculations of production and process data. It is important to have a wide range of monitoring parameters as disturbances in the process can develop in different ways.

6.1. Biogas production

The quickest and clearest answer to how the process functions is to evaluate raw biogas production. The parameter biogas production should, for the purposes of this report, be understood to mean the production of biogas in the anaerobic digesters, unless otherwise indicated. The raw biogas consists mainly of methane and carbon dioxide, in which the proportions depend largely on which substrate is digested. In a conventional WWTP, the methane content is normally 60-70% (VAV 1981). Production of biogas in the anaerobic digesters is, in normal operation, relatively constant with the same hydraulic and organic load. If problems develop in the charging of the anaerobic digesters (e.g. a breakdown of the charging pump), the influence on the biogas flow will be evident instantaneously. These observations are made in daily operation and are the most important evaluation factor in preventing process disturbances, taking any action and having stable and high levels of production.

Biogas production has increased during the evaluation period (Table 6). The methane concentration also increased during the evaluation period. This is probably due to the fact that more grease is received for digestion as the degradation of grease produces a biogas with a higher methane concentration. If the influent flow of grease to the anaerobic digesters is correlated to the methane concentration in the biogas produced, a correlation is apparent.

Table 6. Total biogas flow (Nm^3/h) from the digestion process during the evaluation period. Values are calculated annual means.

Year	Biogas production annual mean [Nm^3/h]	CH_4 concentration annual mean [%]	Methane production annual mean [Nm^3/h]
2000	1021	64.7	661
2001	975	65.1	635
2002	1029	65.2	672
2003	1087	65.8	716
2004	1085	66.5	722
2005	1125	66.5	749
Mean±SD 2000-2005	**1054±132**	**65.6±1.7**	**693±95**

Biogas production from each anaerobic digester is measured with a separate gas flow meter. Over the year, biogas production shows the same pattern, with reduced biogas production during the summer months. This is due to the fact that the load to the entire treatment plant decreases, as does the load to the anaerobic digesters. The VS concentration of the sludge actually increases slightly at lower flows, but the organic load to the anaerobic digesters is lower during weeks 27 - 34 each year. The weeks of the period varies slightly between the years. This reduction in the load is clearly apparent as a reduction in biogas production in Figure 16 during the same weeks. During the summer months, it is therefore appropriate to take anaerobic digesters out of operation for maintenance. The lower organic load also provides an opportunity to receive extra EOM and achieve a more uniform biogas production around the year.

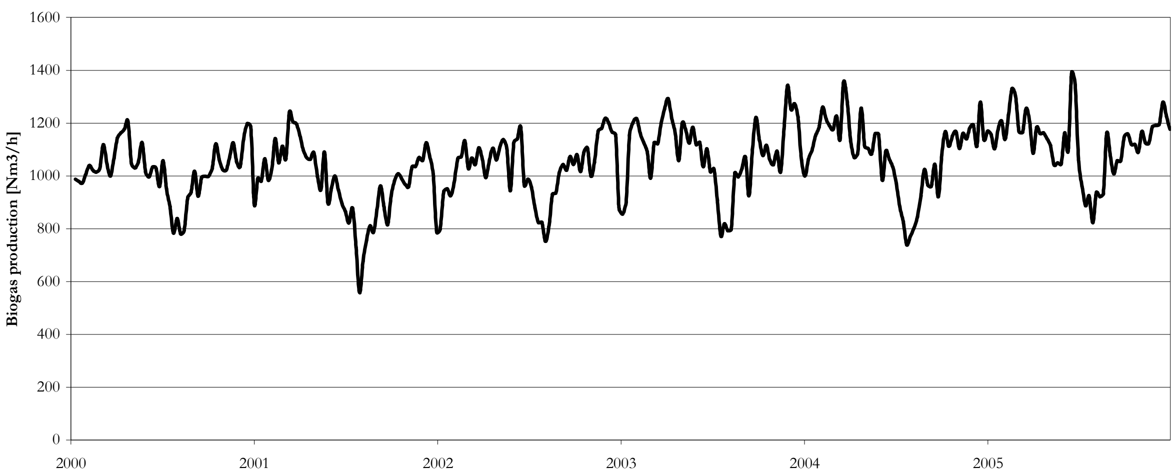

Figure 16. Total biogas flow (Nm^3/h) from the digestion process during the evaluation period.

6.2. Specific biogas production

A more detailed evaluation is obtained by monitoring the chemical analyses of the sludge. To determine how effectively the micro-organisms degrade organic material, two expressions are mainly used, specific biogas production and degree of degradation. Specific biogas production provides a quicker result and reflects instantaneous changes, whereas the degree of degradation is a slower parameter in which the process must be given time to become established and reach steady state.

Specific biogas production is the biogas produced in relation to the organic load and is calculated by Formula 6:

Formula 6. Calculation of specific biogas production.

$$Specific\ biogas\ production\left[Nm^3/kg\,VS\right] = \frac{quantity\ of\ biogas\ produced\left[Nm^3\right]}{quantity\ of\ charged\ organic\ matter\left[kg\,VS\right]}$$

Specific biogas production provides information about two things. For a process charged with a substrate that does not vary much in the composition of organic matter, it can be seen over a period of time how the degradation of the material changes. If specific biogas production increases, the efficiency of the microbial process of degradation has been improved. The efficiency improvement may have many explanations, such as more favourable temperature conditions for the micro-organisms and better mixing conditions in the anaerobic digesters, which increases the accessibility of the substrate. If the absolute biogas production is changed, with the same composition of the substrate, it can be established with the aid of the specific biogas production whether this is a result of a change in either charging or the microbial process of degradation. Specific biogas production is also used for the evaluation of different substrates and substrate mixtures. Depending on the composition of the organic matter, the substrate has different potential for biogas production. The biogas potential for a substrate is normally expressed as a specific biogas production potential. The result from the calculations from existing operating data is shown in Figure 17.

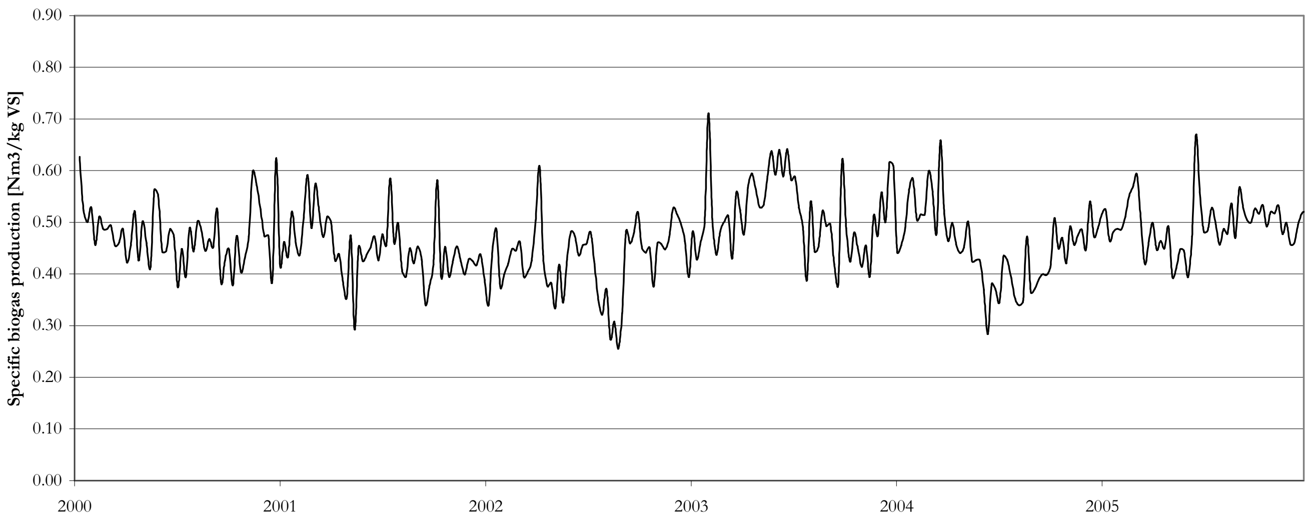

Figure 17. Specific biogas production from the digestion process during the evaluation period.

The quantity of biogas produced can be described in various ways. Table 7 shows some of the biogas production parameters. Typical values for these parameters for digestion of sludge at a WWTP are 0.5 – 0.75 Nm^3 biogas/kg VS_{in} and 0.75 – 1.12 Nm^3 biogas/kg $VS_{reduced}$ (VAV 1981). Compared with these values, specific biogas production at Henriksdal is slightly lower than expected, while gas produced per kg of reduced VS is in the middle of the expected range.

Table 7. Mean values of biogas production parameters during the evaluation period.

Year	Biogas production				Methane concentration	Specific Methane Production
	[Nm³/year]	[Nm³/kg VS]	[Nm³/m³ sludge]	[Nm³/kg VS_{red}]	[%]	[Nm³/kg VS]
2000	8 970 000	0.47	13.0	1.02	65	0.31
2001	8 540 000	0.45	12.6	0.98	65	0.29
2002	9 010 000	0.43	13.4	0.78	65	0.28
2003	9 520 000	0.52	14.3	1.03	66	0.34
2004	9 530 000	0.45	12.9	0.93	67	0.30
2005	9 860 000	0.50	13.9	1.03	67	0.33
Mean±SD	**9 240 000± 1 160 000**	**0.47±0.07**	**13.4±1.8**	**0.96±0.27**	**66±1.7**	**0.31±0.05**

Monitoring of biogas production and the degradation of organic matter are carried out by analyses of substrate and digested sludge and also of the products dewatered sludge and biogas.

6.2.a. Dependence of biogas production on process conditions

In Figure 18, HRT has been compared with specific biogas production. The values are weekly means throughout the evaluation period. The retention times are inversely proportional to the sludge flow and have rarely been stable for longer periods. For a better evaluation of the importance of the retention time for specific biogas production, it is desirable for the process to reach steady state at different retention times (see retention time experiment in section 6.3.a.). No significant trend can be seen in data indicating that a longer HRT gives more complete degradation (more biogas per kg VS). The diagram indicates, however, that specific biogas production decreases when the retention time decreases below 15 days. In area A in the figure (HRT < 13 d), two of the values belong to a period during 2004 when two anaerobic digesters were emptied at the same time for cleaning and two of the values belong to two separate weeks when more than one anaerobic digester were temporary out of order. It was then difficult to keep the temperature at the set point of 37°C, and the mean value in the period of 2004 was 33.3°C in the anaerobic digesters that were in operation. Values with specific gas production below 0.32 (area B in the figure) have its origin mainly from a period in August 2002 when the organic concentration of the primary sludge showed higher values than normal.

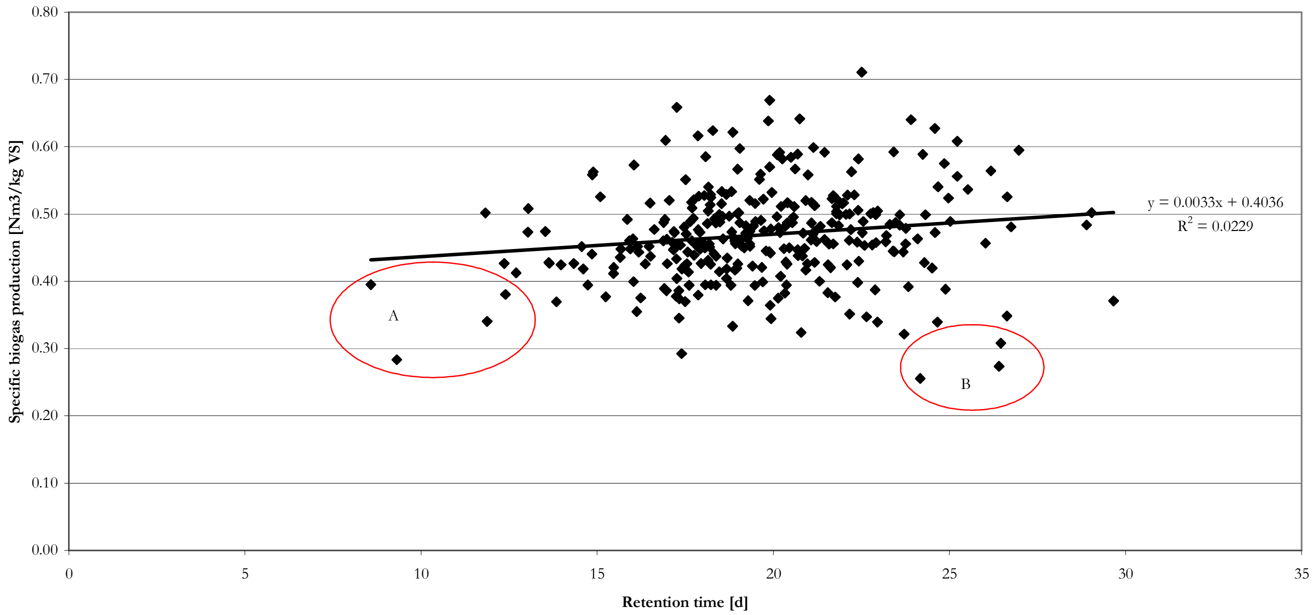

Figure 18. Specific biogas production as a function of retention time (HRT). The linear regression shows that there is no strong correlation between the variables.

6.2.b. Batchwise digestion of mixed primary and excess activated sludge

Batchwise digestion investigations on mixed PS and EAS have been conducted at JTI, and the entire report is presented in Appendix V. Two studies were conducted with three replicas for each study. In one study, only inoculum was added, and in the second study inoculum + substrate were added. The substrate consisted of PS, 75.5% of DM, and EAS, 24.5% of DM. The digestion temperature was kept constantly at +37°C.

Biogas and methane production from the substrate was calculated as the difference between average gas production from bottles with inoculum and substrate and average gas production from bottles with only inoculum. The mean value for cumulative methane production was 0.34 NL/g VS for the mixture of primary and secondary sludge (Figure 1 in Appendix V). The methane concentration at the end of the study was 68%. The study went on for 55 days. After 23 days, the methane yield was 0.32 NL/g VS (91% of the yield at the end of the study), which indicates that retention times above 23 days only give a marginally increased methane yield relative to the extra reactor volume required. After 15 days, the methane yield was 0.29 NL/g VS (83% of the yield at the end of the study).

The mean value for retention time at Henriksdal is approximately 20 days. If the results from the batchwise investigation[10] are recalculated for a continuously stirred reactor, approximately 88% of the sludge's gas production potential is found to have been utilised at 20 days[11]. If the sludge is instead digested in two equally large continuously stirred reactors connected in series, with a total retention time of 20 d, it is found that

[10] Results from Borggren (2007) indicate that digestion proceeds approximately twice as quickly in batchwise digestion with continuous stirring compared with batchwise digestion in which the bottles are shaken once a day. It has therefore been assumed in the calculations that the digestion recorded at JTI takes place in half the time compared with that recorded.

[11] The gas production potential of the sludge is defined here as the amount of methane produced after 54 d in batchwise digestion without continuous stirring.

approximately 94% of the gas production potential can be utilised. Extrapolation of the results from the batchwise investigation therefore indicates that gas production would increase by approximately 7% if serial operation was to be applied instead of parallel operation. An increase in the retention time from 20 to 30 d, for a continuously stirred reactor, increases the degree of utilisation from approximately 88 to just fewer than 92%, which corresponds to a gas production increase of just under 4%. Another interesting result is that the degree of degradation decreases relatively sharply when the retention time decreases below 15 d (Figure 19).

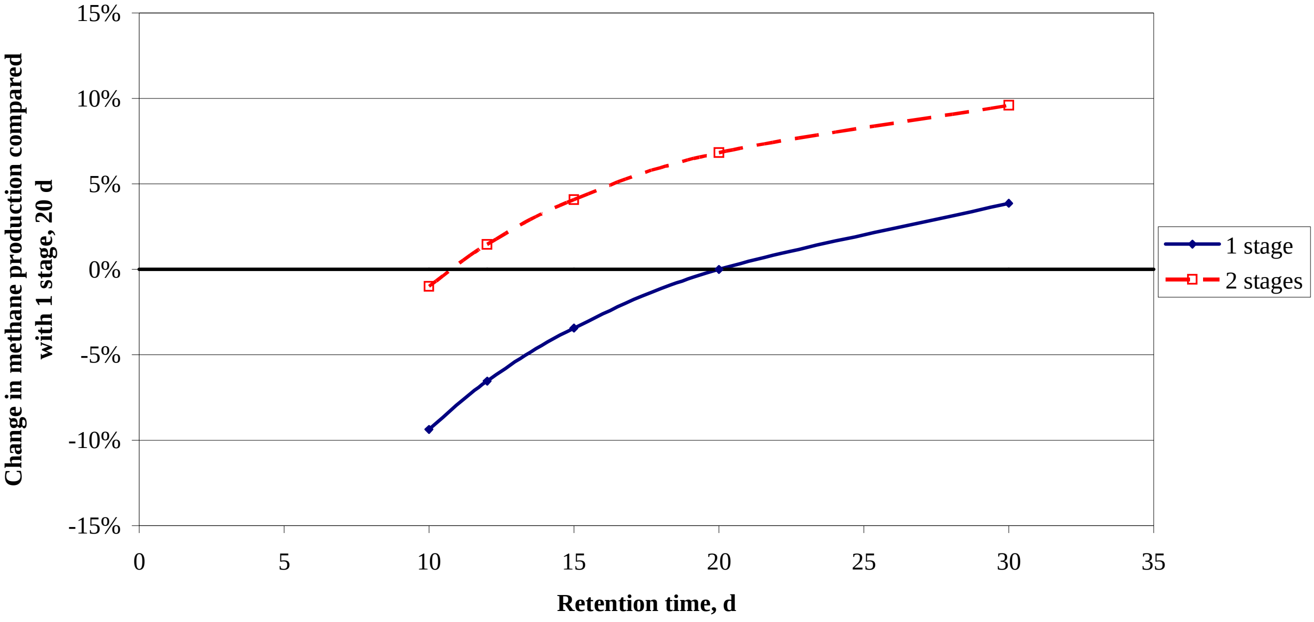

Figure 19. Expected change in methane production in serial operation compared with parallel operation in the case of a retention time of 20 d. Calculations carried out with the aid of data from JTI's digestion investigation corrected with the assumption that degradation takes place approximately twice as quickly in the case of good stirring.

6.3. Degree of degradation

The degree of degradation shows how effectively the substrate has been used by measuring VS in the digested sludge and comparing this with VS in the substrate. This then gives a measure of how effectively the process has digested the material. The term is synonymous with the concept of degradation degree, breakdown level, decomposition level and stabilisation level, which are all used in evaluating the process. The degree of degradation can be determined in two ways. One way is to calculate it by using the mass balance with Formula 7, where it is assumed that all organic matter, not leaving the anaerobic digesters with the digested sludge, is degraded and has formed gas. The main disadvantage is that the concentration of volatile solids in substrate and digested sludge must be accurate to give a correct result when calculating the degree of degradation. However, the experience shows that this is not always the case. The volume of influent is generally assumed to be equal to the volume of effluent in practice (but not in theory), which is not always accurate:

Formula 7. Calculation of degree of degradation with the mass balance concept.

$$Degree\ of\ degradation\ [\%] = \left(\frac{Qin * VSin - Qut * VSut}{Qin * VSin}\right) * 100$$

Another way of calculating the degree of degradation is described in Hawerman *et al.* (1979). The degree of degradation is then calculated with Formula 8. Flows and concentrations of DM are not included in the formula, and the calculations thus become less vulnerable to variations in both flow measurement and DM analyses:

Formula 8. Calculation of degree of degradation with flow independence and DM independence.

$$Degradation\ degree\ [\%] = (1 - \frac{ROI_{in} * LOI_{out}}{ROI_{out} * LOI_{in}}) * 100$$

It is assumed in this formula that the mass flow to the anaerobic digesters of inert material is the same as the outflow, i.e. it is assumed that inert material is not reduced, accumulated or produced in the digestion process[12] (VAV 1981). Bottom discharges are, however, carried out from the anaerobic digesters, known as "purging", which means that this formula does not fully apply. Purging is carried out once a week in each anaerobic digester. Maximum 93 m^3 digested sludge is drained in total each week, which is equivalent to approximately 13 m^3/d or 0.7% of digested sludge removed. The annual means for the degree of degradation at Henriksdal for the evaluated period are shown in Table 8. The values have been calculated for weekly random samples and manual analyses of DM and VS.

Table 8. Annual means ± standard deviation (median values) for degree of degradation at Henriksdal during the evaluation period. Data for "set point 35ºC" and "set point 37ºC" indicate mean value ± standard deviation (median value) for 90 weeks before or after October 2001 when the set point was increased from 35ºC to 37°C.

	Temp., ºC	HRT, d	Mean (median) degree of degradation Formula 7 [%]	Mean (median) degree of degradation Formula 8 [%]
2000	34.3	19.5	47.9 ± 5.7 (46.8)	50.1 ± 7.8 (49.4)
2001	35.0	18.9	46.8 ± 8.5 (47.3)	49.3 ± 8.0 (50.9)
2002	36.2	21.1	55.1 ± 7.0 (53.7)	50.6 ± 9.7 (52.9)
2003	36.4	20.3	51.1 ± 6.8 (51.3)	49.6 ± 7.1 (50.1)
2004	35.5	18.5	48.8 ± 6.3 (50.1)	45.5 ± 8.3 (45.8)
2005	35.6	19.8	47.1 ± 5.2 (47.0)	44.1 ± 8.0 (46.3)
Set point 35 ºC	34.4	19.1	46.8 ± 7.4 (46.4)	49.6 ± 8.2 (50.4)
Set point 37 ºC	36.2	21.3	53.8 ± 7.1 (53.0)	50.1 ± 8.5 (51.9)
Mean±SD 2000 - 2005	**35.5±1.2**	**19.7±3.2**	**49.5 ± 7.2 (49.4)**	**48.2 ± 8.5 (49.2)**

In interpreting the results, account should be taken of the fact that if recorded incoming DM concentrations are lower than actual concentrations, an underestimate of the degree of degradation is obtained when formula 7 is used. This may be the case for EAS as the sampling took place mainly during the part of the day when DM concentrations are lowest (Åkerlund, 2008). As mentioned above, formula 8 is based on the assumption that the amount of incoming inert material is as great as the amount of outgoing inert material and that this is not entirely true because bottom discharges take place to remove sand and gravel that has accumulated in the anaerobic digesters. Nevertheless, it may be assumed that the material removed by bottom discharges has a higher concentration of fixed solids than the sludge in the anaerobic digester effluent. This means in turn that, with the bottom discharges taken into account, the actual degree of degradation is slightly underestimated. The overall

[12] Or that these processes cancel each other out so that the net quantity of inert material is not changed.

picture is thus that the degree of degradation is around 50%, which is similar to, for example, the Nykvarn WWTP in Linköping, where it is 52.4 % (Vallin *et al.*, 2007).

A trend over time cannot be confirmed, and nor are clear seasonal variations identifiable for the degree of degradation (Figures 20 and Figure 21). A slight decrease over time in the degree of degradation may be evident in Figure 21. It is notable, however, that the years with the longest mean retention time and highest temperature, i.e. 2002 and 2003, also have the highest degrees of degradation (Table 13 in Appendix IV)[13].

In 2002, the degree of separation of organic matter in the pre-sedimentation tanks was higher than for other years during the period under investigation (Appendix III). In addition, a primary sludge with a relatively high DM was obtained (Table 5). The amount of organic matter to the digestion process was highest during that year; see Table 13 in Appendix IV. However, biogas production did not show a corresponding increase and these is apparent in specific gas production in 2002 with a low value, see Table 7, and also in the volume of biogas produced according to Table 13.

When the degree of degradation for the period before and after the increase in the set point in October 2001 is compared, it can be seen that the mean value for the degree of degradation is substantially higher at the higher temperature where formula 7 is used (Table 8). In the case of calculation in accordance with formula 8, the difference is smaller, and corresponds to an increased digestion of 1%[14]. It should be pointed out, however, that the differences are not statistically significant.

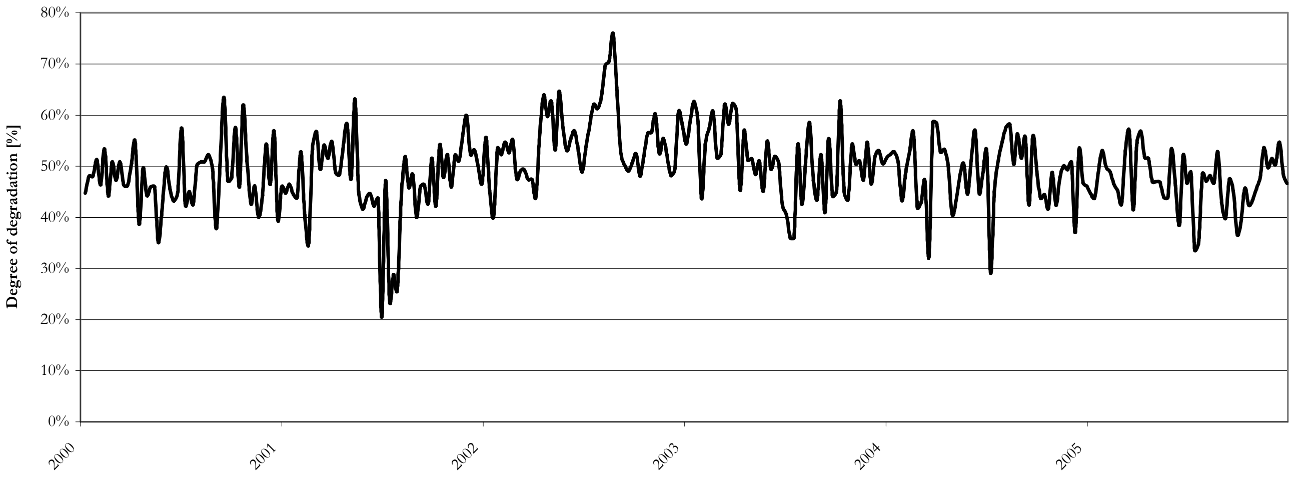

Figure 20. Degree of degradation of the organic matter during the evaluation period, calculated with.

[13] Over the period 09/07/2003 – 21/11/2003, the flow meter for primary sludge was out of operation. To capture the seasonal variations, flow values were taken from the same period in 2002 and 2004. A mean value from the weekly means for 2002 and 2004 was calculated and used as a flow value for the corresponding week in 2003. These calculated values were used throughout the study.

[14] I.e. 1% more organic matter is degraded at the higher temperature.

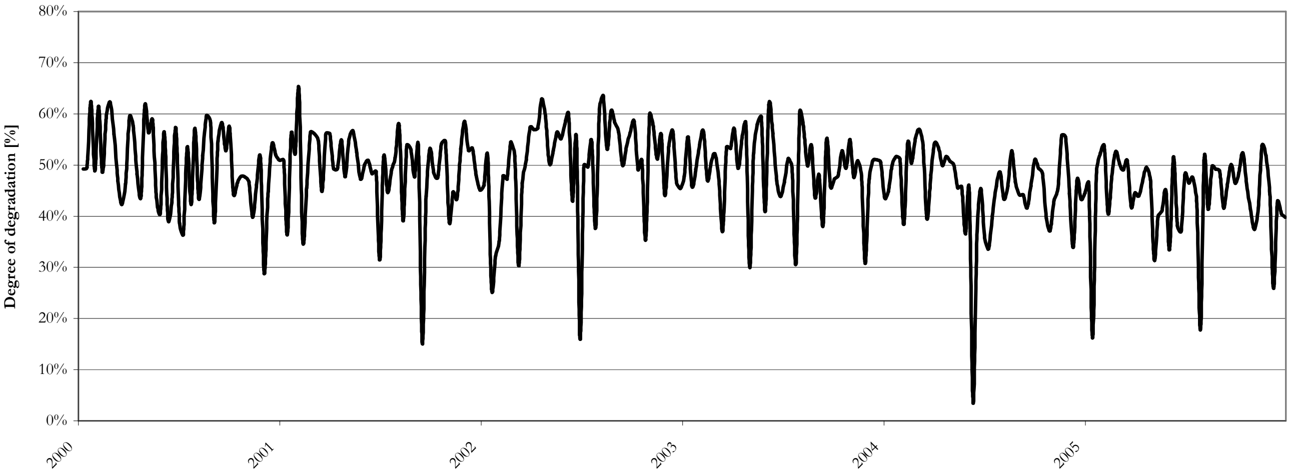

Figure 21. Degree of degradation of the organic matter during the evaluation period, calculated with Formula 8.

6.3.a. Significance of temperature and retention time – investigation results

A number of factors affect the degree of degradation and biogas production. To be able to study the impact of temperature alone, a couple of comparisons were made between two anaerobic digesters at Henriksdal that were to be operated under identical conditions with the exception of the parameter investigated. The investigation was primarily focused on studying the significance of temperature, but additional experiments were also conducted to study the significance of retention time.

Anaerobic digester 3 (AD3) was chosen as a reference digester and anaerobic digester 4 (AD4) was varied operationally. AD3 was given a set point of +37°C and AD4 was modified during periods with set points of +31°C, +33°C, +35°C and +37°C (Table 9). With each change, AD3 and AD4 were operated for at least two weeks with the new set point values before samples were taken.

During Christmas and New Year (2006/2007), an investigation was conducted to operate AD3 and AD4 with different retention times, with the anaerobic digesters achieving retention times of 20 and 16 days respectively (experiment 5). During this period, however, the temperature was +36°C in AD3 and +34°C in AD4 owing to the insufficient capacity of existing heat exchangers[15]. With differences in both retention time and temperature, the impact of different retention times alone could not be evaluated. To obtain a smaller temperature difference between the anaerobic digesters, the set point was reduced to +35°C (experiment 6 in Table 9). There was still a difference in actual temperature, 1.0°C, but the results can nevertheless be considered to confirm the hypothesis that the retention time is important for the degree of degradation. The difference in retention time was 3.5 days. During experimental period 7, AD3 and AD4 operated again with equally long retention times, but with +35°C as the set point instead of +37°C as the set point (experiment 4).

The results show that there is a clear temperature effect as there is a significant difference in degree of degradation for experiments 1 and 2, in which the temperature difference is also greatest. The results from experiments 3 and 5 also indicate that there is additionally a difference in connection with a temperature difference of approximately 2°C, but the difference is, however, not statistically significant. In experiment 5, the retention times in the anaerobic digesters also differ, which makes it difficult to distinguish the effect of differences in temperature and differences in retention time. Furthermore, the results indicate that the degree of

[15] The set point + 37°C could not be achieved in any anaerobic digester.

degradation decreases to a relatively large extent if the retention time is reduced from approximately 15 d to 11 d (experiment 6), but the difference is not statistically significant. Finally, the results from experiment 5, when compared with the results from experiment 3, indicate a slight increase in the degree of degradation when the retention time is extended from 16 d to 20 d.

It is also interesting to compare the effect on biogas production with the heat required. A very approximate mean from calculation of the values shows that gas production increases by approximately 1%/°C with retention times of 15-19 d. The results indicate that this applies also to an increase in temperature from 35 to 37°C. The temperature effect is probably greater with shorter retention times, but it is assumed in the following discussion that an effect of approximately 1%/°C can be obtained under normal operating conditions, i.e. with a retention time of approximately 20 d. If the energy content of the raw biogas is assumed to be 6.5 kWh/Nm^3, this means that the biogas production corresponds to approximately 60 GWh/year at Henriksdal. This means that an increase of 1% corresponds to 0.6 GWh/year. With a sludge flow of approximately 1900 m^3/d and an energy need of approximately 1.2 kWh/m^3/°C, a gross heat need of 0.83 GWh/°C is obtained. However, it should be taken into account that the biogas is an energy source with a quality (i.e. exergy) that is considerably higher than the energy quality of heat. This is taken into account by using the exergy concept. During 2007, Henriksdal was connected to the district heating network, and in the future the heating of sludge will take place with this heat source. The exergy factor for district heating is approximately 0.3 kWh exergy/kWh energy, which means that the exergy requirement is approximately 0.25 GWh/°C/year. This means that the "net exergy" is approximately 0.35 GWh/°C/year for a change in the temperature around the "the normal operating situation" of a 20-day retention time and a temperature around 35°C.

From the energy perspective, the total sludge flow is very important. A reduction in the retention time from 20 to 15 d corresponds, when all anaerobic digesters are in operation, to an increase in the sludge flow of 650 m^3/d. To increase the temperature of a sludge flow of 650 m^3/d by 20 °C, e.g. from 15°C to 35°C, the additional heat requirement will be approximately 5.5 GWh/year. If, on the other hand, the sludge can be thickened further so that the retention time can be increased to 25 d, this means that the flow is reduced by less than 400 m^3/d, which means a reduced heating requirement of approximately 3.4 GWh/year. An increase in the retention time from 20 to 30 d means that the sludge flow must be reduced by 650 m^3/d, and this gives a reduction in the heating requirement of approximately 5.5 GWh/year. The effect on biogas production of increasing the retention time from 20 to 30 d is approximately just under 4%, which is equivalent to just over 2 GWh/year (Figure 19).

Table 9. Results from experiments with different temperature and retention times for paired comparison of operation of anaerobic digesters 3 and 4 at the Henriksdal WWTP. [3]

Experiment (period) w = week	**Temperature, °C[16] (set point)**			**Retention time, d**			**Difference in degree of degradation, % mean ± std. dev. Δ(AD3 – AD4)**		**Gas production**	
year 2006/ 2007	AD3	AD4	difference, AD3-AD4	AD3	AD4	diff., AD3 - AD4	Form. 7 (VS red.)	Form. 8 (ROI/ LOI)	Nm³/kg VS in Δ(AD3-AD4)	increase, %[17]
1 (w21-w27)	36.2 (37)	30.9 (31)	5.3 (6)	14.5	14.5	0	3.6±2.0	3.0±1.1	0.09	22 (6.3)
2 (w31[1]-w34)	36.6 (37)	32.9 (33)	3.7 (4)	18.4	18.5	-0.1	1.0±1.2	1.6±1.2	0.09	20 (3.1)
3 (w37[1]-w40)	36.5 (37)	34.8 (35)	1.8 (2)	15.2	15.2	0	0.6±2.7	1.0±1.5	0.05	11 (2.5)
4 (w43-w45[1])	36.2 (37)	36.0 (37)	0.2 (0)	13.5	13.8	-0.3	-1.4±1.4	0.3±1.4	0.04	9 (0.6)
5 (w49-w8)[2]	35.5 (37)	33.7 (37)	1.9 (0)	19.9	15.9	4.0	0.9±3.2	1.5±1.9	0.18	40 (3.6)
6 (w20-w23)	34.7 (35)	33.7 (35)	1.0 (0)	14.7	11.2	3.5	3.5±6.9	5.1±6.2	0.12	24 (12.4)
7 (w27-w36)	34.8 (35)	34.9 (35)	-0.1 (0)	15.0	15.2	-0.1	-2.1±1.7	-0.5±0.9	0.02	4.0 (-1.0)
7 (w27-w36)	34.8 (35)	34.9 (35)	-0.1 (0)	15.0	15.2	-0.1	-2.1±1.7	-0.5±0.9	0.02	4.0 (-1.0)

[1] = half the week, [2] = not week 52 - week 3, [3] for raw data, see Appendix VII

6.3.b. Simulation of the effect of series operation

Jeppsson (2007a; 2007b) conducted a simulation with the aid of "IWA Anaerobic Digestion Model no 1" (ADM1) to study the effect of a possible serial operation of the anaerobic digesters at Henriksdal. Furthermore, the effect of an increased organic load, which may be expected in about 10 years, has been simulated[18].

[16] Temperature data are taken from the computer program WASTE, but corrected on the basis of manually measured temperatures with the same thermometer for both anaerobic digesters.

[17] The increase in biogas production calculated on the basis of the change in the degree of degradation is given in parenthesis. These values probably provide a more accurate representation of the impact on biogas production as gas flow measurement is subject to greater uncertainty than DM and VS analyses.

[18] The increase in load to Henriksdal is approximately 1%/year and a 10% increase has been studied here.

It has been assumed in the simulations that in the case of serial operation, stage 1 has a volume of 23700 m^3 and stage 2 has a volume of 15200 m^3[19]. In the case of serial operation, it is assumed that all sludge and external organic matter is supplied to stage 1. All anaerobic digesters were assumed to be continuously stirred.

Table 10. Assumed flows and organic loads for "current situation" and "future" operating scenario.

	Primary sludge		Excess activated sludge		External organic matter	
	m^3/d	tonne VS/d	m^3/d	tonne VS/d	m^3/d	tonne VS/d
Current situation	1450	37.6	390	11.1	70	6.7
Future	1595	41	429	12	336	31.9

In interpreting the results, it should be taken into account that the data for characterising the sludge in a manner that is desirable from the modelling perspective were insufficient. Only total amounts of organic matter and comparisons with actual degrees of degradation were available in the simulations.

With regard to the external organic matter, it has been assumed for the current situation that this consists to 100% of fat. The entire increase in EOM from the "current situation" to "future" is assumed to come from source separated organic waste, mainly from restaurants and shops.

In ADM1, there is a possibility for using "interface models", referred to below as the interface model. If this model is not used, all COD in the sludge is assumed to enter the anaerobic digesters as composite material and is then divided into proteins, carbohydrates, fats and inert material in accordance with the assumption predefined in the "ADM1 model". Disintegration of the sludge to proteins, etc. is the slowest process in the AMD1 model. If the interface model is used, this means that disintegration takes place instantaneously. The main motive for using the interface model is to distinguish the disintegration of internal material, i.e. degradation of biomass, from the disintegration of the sludge as it is significantly faster.

The results presented in Table 11 come from simulation of the two extreme cases, i.e. partly it has been assumed that all sludge and EOM has been incorporated as composite material and partly it has been assumed that all sludge and EOM disintegrates instantaneously. Generally, the degree of degradation and biogas production are substantially higher than reported for Henriksdal during 2000 – 2005. However, it can be stated that simulation without the interface model yields the best match with degree of degradation measured. If the results from these simulations are used to assess the impact on biogas production, an expected increase of approximately 5% is obtained for the transition from parallel operation to serial operation. Jeppsson (2007b) considers, however, that modelling with the interface model gives more reliable results with regard to degree of degradation.

[19] The chosen volume distribution is based on the volume of the existing anaerobic digesters and what was initially considered a reasonable volume distribution between the two stages, (in the proposition AD4 - AD7 belong to stage 1 and AD1 - AD3 belong to stage 2).

Table 11. Calculated degree of degradation and expected methane production[20] for the various operating scenarios.

	Current situation				Future			
	With interface model		Without interface m.		With interface model		Without interface m.	
	degradation degree, %	methane, Nm^3/d	degradation degree, %	methane, Nm^3/d	degradation degree, %	methane, Nm^3/d	degradation degree, %	methane, Nm^3/d
Parallel operation	64.2	22349	58.2	20589	66.3	34237	61.4	31986
Serial operation	65.1	22618	62.2	21774	67.3	34661	64.8	33520
increase (%)		1.2		5.8		1.2		4.8

The results also show that the degree of degradation may be expected to increase in future despite an increased load. This is, however, an effect of the fact that the proportion of EOM increases sharply[21] and that this fraction is easier to degrade than the sludge.

6.4. COD balance for digestion

A mass balance can be carried out on the various treatment stages of a WWTP to form an idea of material flows. The system for the mass balance is delimited in accordance with Figure 22 and the balance is arranged as follows:

PS + EAS + EOM = BIOGAS + DIGESTED SLUDGE

A variable often used in mass balance calculations of organic material is COD. COD is chemical oxygen demand, i.e. the amount of oxygen equivalent to the organic matter that can be oxidised by using a strong chemical oxidising agent. The COD concentration is measured in the various sludge streams and calculated for the biogas produced. A COD balance has been made for the respective year and the calculated values are shown in Appendix VI.

[20] In calculations, production in kg methane/d reported by Jeppsson (2007b) has been converted to volume via the density 0.717 kg CH_4/Nm^3, (the theoretical density is 0.716 kg CH_4/Nm^3).
[21] The proportion of EOM increases from approximately 11% of the VS in the substrate to just over 37% of the VS in the substrate.

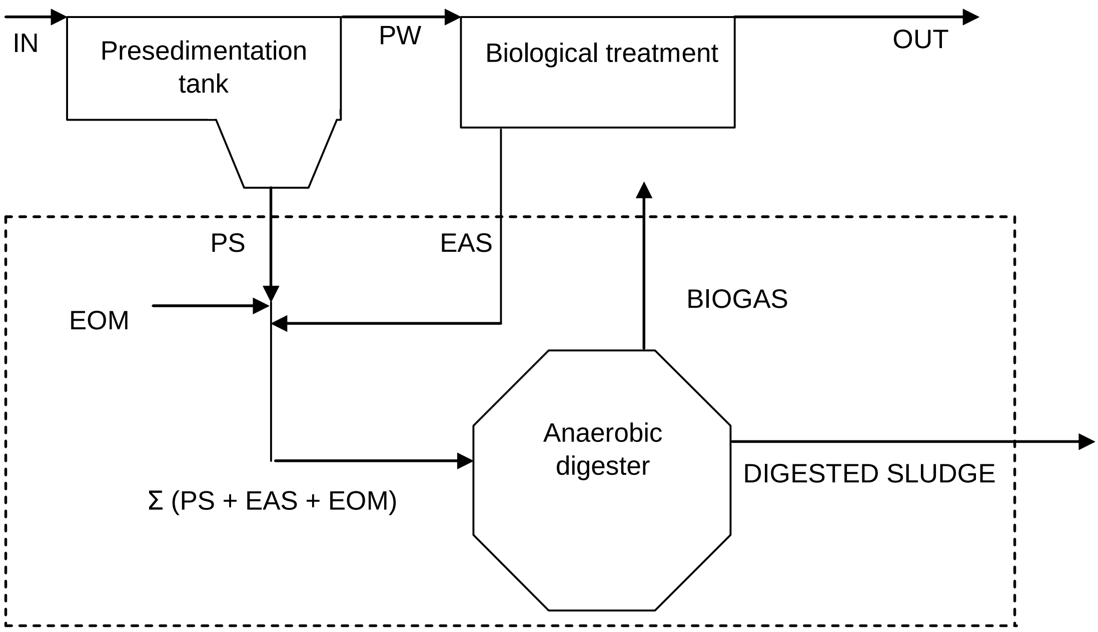

Figure 22. The system limit for COD balance over the digestion process is shown by the dotted line.

The energy in the organic matter is converted in the digestion process to biogas, or alternatively remains as organic matter in the digested sludge. The COD of the substrate to the anaerobic digesters is equal to the total amount of organic matter in PS, EAS and EOM expressed as COD. The amount of COD from PS and EAS is relatively constant over the years and has been calculated from flows and analyses of DM and VS (Table 12, Appendix III and Appendix VI). The amount of COD from EOM has slowly increased from the start of receiving in the year 2000. On average, almost 46% of the COD in the substrate was found in the digested sludge, and just about 52% as CH_4. Thus, almost 100 % of the COD from incoming sludge and EOM are found in the digested sludge and the biogas. If the year 2002 is excluded (87%), the values are in the range 97 - 103%. Raw data for the COD balance are presented in Appendix VI. The degree of degradation based on the COD balance gives a higher value, approximately 53% on average, than that calculated with the aid of VS (barely 50%). This is explained mainly by the relatively high COD/VS quotient for EOM. EOM is, after all, more readily degradable than sludge, and EOM's share of incoming substrate is greater if the calculation is based on COD than if the calculation is based on VS.

Table 12. Results from calculation of the COD balance of the digestion process.

Year	Σ to AD	Digested sludge		CH_4		Σ Digested sludge + CH_4	
	[t COD/d]	[t COD/d]	[% of COD supplied]	[t COD/d]	[% of COD supplied]	[t COD/d]	[% of COD supplied]
2000	85	42	49	45	54	87	103
2001	88	41	47	44	50	85	97
2002	98	39	40	46	47	85	87
2003	86	38	44	49	57	87	101
2004	97	44	46	50	51	94	97
2005	92	43	47	51	56	94	103
Mean	**91**	**41**	**46**	**47**	**52**	**89**	**98**

6.5. pH and alkalinity

pH and alkalinity both provide a measure of how well the process functions. Alkalinity provides a measure of the system's buffer capacity and thus informs of how sensitive the process is to disturbances.

Enzyme activity and digestion efficiency are highly dependent on pH. Hydrolysing micro-organisms have high levels of activity in the case of a pH above 5.0 while methane-producing micro-organisms cannot function below a pH of 6.2. Most digestion processes at WWTPs have a pH between 6.8 and 7.2. pH is highly dependent on which substrate that is supplied to the anaerobic digesters. If a protein-rich substrate is supplied, the nitrogen content in the form of ammonium will increase the pH and a stable process with a pH value above 8.0 can be obtained. If the pH value becomes much too high, especially in combination with high concentrations of ammonium, the process might be negatively affected.

In the digestion process at Henriksdal, pH is measured once a week in the respective anaerobic digester. The value is very stable at 7.2.

The stability in pH is strongly linked to alkalinity and thus the buffer capacity which counteracts variations in pH. Alkalinity exists mainly in the form of hydrogen carbonate in equilibrium with carbon dioxide at a given pH. As organic matter is anaerobically degraded, carbon dioxide is a degradation product. The carbonate buffer system can be described with the carbon dioxide produced in equilibrium with carbonic acid, hydrogen carbonate alkalinity and carbonate alkalinity.

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

As protein-rich substrate is degraded, the above formula still applies to the carbon, but a further contribution to the alkalinity is obtained via the release of ammonium ions.

$$NH_3 + H^+ \leftrightarrow NH_4^+$$

A reduction in alkalinity in the case of an unchanged substrate composition indicates a disturbance in the process and probably an accumulation of organic acids.

During the temperature experiments, alkalinity in AD3 and AD4 was measured to gain information on whether the modified conditions results in a lower buffer capacity. However, alkalinity was uniform in the two anaerobic digesters and had a mean of 3400 mg HCO_3/l. A value above 2000 mg/l is normally sufficient for a municipal anaerobic digester.

6.6. Organic acids

Volatile fatty acids or VFAs are fatty acids with a carbon chain of six carbons or fewer (such as formic acid, acetic acid, propionic acid and butyric acid). VFA provide a measure of the state of the process. Organic fatty acids are formed as part of the digestion process. As the formation of organic acids takes place early in the digestion process, a change in the process is first seen in this analysis. Often, organic acids are measured as a combined parameter and the result is expressed in the quantity of acetic acid per litre, [mg HAc/l]. The analysis is vulnerable to variations in sample handling. As the acids are an intermediate product in the digestion process, it is important that the digestion is stopped after sampling. This is done by the sample being cooled directly after sampling and then analysed as soon as possible.

The concentration of organic acids is normally low at Henriksdal. During 2006, the VFA concentration was below 100 mg/l. In most analyses it is important to see not only the absolute value of the analysis response but also trends and variations in prior measurements.

6.7. Process stability

With the annual variation that occured during the investigated period, there is a risk of process disturbances. New heat exchangers with a greater capacity have been installed during 2008. After the exchange, it is possible to heat the sludge to the desired set point of temperature. District heating was installed in Henriksdal in autumn 2007, which made it possible to upgrade more of the raw biogas to biomethane instead of using it to warm the anaerobic digesters.

There should be a greater knowledge of external organic materials and their impact on the total load. What is received affects not only the digestion but also the entire wastewater treatment process. As the wastewater treatment is the primary activity, no external organic material that complicates or inhibits the treatment of the wastewater should be received. With an increased load, the process may also be more vulnerable to process disturbances. At the Tekniska Verken in Linköping, a product with the name KemwaterTM PIX-KMB1 has been developed together with Kemira Kemi AB. This product has made it possible to load a digestion process with a higher proportion of organic material without foaming occuring. This has been demonstrated in laboratory experiments, and Figure 23 shows two experimental reactors, with the reactor on the left having received an addition of KMB1 and the reactor on the right not having received an addition of KMB1. This addition may also be an alternative for the digestion at Henriksdal if the load of external organic matter increases.


Figure 23. Two experimental reactors from the laboratory at the Tekniska Verken in Linköping for the development of the process aid KMB1. The left-hand photograph shows the experimental reactor with KMB1 added and the right-hand photograph shows the reference reactor. The photographs were taken on the same day; while the experiment was being performed with a high load.

7. Discussion and conclusions

The evaluation of the biogas production at the Henriksdal WWTP has provided a good insight into the plant and the processes. The focus has been on the anaerobic digestion of organic matter and raw biogas production, though also on the influence of the digestion on the wastewater treatment processes and the influence of these processes on the anaerobic digestion. If, for example, there is a well functioning separation of solid material in the pre-sedimentation tanks, this provides good conditions for degradation of more organic matter in the anaerobic digesters. It is important to conduct a study of the production and separation of primary sludge in the pre-sedimentation tanks and to optimise these processes.

Through inspection and documentation in connection with emptying, it was found that AD2 was in a good condition (Appendix I). Few rags, shreds and coatings had accumulated in the anaerobic digester. It is recommended that a documentation of the condition of the interior of the anaerobic digesters is performed at each emptying occasion. This will facilitate a more systematic evaluation of the need for maintenance, e.g. it will be possible to evaluate if the frequency of emptying the anaerobic digesters can be prolonged. The trace element study showed that the stirring in AD5 functions satisfactorily. These two conclusions concerning the operation of the anaerobic digesters indicate good conditions for continuously mixed processes, one of the main parameters for digestion.

To conduct a satisfactory evaluation of the process and the biogas production, more information should therefore be available, and not just data from the digestion process. Seasonal variations contribute to the wastewater having a variable quality, and repairs and maintenance work are also undertaken which has consequences for operation. These various events should be taken into account and considered for when processing data. At the same time as being aware of major parameters affecting production, data and measurements should be examined more rigorously. Flow meters, temperature sensors and analytical results play a major part in the calculations underlying the evaluation and conclusions. Uncertainty in measurement data has been encountered on several occasions in the work of evaluating production. The measurement data found to be most uncertain are measurements concerning the flow of raw biogas from the anaerobic digesters and the DM and VS concentration of EOM.

- Biogas can in many cases be difficult to measure as the gas is a mixed gas and has a high water concentration. At Henriksdal, the gas pipe system is under-sized relative to current biogas production, which reduces the possibility of reliable flow measurement of the biogas. These problems are particularly acute with high biogas flows and when the pressure in the anaerobic digesters is high. In the case of high and varying pressure, it is not uncommon either for the water seal, which functions like safety valves, to "blow" and for the biogas then not to reach the biogas equalisation tank, but to be passed directly to the air outdoors. A detailed investigation concerning the capacity of the biogas system with proposals for specific actions was undertaken in 2007 (Mattsson and Stegberg, 2006; 2007). As a first measure, a parallel biogas pipe was installed in February 2007 which made it possible for the biogas to bypass the biogas equalisation tank[22]. Raw biogas leakage has subsequently been reduced sharply. During spring 2008, the possibility of replacing the existing water seal was investigated, including allowing a higher pressure in the biogas system[23].
- The routines concerning monitoring of EOM should be reviewed and the quality of the EOM received by the plant should be thoroughly investigated. Proposals for ensuring the quality of data concerning EOM, including the performance of sampling and analysis procedures should therefore be established. This is important not least for planned increased reception of EOM in the future.
- A third point to highlight is the benefit of a well functioning system for documenting events and measures that have developed in the process. A good maintenance system may simplify the handling of the documentation concerning shutdowns and renovations of objects in operation. It is also important

[22] The biogas pipe before the biogas equalisation tank was previously the most narrow and thereby confined section in the biogas system.

[23] Which also means that the flow capacity for the biogas system as a whole increases.

that contact between operation and support, such as research engineers and project engineers, functions well. An interest in production is essential and creates commitment. Possibilities of updating documentation and maintenance systems that function less well should exist within reasonable bounds.

Maintaining a uniform, and sufficiently high, temperature in the anaerobic digesters is essential for a stable and effective process. During the period investigated, the preset set point for temperature in the anaerobic digesters was not always achieved. This is explained by the fact that the heating system was under-sized and that there were severe problems with clogging of the pumps, situated before the heat exchangers, with rags. Relatively sharp temperature drops have therefore occurred, particularly in connection with snow melting during the spring season with higher flows of cold water into the treatment plant. Present conversion of the heating system, including the installation of new heat exchangers in 2008 with a higher capacity, will, however, make it possible to ensure a sufficiently high and uniform temperature in the anaerobic digesters. A recommendation is to review routines for cleaning pipes, pumps and possibly heat exchangers.

To reduce the heat needed, it would be desirable to decrease the volume of sludge received by the anaerobic digesters. This can be done by reducing the water content of incoming sludge, for example by thickening the primary sludge. There are a number of techniques for thickening, and which is most suitable varies according to plants and sludge conditions. The excess activated sludge is currently centrifuged before it is pumped to the anaerobic digesters, but there are possibilities for operating these centrifuges even more effectively (Åkerlund, 2008). More effective thickening decreases the inflow to the anaerobic digesters and thus releases volume for receiving additional EOM, for example. Even if more EOM is not received, a reduced hydraulic load is positive as it yields an even longer retention time and thus better digestion.

The retention time is in itself not a critical factor at Henriksdal, but a reduced retention time results in a deterioration of the degree of degradation and biogas production. During the period May – June 2004, two anaerobic digesters were taken out of operation for cleaning at the same time, and during this period HRT in the digestion process was low and the load to the remaining anaerobic digesters was higher than normal. The mean value for HRT was 14 d and the specific organic load was 2.3 kg VS/($m^3 \cdot d$) during these weeks, compared with a HRT of 19 d and a specific organic load of 1.6 kg VS/($m^3 \cdot d$) during other weeks in 2004. During May – June 2004, the specific gas production was low and the degree of degradation of the substrate was lower than normal. Hence, it is strongly recommended to follow the standard procedure to only take one anaerobic digester out of operation at the time. Despite a high load and a short retention time, there seemed to be no obvious malfunction of the process in other respects. It was probably not only the reduced retention time itself that caused the reduced biogas production during the period with two anaerobic digesters out of operation. Another explanation is that the high specific inflow to each anaerobic digester in operation resulted in a lower temperature in the digesters due to deficient heating capacity.

Based on the digestion studies and simulations carried out, the following proposed measures to increase raw biogas production can be described:

- Changing to serial operation should increase biogas production by 5 - 7%.
- Operation of the anaerobic digesters at 37ºC compared with 35ºC probably yields approximately 2% more biogas, and since September 2008, the anaerobic digesters have being operated at 37ºC.
- Lengthening of the retention time as a result of thickening of sludge gives slightly increased biogas production, but mainly a substantial reduction in the heating requirement. Another advantage of reduced sludge flow is that volume is released to receive more external organic matter.
- Increased production of primary sludge is another alternative to produce more biogas.
- A combination of an extended retention time and a change to serial operation should probably increase the specific biogas production by almost 10 %.
- The greatest potential for increased biogas production lies, however, in increasing the organic load to the anaerobic digesters. The requirements for this have previously been investigated by Stockholm Water Company and are planned to be described in a separate subproject within Biogasmax.

- As part of the Biogasmax project, investigations are also being conducted with various lysing methods. The introduction of such methods may possibly lead to a small increase in the degree of degradation and increased biogas production. These are, however, described in a separate report (Åkerlund, 2008).
- As part of the Biogasmax project, studies are being conducted on a laboratory scale with various additions of enzymes to the anaerobic digesters (Beijer, 2008). The enzymes are added to increase the degree of degradation of the organic matter. The greatest restriction here is the economic side as the cost of purchasing enzymes is very high.

Besides the above measures, present and planned measures also need to be conducted to reduce the leakage of methane from digested sludge and biogas handling[24]. Such measures will also increase the amount of methane that can be utilised. The possibility of using existing storage tanks for digested sludge as post-digestion tanks has also been investigated. The main result from this investigation is presented in another planned publication within the Biogasmax project.

[24] Among other things, a plant for waste biomethane combustion has been installed to process the waste air from the raw biogas upgrading plant where biomethane is produced.

8. Recommendations for further work

The evaluation indicates certain points on which it is extra interesting to investigate further:

- Optimisation of the primary sludge removal from the pre-sedimentation tanks. Pumping times and control of the withdrawal to identify sludge that is as "fresh" as possible and also chemical dosing or similar to increase the quantity of primary sludge removed should be investigated.

- Thickening of primary sludge. Pilot experiments with thickening have been conducted at other treatment plants, including the Linköping WWTP. Results obtained and experience gained should be applied to the digestion process at Henriksdal.

- More uniform temperature in the anaerobic digesters. During the evaluation period, the temperature has proven to be very uneven in spring in connection with high flows during periods of snow melting. Conversion of the heating system in 2008 has, however, provided the anaerobic digesters with a sufficiently high and uniform temperature.

- Retention time > 15 d. In the case of retention times of less than 15 days, it has been shown that the specific gas production decreases. The amount of substrate to be digested should therefore be adapted to the flow that gives sufficient retention times in the anaerobic digesters. This can be achieved by thickening the primary sludge. Emptying and maintenance work in the anaerobic digesters should also be planned so that the retention time is not less than 15 days.

- Characterisation and control of EOM. Routines for sampling, analysis and planning of influent EOM to the anaerobic digesters. As the quantity of EOM may be increased in future, it is important to incorporate already at present a good system for receiving and handling EOM.

- Investigation of serial operation of the anaerobic digesters. Investigate possibilities for serial operation in the existing plant and evaluate the impact on retention times, loads, degree of degradation and biogas production.

- Post-digestion. Calculation of the potential for post-digestion in the digested sludge, preferably in the sludge storage tanks, should be carried out, and also a technical investigation of the incorporation of raw biogas from the post-digestion to the biogas system.

9. Acknowledgements

Thanks go to:

- Eva Hagland for delivering background material and examining the report.
- Mikael Médoc, Fredrik Pettersson and operating personnel at Henriksdal's treatment plant for their valuable views during the work with the report and for help in producing data and sampling.
- Stefan Remberger for the performance of the trace element study.
- Bo Jonsson for assistance and documentation of the emptying work on AD2.
- Ulf Jeppson, Lund University, for computer simulation of serial operation of anaerobic digesters.
- Åke Nordberg, Mikael Hansson and Johnny Ascue, JTI, for work with digestion experiments on a laboratory scale.
- Bruce Hanworth for translation of the report from Swedish to English.[25]

[25] This report has been modified after the translation. Hellström and Jonsson are responsible for the text and layout of the final report.

10. References

Beijer, R. (2008). "Enzymatic treatment of wastewater sludge in presence of a cation binding agent - improved solubilisation and increased methane production." Master's thesis. Linköping University, LITH-IFM-A-EX-08/1930-SE. Stockholm Vatten AB Report No 4, April 2008.

Borggren, C. (2007). "Mätning av metanpotentialen hos slam på Henriksdal och Bromma : metodutveckling och utvärdering av labutrustningen "BCS-CH_4 Biogas"." Master's thesis. The Royal Institute of Technology. Trita-IM, 1402-7615 ; 2007:46.

Brook T., Madigan M., Martinko J. and Parker J. (1999). "Biology of micro-organisms." 9. ed. Prentice Hall Publishers, Englewood Cliffs. N.J.

Gerardi, M. (2003). "The microbiology of anaerobic digesters." John Wiley & sons, Inc. N.J.

Hawerman, B., Lind, J. E., Jacobsson, F., Ulmgren, L., Stenberg, Å. and Bäcklin, G. (1979). "Avloppsteknik. Slambehandling." Kommunförbundets kompendium i avloppsteknik, no. 5, 1979.

Hellström, D., Jonsson, L. and Vallin, L: (2009). "Uppföljning av biogasproduktionen vid Henriksdals reningsverk 2000 - 2005." Stockholm Vatten AB Report No. 1, January 2009.

Jeppsson, U. (2007a). "Investigation of Anaerobic Digestion Alternatives for Henriksdal's WWTP". Technical report no. LUTEDX/(TEIE-7225)/1-111/(2007), Department of Industrial Electrical Engineering and Automation, Lund University, Lund, Sweden.[26]

Jeppsson, U. (2007b). "Investigation of Anaerobic Digestion Alternatives for Henriksdal's WWTP – Supplement". Technical report no. LUTEDX/(TEIE-7226)/1-60/(2007), Department of Industrial Electrical Engineering and Automation, Lund University, Lund, Sweden. [27]

Mattsson, S. and Stegberg, P. (2006). "Utredning avseende Åtgärdsförslag på Henriksdals reningsverks rötgasledningar FAS 2." Report from FVB, Västerås.

Mattsson, S. and Stegberg, P. (2007). "Uppföljning av åtgärd. Tryckfall på Henriksdals reningsverks rötgasledningar." Report from FVB, Västerås.

"Miljörapport 2005." Stockholm Vatten AB.

[26] Available via www.iea.lth.se/publications/pubtech.html

[27] Available via www.iea.lth.se/publications/pubtech.html

Negre, J. (2007). ”Sludge treatment in an Anaerobic BioReactor with external Membranes.” Stockholm Vatten AB Report No. 16, September 2007.

STO 2006. Stockholm Vatten website. www.stockholmvatten.se

Vallin, L., Christiansson, A., Arnell, M. and Undén, P. (2007). “Operational experiences of cost effective production in Linköping, Sweden.” D2.2, Svensk Biogas, contract number 019795, Linköping, Sweden.

VAV 1981. ”Rötning av kommunalt slam – Teknik med nya möjligheter.” Publication VAV P42.

Åkerlund, A. (2008). “Evaluation of a disintegration technique for increased biogas production from excess activated sludge.” Master’s thesis. The Swedish University of Agricultural Sciences, ISSN 1401-5765. Stockholm Vatten AB Report No. 3, April 2008.

Appendix I – Emptying of AD2.

Henriksdal WWTP, internal observations in AD2.

Normally, at Henriksdal WWTP, one of seven anaerobic digesters is taken out of operation for maintenance and cleaning each year. AD2 was last emptied in May 2004, and the reason why it was emptied again in April 2006 was that other repair work was going to be done in connection with the anaerobic digester and that it was appropriate to empty AD2 already at this time. The task consisted in visually assessing in accordance with experience, once the sludge had been cleared, the amount of rags and shreds around stirrers, on walls and other things and also whether this may affect the operation of AD2.

In mid-June, AD2 had been emptied and there was an inspection on 21/06/2006.

The stirrer's upper propeller had a number of shreds, as did the stirrer shaft's connection boxes, but the quantities were modest. The stirrer's lower propeller was completely shred-free and as the substantial pumping takes place with the lower propeller, the continuous mixing ought in principle to be unaffected even with the shreds located higher up, provided that the stirrer is correctly dimensioned.

There are a few pipes in the top of AD but they are mainly in the gaseous phase and should therefore not disturb the stirring process. There was, so far as could be observed, no disturbing piping in the sludge phase.

After emptying, a small quantity of material was left in the bottom of AD which, according to information from personnel at Henriksdal WWTP, mostly consists of fine-grained sand. This indicates that the sand trap is not performing as expected. This takes up space in the anaerobic digester, but probably does not impair the operation of the stirring process.

The conclusion is that the shred coatings after two years' operation are extremely modest and should not disrupt the continuous mixing of AD.

This document is based on a report from Bo Jonsson 29/06/2006. The original text can be found in a Swedish version of this report, i.e. Hellström *et al.* (2009).

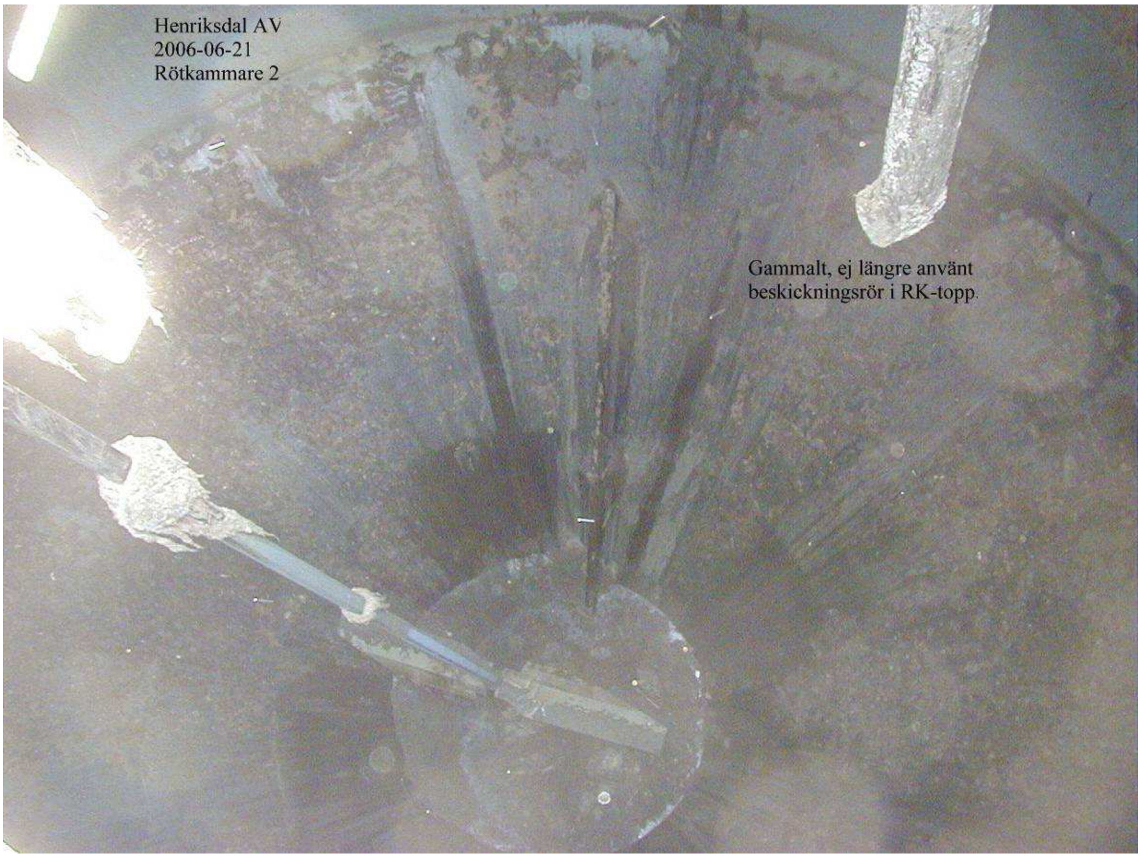

Figure 24. The lower propeller blade is completely free from shreds.

Henriksdal WWTP on 21/06/2006, Anaerobic Digester 2. Lower propeller without shreds. In the upper right corner: Old charging pipe no longer used in the top of AD. Down in the middle: The lower propeller without shreds.

Figure 25. The upper propeller blade is clogged with shreds.

Henriksdal WWTP on 21/06/2006, Anaerobic Digester 2. Upper propeller with shreds.

Appendix II – Temperature history in the anaerobic digesters.

Figure 26. Temperature history for AD1. Values from database henriksdal6m with channel number 163 in WASTE.

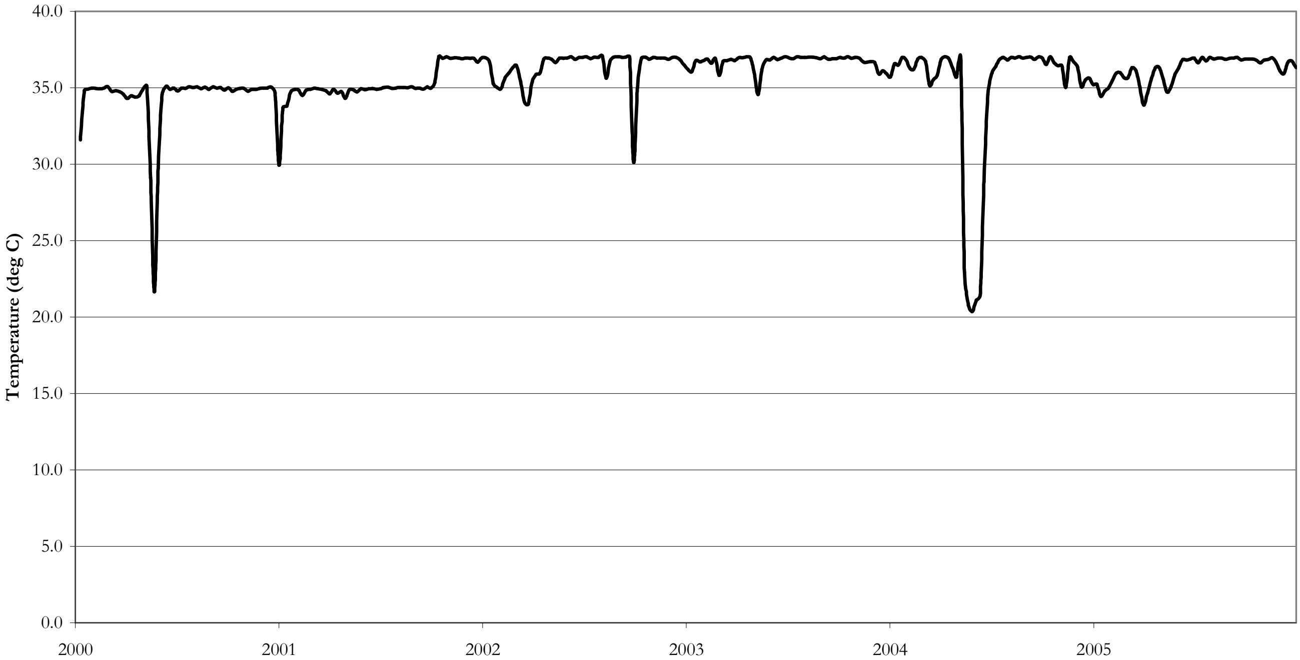

Figure 27. Temperature history for AD2. Values from database henriksdal6m with channel number 164 in WASTE.

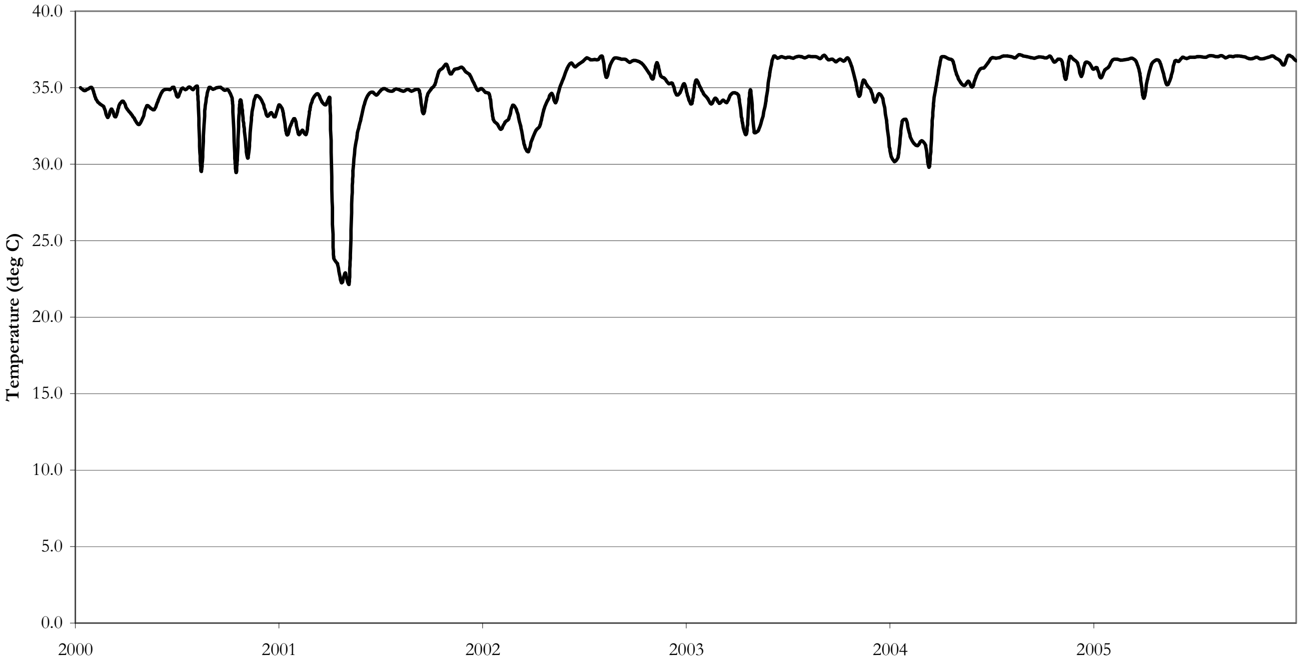

Figure 28. Temperature history for AD3. Values from database henriksdal6m with channel number 165 in WASTE.

Figure 29. Temperature history for AD4. Values from database henriksdal6m with channel number 166 in WASTE.

Figure 30. Temperature history for AD5. Values from database henriksdal6m with channel number 167 in WASTE.

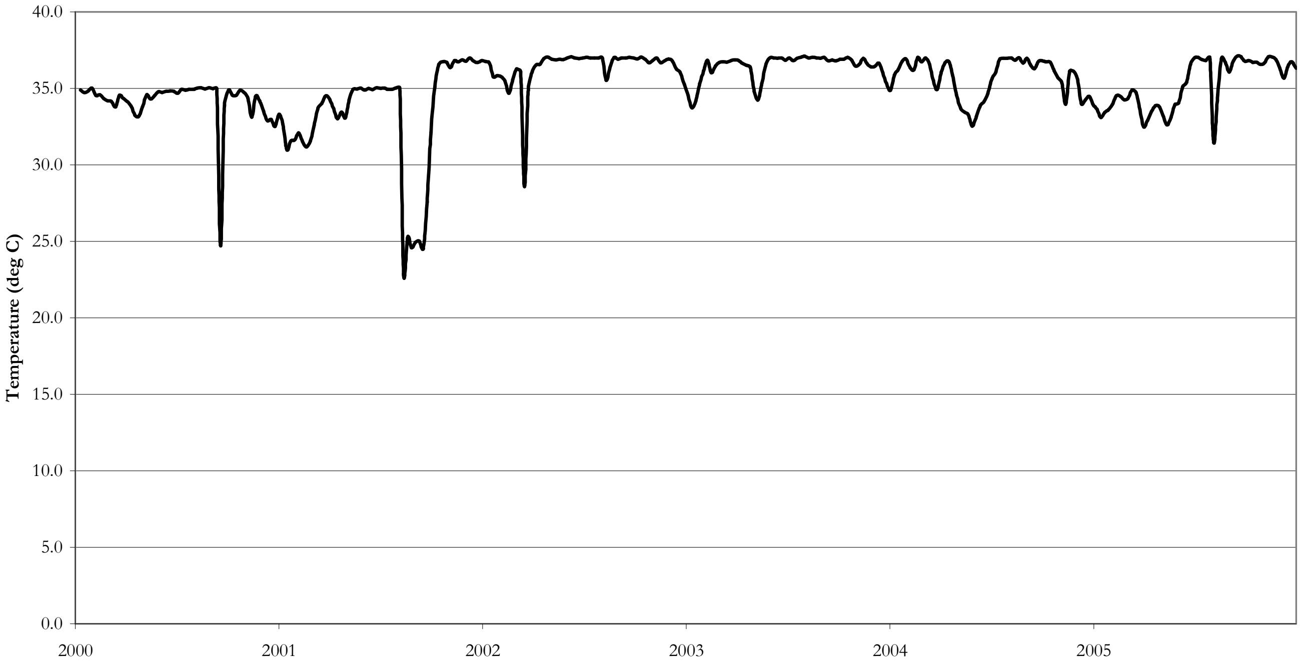

Figure 31. Temperature history for AD6. Values from database henriksdal6m with channel number 168 in WASTE.

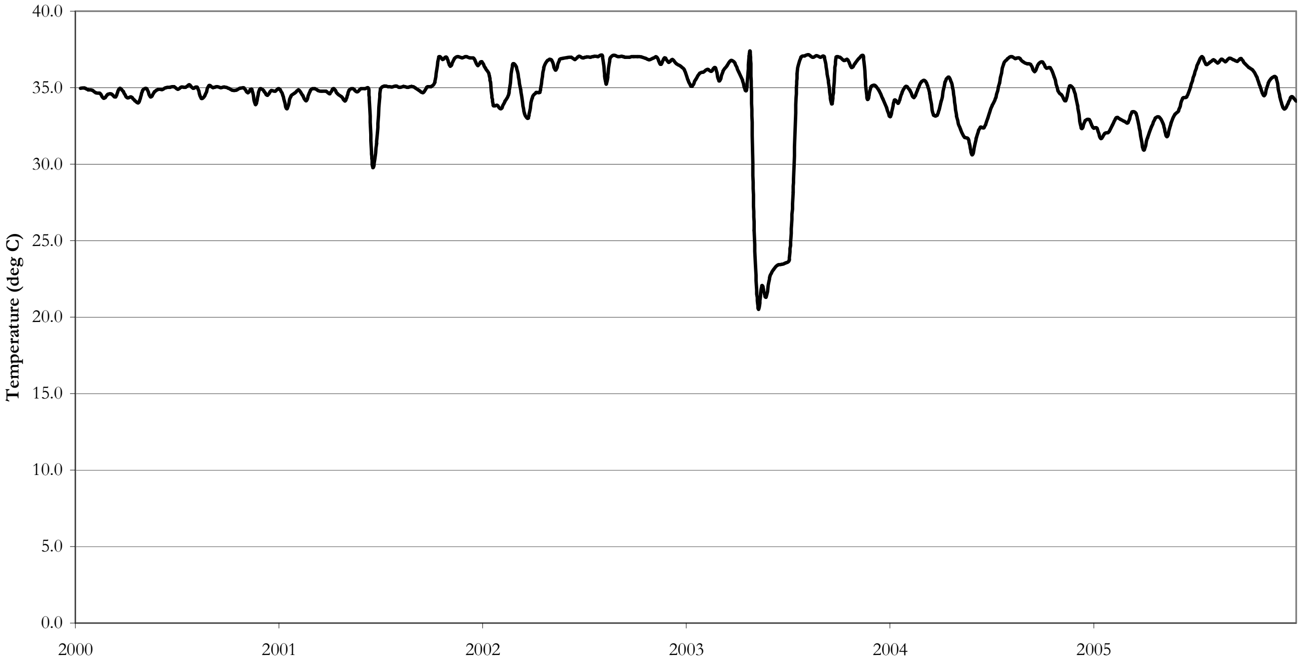

Figure 32. Temperature history for AD7. Values from database henriksdal6m with channel number 169 in WASTE.

Appendix III – COD balance for the pre-sedimentation process.

2000	Flow m^3/d	VS tonne/d	COD factor (gCOD/gVS)[1]	COD tonne/d	% of influent
IN				111	
PW				46	41%
PS	1466	38	1.56	59	54%
2001					
IN				105	
PW				47	45%
PS	1443	36	1.56	57	54%
2002					
IN				110	
PW				49	45%
PS	1452	41	1.56	63	58%
2003					
IN				106	
PW				49	46%
PS	1388	36	1.56	57	53%
2004					
IN				122	
PW				54	44%
PS	1560	40	1.56	62	51%
2005					
IN				113	
PW				53	47%
PS	1411	36	1.56	57	50%

PW = presedimented wastewater, PS = primary sludge

[1]The quotient 1.56 g COD/g VS is analysed from a collection of random samples.

Appendix IV – Annual means for process data.

Table 13. Annual means for process data during the evaluation period.

Year	Quantity of organic material for digestion [tonne VS/year]	Specific organic load [kg VS/(m³ · d)]	HRT [d]	Temp.[28] [°C]	Gas flow [Nm³/h]	Methane concentration [%]	Gas production [Nm³ biogas/ m³ pumped in]	Specific gas production [Nm³biogas/ kg VS]	Degree of degradation[29] [%]	Degree of degradation[30] [%]
2000	19 200	1.46	19	34.3	1021	64.7	13	0.47	48	50
2001	19 300	1.53	19	35.0	975	65.1	13	0.45	47	49
2002	21 500	1.54	21	36.2	1029	65.2	13	0.43	55	51
2003	18 700	1.40	20	36.4	1087	65.8	14	0.52	51	50
2004	21 300	1.62	19	35.5	1085	66.5	13	0.45	49	46
2005	20 000	1.44	20	35.6	1125	66.5	14	0.50	47	44
Mean±SD	**20 000±3 200**	**1.50±0.31**	**20±3**	**35.5±1.2**	**1054±132**	**65.6±1.7**	**13±2**	**0.47±0.07**	**49±7**	**48±8**

[28] The temperature is volume-weighted from the anaerobic digesters that were in operation during the period in question.
[29] Calculated with Formula 7.
[30] Calculated with Formula 8.

Appendix V – Batch digestion.

JTI

Commissioned report

Batch digestion of blended primary and secondary sludge from Henriksdal's wastewater treatment plant

A project conducted on behalf of Stockholm Vatten AB

Johnny Ascue
Åke Nordberg

Aim

The aim of the study was to investigate biogas and methane production for batch digestion of blended sludge (primary sludge and excess activated sludge) from the Henriksdal WWTP. Gas production was determined as normal L/g VS.

Materials and methods

Primary sludge and excess activated sludge from the Henriksdal WWTP was collected on 23/01/2007 – 29/01/2007 and stored in a cool room. Inoculum was taken from an anaerobic digester at Henriksdal on 29/01/2007 and supplied at the same time as collected primary and excess activated sludge to JTI.

On arrival, the sludge was blended in the following proportions with reference to DM: Primary sludge 75.5% and excess activated sludge 24.5%.

The batch digestion operations were conducted in 1-L bottles at 37ºC with inoculum from an anaerobic digester at the Henriksdal WWTP. The experimental bottles were placed in a room at a constant temperature. The bottles were shaken in connection with gas samples being taken. The experiments were conducted with three parallels as follows:

3 x inoculum (background production of biogas and methane), pH = 7.32
3 x blending of primary sludge, excess activated sludge and inoculum, pH = 6.55

All sludge and inoculum was analysed for dry matter (DM) and volatile solids (VS). Gas production was calculated by the pressure in the bottles being measured with a digital pressure meter (GMH 3110) fitted with a pressure sensor (GMSD 2BR; -1000 to 2000 mbar). The pressure was then converted to normal gas volume. Gas samples were taken and analysed on a gas chromatograph (Chrompack CP 9001; Kolonn Hayesep-R 2.5 m x 1/8”. FID detector, Carrier gas: He, flow rate 18 mL/min. Temp injector: 125ºC).

The experiment proceeded for 55 days.
The characteristics of the various sludges and the inoculum are presented in Table 1, and quantities used in the experiments are shown in Table 2.

Table 1. Analysis of DM and VS

	DM, %	VS, %
Primary sludge	4.85	3.22
Excess activated sludge	4.50	3.11
Inoculum	2.62	1.43

Table 2. Quantities of sludge and inoculum used

	Experiment		Control	
	mL	g VS	mL	g VS
Primary sludge	79	2.53	*	0
Excess activated sludge	26	0.8	*	0
Inoculum	650	9.1	650	9.1

* total of 105 mL water

Results and comments

Results from the study are presented in Figure 1 as an average of three parallels. The deviation between the various parallels was very small. The cumulative biogas and methane production is reported as normal litres (at 1 atm and 0ºC) in relation to the quantity of VS supplied. The quantity of methane produced by the inoculum has been deducted. The methane content of the bottles of blended sludge and inoculum was 68% at the end of the experiment.

The mean for cumulative biogas production was 0.67 NL/g VS and methane production was 0.34 NL/g VS for the blending of primary and secondary sludge (Figure 1).

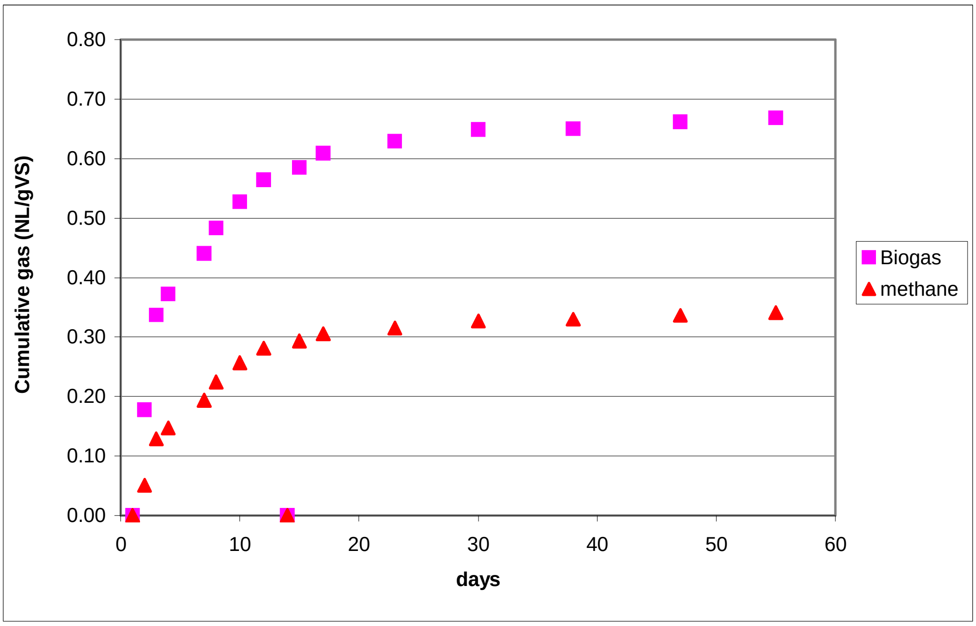

Figure 1. Cumulative biogas and methane production in relation to VS supplied from blending of primary and excess activated sludge.

Previous digestion experiments on primary and excess activated sludge from Käppala (Leksell, 2005) gave a methane yield of 0.35 NL/g VS for primary sludge and 0.16 NL/g VS for excess activated sludge. (The corresponding biogas exchange was 0.62 NL/g VS for primary sludge and 0.31 NL/g VS for excess activated sludge). The result from this study therefore appears reasonable in view of the fact that there may be some variation in composition between different wastewater treatment plants.

After 23 days, the methane yield was 0.32 NL/g VS (91% of the yield at the end of the experiment), which indicates that retention times of more than 23 days give only a marginally increased methane yield in relation to the extra reactor volume required. After 15 days, the methane yield was 0.29 NL/g VS (83% of the yield at the end of the experiment). The lower methane yield is in this case set against the possibility of increasing the treatment capacity in an already existing anaerobic digester.

Appendix VI – COD balance for the digestion process.

2000	Flow m^3/d	VS tonne/d	CH_4 Nm^3/d	COD factor (gCOD/gVS)	COD tonne/d	separation in digester tanks
IN					111	
EAS[1]	391	10.6		1.52	16	
PS[1]	1466	38		1.56	59	
EOM[2]	39	3.67		2.5	9	
TOTAL PS, EAS, EOM	1896	**52.3**			**85**	
BIOGAS[3]			15862	0.35	45	54%
DIGESTED SLUDGE[1]	1869	27.2		1.54	42	49%
2001						
IN					105	
EAS[1]	358	10.5		1.52	16	
PS[1]	1443	36		1.56	57	
EOM[2]	65	6.12		2.5	15	
TOTAL PS, EAS, EOM	1866	**52.9**			**88**	
BIOGAS[3]			15234	0.35	44	50%
DIGESTED SLUDGE[1]	1841	26.8		1.54	41	47%
2002						
IN					110	
EAS[1]	330	11.8		1.52	18	
PS[1]	1452	41		1.56	63	
EOM[2]	70	6.57		2.5	16	
TOTAL PS, EAS, EOM	1852	**59.0**			**98**	
BIOGAS[3]			16131	0.35	46	47%
DIGESTED SLUDGE[1]	1822	25.6		1.54	39	40%
2003						
IN					106	
EAS[1]	400	8.7		1.52	13	
PS[1]	1388	36		1.56	57	
EOM[2]	69	6.46		2.5	16	
TOTAL PS, EAS, EOM	1857	**51.4**			**86**	
BIOGAS[3]			17193	0.35	49	57%
DIGESTED SLUDGE[1]	1831	24.5		1.54	38	44%
2004						
IN					122	
EAS[1]	393	10.9		1.52	17	
PS[1]	1560	40		1.56	62	
EOM[2]	78	7.29		2.5	18	
TOTAL PS, EAS, EOM	2031	**58.2**			**97**	
BIOGAS[3]			17332	0.35	50	51%
DIGESTED SLUDGE[1]	2004	28.9		1.54	44	46%
2005						
IN					113	
EAS[1]	468	11.1		1.52	17	
PS[1]	1411	36		1.56	57	
EOM[2]	79	7.41		2.5	19	
TOTAL PS, EAS, EOM	1958	**54.9**			**92**	
BIOGAS[3]			17986	0.35	51	56%
DIGESTED SLUDGE[1]	1934	28.0		1.54	43	47%

[1] The quotients1.52, 1.56 and 1.54 g COD/g VS are analysed from a collection of random samples.

[2] COD conversion of EOM from an assumption that it contains 75% grease COD eq. = 2.9 and 25% protein COD eq. 1.4. = 2.5 g COD/g VS EOM.

[3] 0.35 Nm^3 CH_4/kg COD.

Appendix VII – Raw data and calculated values for the evaluation.

Raw data and calculations for the evaluation are presented in the tables below.

The values are taken from online meters linked to various channels in the database henriksdal6m associated with the computer program WASTE.

Value	channel number
Primary sludge flow	117
Flow of thickened excess activated sludge	1421
Flow of external organic matter	1543
Raw biogas flow from AD1	177
Raw biogas flow from AD2	178
Raw biogas flow from AD3	179
Raw biogas flow from AD4	180
Raw biogas flow from AD5	181
Raw biogas flow from AD6	182
Raw biogas flow from AD7	183
Raw biogas flow, total	184
Methane concentration of the raw biogas	187
Proportion of flow to AD1	118
Proportion of flow to AD2	119
Proportion of flow to AD3	120
Proportion of flow to AD4	121
Proportion of flow to AD5	122
Proportion of flow to AD6	123
Proportion of flow to AD7	124
Temperature in AD1	163
Temperature in AD2	164
Temperature in AD3	165
Temperature in AD4	166
Temperature in AD5	167
Temperature in AD6	168
Temperature in AD7	169

DM and ROI were analysed at Stockholm Water Company's accredited laboratory. Total DM and ROI have been calculated on a flow-weighted basis from the respective subflow. The flow of the effluent digested sludge has been calculated from influent flows less the proportion of VS that has been degraded in accordance with the degree of degradation from formula 8, (Qprimary sludge + Qprethickened excess activated sludge + Qgrease sludge) • (1 - DMin • (1 - ROIin) • degree of degradation). Effluent DM and ROI are volume-weighted values from the anaerobic digesters that were in operation during the period in question.

Appendix VII - Background data to experiments with AD3 and AD4.

Date	AD	AD	AD3	AD4	AD3	AD4	AD3	AD4	AD3	AD4	AD3	AD4
	DM tot, in	ROI tot, in	Qin 2 w. before	Qin 2 w. before	DMout	DMout	ROIout	ROIout	temperature	temperature	gas prod	gas prod
	%	% of DM	m^3/day	m^3/day	%	%	% of DM	% of DM	°C	°C	Nm^3/kgVS	Nm^3/kgVS
2006-05-15	*3.3*	*27.3*	*271*	*271*	*2.4*	*2.5*	*41.8*	*41.3*	*35.5*	*30.5*	*0.634589331*	*0.5136952*
2006-05-22	4.2	26.0	242	242	2.7	2.7	41.3	40.6	35.3	30.7	0.500433867	0.4127593
2006-05-29	3.8	27.5	288	287	2.6	2.7	43.1	41.9	35.8	31.1	0.505356578	0.4121587
2006-06-01	3.8	27.5	288	288	2.7	2.9	42.9	41.5	35.6	31.0	0.505356578	0.4121587
2006-06-08	4.6	29.2	254	254	2.5	2.6	42.8	41.2	36.7	30.6	0.422423811	0.3526313
2006-06-12	4.0	27.6	319	319	2.5	2.6	42.4	40.8	36.6	30.8	0.528181631	0.4309768
2006-06-15	4.0	27.6	319	319	2.6	2.8	40.1	38.2	36.3	30.9	0.528181631	0.4309768
2006-06-19	3.5	26.0	264	264	2.6	2.7	40.4	39.3	36.4	31.0	0.633948518	0.5075448
2006-06-26	3.6	24.2	305	305	2.4	2.5	41.1	39.8	36.4	31.2	0.462438621	0.3732921
2006-06-29	3.6	24.2	305	305	2.6	2.6	41.6	40.7	36.3	30.9	0.462438621	0.3732921
2006-07-03	3.3	24.4	278	278	2.5	2.5	42.4	40.0	36.8	30.6	0.461439475	0.3890463
2006-07-06	2.8	25.3	278	278	2.3	2.5	41.8	40.5	36.8	31.2	0.552401521	0.4657377
2006-07-10	*3.9*	*26.9*	*283*	*283*	*2.4*	*2.4*	*41.0*	*40.3*	*37.0*	*33.2*	*0.414420499*	*0.365444*
2006-07-17	*2.9*	*22.2*	*254*	*254*	*2.4*	*2.5*	*43.6*	*42.3*	*36.9*	*33.0*	*0.554492253*	*0.5070764*
2006-07-24	*3.5*	*30.9*	*264*	*269*	*2.4*	*2.4*	*42.7*	*41.9*	*36.5*	*32.8*	*0.495952267*	*0.4349603*
2006-07-31	*3.7*	*26.2*	*254*	*254*	*2.4*	*2.5*	*43.3*	*42.8*	*36.9*	*33.3*	*0.525673809*	*0.45361*
2006-08-03	3.7	26.2	254	254	2.5	2.5	42.8	42.0	36.7	33.0	0.525673809	0.45361
2006-08-07	3.9	26.5	254	254	2.5	2.5	42.4	41.6	37.0	33.4	0.507783093	0.4341084
2006-08-10	3.9	26.5	254	254	2.4	2.4	43.0	42.2	36.7	32.7	0.507783093	0.4341084
2006-08-14	3.8	26.8	247	247	2.3	2.3	41.8	42.0	36.8	32.9	0.593961267	0.4876862
2006-08-17	3.8	27.8	247	247	2.5	2.6	44.2	42.6	36.4	32.8	0.602691348	0.4948542
2006-08-21	4.0	26.2	259	257	2.4	2.4	44.3	42.9	36.5	32.8	0.535600978	0.4378239
2006-08-24	4.0	26.2	259	257	2.7	2.7	45.4	44.9	36.6	32.9	0.535600978	0.4378239
2006-08-28	*4.8*	*33.5*	*271*	*271*	*2.7*	*2.7*	*45.9*	*44.9*	*36.6*	*33.2*	*0.434121471*	*0.3688798*
2006-09-04	*4.8*	*37.3*	*262*	*262*	*2.6*	*2.7*	*43.9*	*43.8*	*36.5*	*35.1*	*0.447359467*	*0.3869206*
2006-09-11	*3.7*	*30.0*	*261*	*262*	*2.5*	*2.6*	*43.3*	*43.4*	*36.7*	*35.1*	*0.512386031*	*0.4266643*
2006-09-14	3.7	30.0	261	262	2.4	2.5	42.8	42.1	36.9	34.8	0.513634151	0.426947
2006-09-18	3.9	34.6	242	241	2.6	2.6	42.1	41.9	36.5	34.8	0.591312039	0.5147135
2006-09-21	3.9	34.6	242	241	2.6	2.4	42.1	42.4	36.7	35.1	0.591312039	0.5147135
2006-09-25	4.4	27.8	239	237	2.4	2.5	41.3	41.1	36.5	35.1	0.437105638	0.4144445
2006-09-28	4.4	27.8	239	237	2.4	2.5	41.1	39.4	36.6	34.4	0.437105638	0.4144445
2006-10-02	4.1	24.5	273	273	2.5	2.5	39.3	39.2	36.5	34.7	0.416058444	0.393294
2006-10-05	4.1	24.5	273	273	2.6	2.6	40.3	39.8	36.4	34.6	0.416058444	0.393294
2006-10-09	*3.2*	*24.5*	*256*	*254*	*2.6*	*2.6*	*40.8*	*40.4*	*36.3*	*34.6*	*0.565323165*	*0.5416926*
2006-10-16	*4.0*	*26.8*	*251*	*251*	*2.4*	*2.4*	*40.6*	*40.8*	*36.4*	*35.8*	*0.49870627*	*0.4559152*
2006-10-23	3.2	25.7	279	278	2.2	2.2	38.6	37.8	36.6	36.3	0.514277655	0.4769198
2006-10-26	3.2	25.7	279	278	2.4	2.3	40.3	40.2	36.3	35.8	0.514277655	0.4769198
2006-10-30	3.4	20.6	249	249	2.4	2.3	41.7	41.3	36.3	36.2	0.52022906	0.4484308
2006-11-06	5.3	34.5	246	253	2.5	2.4	40.5	41.0	35.6	35.6	0.393260995	0.3751213
2006-11-09	5.3	34.5	246	253	2.3	2.4	41.5	41.4	35.3	34.2	0.393260995	0.3751213
2006-11-13	4.1	27.5	319	313	2.5	2.5	41.7	41.1	35.1	33.8	0.487982661	0.4306224
2006-11-16	4.1	27.5	319	313	1.7	2.4	40.6	41.3	34.7	33.8	0.487982661	0.4306224
2006-11-20	*3.6*	*26.2*	*332*	*332*	*2.4*	*2.3*	*42.2*	*41.9*	*33.6*	*32.8*	*0.450124704*	*0.4219852*
2006-11-27	*3.6*	*28.9*	*404*	*401*	*2.5*	*2.3*	*42.7*	*41.5*	*35.2*	*32.6*	*0.386611793*	*0.3626042*
2006-12-04	3.5	29.5	273	346	2.3	2.6	43.7	41.4	36.6	32.9	0.610550781	0.4641985
2006-12-08	3.5	29.5	273	346	2.6	2.7	43.7	42.5	36.4	33.9	0.610550781	0.4641985
2006-12-11	3.9	28.8	209	270	2.6	2.5	43.3	42.9	36.2	33.9	0.782601527	0.5314133
2006-12-14	3.9	28.8	209	270	2.7	2.7	42.7	43.0	36.4	34.0	0.782601527	0.5314133
2006-12-18	4.7	30.0	242	314	2.4	2.6	44.4	43.0	37.0	34.6	0.58449778	0.4288401
2006-12-21	4.7	30.0	242	314	2.7	2.7	42.1	41.2	36.7	35.0	0.58449778	0.4288401
2006-12-25	4.0	28.1	221	253					36.9	35.6	0.542789184	0.5102644
2007-01-01			186	241					36.7	36.2		
2007-01-08			207	269	2.4	2.6	43.7	41.7	36.8	35.8		
2007-01-11			207	269	2.6	2.6	43.2	42.3	36.3	35.1		
2007-01-15			222	287	2.5	2.6	44.4	44.6	36.6	34.7		
2007-01-18			222	287	2.7	2.8	45.6	44.8	36.4	34.8		
2007-01-22	4.6	30.4	211	266	2.8	2.8	45.2	45.1	36.2	34.3	0.67920428	0.4305716
2007-01-25	4.6	30.4	211	266	2.9	2.9	44.9	43.7	35.7	34.6	0.67920428	0.4305716
2007-01-29	6.5	38.8	187	243	2.8	2.8	44.5	44.5	35.1	33.5	0.564075631	0.3977493

Figures in italics represent values during changeover periods.

Appendix VII - Background data to experiments with AD3 and AD4.

Date	AD	AD	AD3	AD4	AD3	AD4	AD3	AD4	AD3	AD4	AD3	AD4
	DM tot, in	ROI tot, in	Qin 2 w. before	Qin 2 w. before	DMout	DMout	ROIout	ROIout	temperature	temperature	gas prod	gas prod
	%	% of DM	m^3/day	m^3/day	%	%	% of DM	% of DM	℃	℃	Nm^3/kgVS	Nm^3/kgVS
2007-05-02	*3.4*	*28.5*	*208*	*208*	*2.4*	*2.4*	*41.5*	*40.7*	*34.2*	*33.6*	*0.503168994*	*0.5519707*
2007-05-07	*3.0*	*24.8*	*203*	*236*	*2.4*	*2.4*	*41.4*	*40.6*	*34.5*	*35.1*	*0.763653984*	*0.6899538*
2007-05-14	2.7	25.5	219	286	2.4	2.4	40.6	39.3	34.8	34.1	0.869246241	0.6776065
2007-05-16	2.7	25.5	219	286	2.3	2.4	40.4	39.6	34.8	33.7	0.869246241	0.6776065
2007-05-21	3.1	26.3	269	352	2.3	2.1	40.6	41.4	34.6	33.5	0.550874398	0.4387358
2007-05-28	3.4	28.7	325	425	2.3	2.2	39.2	38.0	35.0	34.1	0.53811496	0.4313547
2007-06-01	3.4	28.7	325	425	2.2	2.6	39.3	33.5	34.6	33.9	0.53811496	0.4313547
2007-06-04	3.2	25.1	292	383	2.2	2.3	39.3	37.0	34.8	33.2	0.492532034	0.4249109
2007-06-07	3.2	25.1	292	383	2.1	2.2	39.9	37.1	34.6	33.4	0.492532034	0.4249109
2007-06-11	3.4	25.3	252	331	2.1	2.2	38.8	37.4	34.6	34.4	0.473410372	0.3754505
2007-06-14	3.4	25.3	252	331	2.1	2.2	38.3	37.1	34.5	34.2	0.473410372	0.3754505
2007-06-18	*2.6*	*24.4*	*284*	*371*	*2.1*	*2.2*	*38.8*	*38.2*	*34.5*	*34.6*	*0.609531968*	*0.4220381*
2007-06-21	*2.6*	*24.4*	*284*	*371*	*2.2*	*2.2*	*39.3*	*40.2*	*34.7*	*34.9*	*0.609531968*	*0.4220381*
2007-06-25	*3.0*	*30.0*	*332*	*401*	*2.0*	*2.1*	*39.8*	*39.2*	*34.5*	*34.5*	*0.460168232*	*0.3425284*
2007-07-02	2.5	29.8	343	343	2.1	2.1	39.9	40.0	34.8	34.9	0.493386311	0.438918
2007-07-09	2.8	25.7	273	272	2.1	2.1	39.7	39.8	34.4	34.7	0.563131421	0.5206865
2007-07-16	2.7	26.8	287	286	2.3	2.2	40.5	41.7	34.9	35.0	0.44532929	0.4399482
2007-07-23	2.9	28.2	319	318	2.1	2.0	41.4	41.0	34.8	35.0	0.392519819	0.3913771
2007-07-30	1.9	23.6	260	260	2.4	2.3	42.5	42.6	35.1	34.9	0.702375615	0.7121845
2007-08-06	3.1	25.0	240	240	2.6	2.6	47.0	47.1	35.0	34.9	0.573957288	0.5475299
2007-08-13	3.1	27.7	237	238	2.6	2.6	48.0	48.3	34.9	34.9	0.562851223	0.5356983
2007-08-20	3.0	28.6	304	304	2.6	2.5	46.3	46.6	35.0	35.1	0.462139144	0.4320006
2007-08-27	2.9	23.6	246	247	2.5	2.4	45.3	45.5	34.9	35.0	0.545928052	0.5109792
2007-09-03	2.9	24.3	221	207	2.5	2.4	43.0	43.8	34.6	35.0	0.69544051	0.707527

Figures in italics represent values during changeover periods.

		Primary sludge				Excess activated sludge				External organic matter				Digested sludge			Gas		
		Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	Dig. gas	Methane	
Year	w	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[Nm^3/h]	[%]	[Nm^3/h]
1999	52	777	3.0	24.5	18	392	4.9	37.9	11					1155	2.41	42.94	922	63	584
2000	1	1203	3.0	24.5	27	374	4.9	37.9	11	0			0	1557	2.41	42.94	987	63	623
2000	2	1382	3.3	24.5	34	407	4.9	37.9	11	0			0	1765	2.41	42.94	979	64	623
2000	3	1279	3.4	16.8	36	423	4.9	37.9	11	0			0	1671	2.67	42.94	973	64	627
2000	4	1295	3.6	24.5	35	443	4.9	37.9	11	0			0	1714	2.42	43.08	1007	63	632
2000	5	1591	3.4	18.3	44	457	4.9	37.9	11	0			0	2012	2.73	43.21	1040	63	658
2000	6	1456	3.4	24.5	37	460	4.9	37.9	11	0			0	1891	2.21	42.69	1021	63	648
2000	7	1561	3.1	18.5	39	435	4.9	37.9	11	0			0	1964	2.60	42.16	1014	65	657
2000	8	1409	3.4	16.2	40	426	4.9	37.9	11	0			0	1801	2.49	41.68	1027	65	664
2000	9	1772	3.1	20.2	44	413	4.9	37.9	11	0			0	2153	2.36	41.20	1118	65	725
2000	10	1356	3.9	24.5	40	389	4.9	37.9	11	49	9.9	5.4	4.6	1769	2.60	40.89	1045	65	677
2000	11	1280	3.9	26.0	37	420	4.9	37.9	11	49	9.9	5.4	4.6	1726	2.79	40.58	1000	65	650
2000	12	1416	3.5	24.5	37	434	4.9	37.9	11	49	9.9	5.4	4.6	1874	2.64	40.85	1067	65	694
2000	13	1475	4.1	17.6	50	472	4.9	37.9	11	49	9.9	5.4	4.6	1956	2.90	41.11	1144	65	744
2000	14	1620	3.5	18.8	46	492	4.9	37.9	11	49	9.9	5.4	4.6	2123	2.35	41.11	1163	64	744
2000	15	1725	3.0	24.5	39	410	4.9	37.9	11	49	9.9	5.4	4.6	2157	2.68	41.11	1178	64	759
2000	16	1857	3.9	26.9	53	462	4.9	37.9	11	49	9.9	5.4	4.6	2337	2.60	41.67	1208	65	790
2000	17	1499	2.9	17.0	36	501	4.9	37.9	11	49	9.9	5.4	4.6	2003	2.64	42.24	1047	67	699
2000	18	1422	3.3	18.2	38	561	3.0	37.9	11	37	9.9	5.4	3.5	2006	2.38	40.97	1030	66	676
2000	19	1648	3.2	17.7	43	558	3.5	33.6	13	52	9.9	5.4	4.9	2222	2.41	39.71	1051	65	681
2000	20	1731	2.5	24.5	33	481	4.3	37.9	11	51	9.9	5.4	4.8	2242	2.39	39.51	1126	67	749
2000	21	1386	3.0	24.5	31	514	4.9	37.9	11	52	9.9	5.4	4.9	1905	2.48	39.32	1016	65	664
2000	22	1550	3.0	18.8	38	474	4.0	37.9	11	25	9.9	5.4	2.3	2052	2.22	40.36	995	64	638
2000	23	1406	3.9	28.9	39	501	4.0	35.3	13	60	9.9	5.4	5.6	1927	2.64	41.40	1034	62	638
2000	24	1182	4.2	24.8	37	576	2.7	37.9	11	42	9.9	5.4	3.9	1768	2.63	41.21	1029	66	677
2000	25	1456	3.6	22.1	41	221	2.6	31.5	4	30	9.9	5.4	2.8	1693	2.61	41.02	960	66	630
2000	26	1761	4.3	29.7	53	431	3.0	37.9	11	43	9.9	5.4	4.0	2211	2.11	42.00	1057	67	711
2000	27	1419	4.1	31.5	40	395	2.9	38.4	7	44	9.9	5.4	4.1	1837	2.71	42.98	950	67	632
2000	28	1586	3.3	24.5	40	435	4.0	37.9	11	42	9.9	5.4	3.9	2032	2.57	44.24	883	68	597
2000	29	1158	3.6	30.7	29	358	3.1	40.8	7	40	9.9	5.4	3.8	1532	2.57	45.49	784	66	518
2000	30	1322	3.2	24.5	32	301	6.0	37.9	11	32	9.9	5.4	3.0	1627	2.59	45.80	839	64	541
2000	31	1022	3.6	30.8	25	281	5.5	42.3	9	31	9.9	5.4	2.9	1318	2.55	46.10	780	64	502
2000	32	1030	3.5	27.7	26	282	4.5	37.9	11	31	9.9	5.4	2.9	1322	2.49	46.30	793	65	512
2000	33	1335	3.7	23.6	38	276	4.5	40.7	7	30	9.9	5.4	2.8	1627	2.65	46.51	914	66	601
2000	34	1347	3.3	23.8	34	282	5.0	37.9	11	45	9.9	5.4	4.3	1642	2.57	45.54	939	64	603
2000	35	2036	2.9	32.6	40	270	6.2	41.1	10	40	9.9	5.4	3.8	2332	2.57	44.58	1018	64	646
2000	36	1140	3.2	24.5	28	271	6.1	37.9	11	47	9.9	5.4	4.4	1432	2.58	44.19	923	63	585

		Primary sludge				Excess activated sludge				External organic matter				Digested sludge			Gas		
		Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	Dig. gas	Methane	
Year	w	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[Nm^3/h]	[%]	[Nm^3/h]
2000	37	1446	4.0	22.6	45	280	6.3	39.3	11	43	9.9	5.4	4.1	1762	2.25	43.79	994	64	641
2000	38	1710	3.2	24.5	41	283	5.9	37.9	11	72	9.9	5.4	6.8	2011	2.54	42.54	999	66	654
2000	39	1636	3.0	20.9	39	277	6.0	38.9	10	48	9.9	5.4	4.5	1931	2.46	41.28	999	65	649
2000	40	1607	4.3	28.0	50	287	5.7	38.9	10	49	9.9	5.4	4.6	1926	2.44	42.17	1029	65	665
2000	41	1667	3.5	26.3	43	245	6.1	39.6	9	60	9.9	5.4	5.7	1936	2.67	41.40	1121	64	717
2000	42	1564	4.0	25.0	47	343	5.7	39.0	12	50	9.9	5.4	4.7	1922	2.10	41.44	1063	66	698
2000	43	1467	3.8	25.3	42	358	5.6	38.6	12	46	9.9	5.4	4.3	1830	2.61	42.02	1023	64	655
2000	44	1552	3.0	30.2	33	356	5.8	29.3	15	33	9.9	5.4	3.1	1936	2.66	43.81	1022	64	654
2000	45	1361	2.6	29.2	25	343	5.7	39.4	12	51	9.9	5.4	4.8	1752	2.24	41.91	1071	64	688
2000	46	1379	2.9	27.9	29	339	5.6	39.2	12	66	9.9	5.4	6.2	1770	2.76	43.26	1126	64	723
2000	47	1419	3.0	24.5	32	423	5.8	37.9	11	72	9.9	5.4	6.8	1872	2.74	43.04	1052	65	685
2000	48	1603	3.1	34.9	32	408	6.0	38.3	15	58	9.9	5.4	5.4	2050	2.00	42.83	1035	65	673
2000	49	1501	3.6	29.6	38	418	5.0	36.9	13	54	9.9	5.4	5.1	1963	2.74	44.05	1140	65	741
2000	50	1557	4.6	24.5	54	357	6.0	36.1	14	69	9.9	5.4	6.5	1947	2.83	43.20	1198	63	758
2000	51	1456	3.0	24.5	33	365	4.9	37.9	11	72	9.9	5.4	6.7	1819	2.70	43.38	1187	66	779
2000	52	1189	3.3	25.0	36	372	4.9	37.9	11	23	9.9	5.4	2.2	1588	2.70	43.38	893	64	572
2001	1	1498	3.3	25.0	36	438	4.7	37.9	11	49	9.9	5.4	4.6	1957	2.70	43.38	991	64	637
2001	2	1477	3.5	33.6	34	392	4.8	36.4	12	85	9.9	5.4	8.0	1934	2.57	43.56	980	65	640
2001	3	1292	3.4	22.1	34	393	3.7	35.8	9	59	9.9	5.4	5.6	1716	2.69	42.65	1065	67	709
2001	4	1596	2.9	24.7	35	343	5.0	35.2	11	57	9.9	5.4	5.4	1970	2.49	42.31	984	65	637
2001	5	1382	3.5	17.3	40	397	4.3	35.7	11	56	9.9	5.4	5.2	1798	2.53	43.01	1023	66	673
2001	6	1718	3.0	32.0	35	418	5.0	34.6	14	55	9.9	5.4	5.1	2171	2.48	41.86	1142	64	735
2001	7	1439	2.3	28.6	24	427	5.1	36.1	14	54	9.9	5.4	5.0	1901	2.55	43.59	1050	65	687
2001	8	1254	3.8	22.7	37	403	4.6	35.0	12	61	9.9	5.4	5.7	1688	2.60	43.28	1112	64	713
2001	9	1066	3.3	21.9	27	423	3.8	35.0	10	70	9.9	5.4	6.5	1534	2.12	42.78	1065	64	685
2001	10	1384	3.7	22.3	40	440	3.8	34.7	11	74	9.9	5.4	6.9	1868	2.60	41.80	1242	65	802
2001	11	1323	4.1	28.2	39	461	5.2	35.7	15	74	9.9	5.4	7.0	1831	2.61	42.72	1205	65	778
2001	12	1236	3.6	21.3	35	467	4.7	35.4	14	75	9.9	5.4	7.0	1747	2.64	42.29	1198	65	779
2001	13	1252	3.4	20.9	34	430	5.3	35.0	15	75	9.9	5.4	7.0	1725	2.43	41.42	1154	65	752
2001	14	1489	3.7	24.5	42	422	4.9	35.0	13	72	9.9	5.4	6.8	1954	2.68	41.00	1098	65	710
2001	15	1417	3.7	24.0	40	422	4.8	35.8	13	60	9.9	5.4	5.7	1870	2.68	40.95	1069	66	706
2001	16	1467	4.0	21.4	46	408	5.1	35.7	13	70	9.9	5.4	6.6	1910	2.63	40.95	1063	65	688
2001	17	1616	4.4	25.0	53	402	5.3	36.6	14	72	9.9	5.4	6.7	2055	2.47	40.89	1088	65	706
2001	18	1300	3.3	20.8	34	394	4.8	36.3	12	48	9.9	5.4	4.5	1715	2.59	41.10	999	65	651
2001	19	1482	5.0	20.6	59	374	4.8	36.6	11	81	9.9	5.4	7.6	1894	2.48	40.90	948	66	625
2001	20	1703	3.2	23.3	42	414	4.2	36.4	11	54	9.9	5.4	5.1	2141	2.50	41.67	1091	64	703
2001	21	1307	3.0	25.0	36	408	4.2	36.8	11	39	9.9	5.4	3.7	1733	2.50	41.57	898	65	587

		Primary sludge				Excess activated sludge				External organic matter				Digested sludge			Gas		
		Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	Dig. gas	Methane	
Year	w	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[Nm^3/h]	[%]	[Nm^3/h]
2001	22	1400	3.3	23.0	36	450	3.1	36.4	9	84	9.9	5.4	7.9	1909	2.49	40.42	954	64	614
2001	23	1508	3.1	22.6	36	403	4.1	36.3	11	68	9.9	5.4	6.4	1952	2.46	40.17	999	65	649
2001	24	1281	3.2	23.2	31	412	3.1	35.8	8	90	9.9	5.4	8.4	1760	2.51	39.46	947	65	612
2001	25	1387	3.4	22.2	37	441	3.1	36.5	9	54	9.9	5.4	5.1	1857	2.46	39.47	896	65	584
2001	26	1299	3.0	32.5	26	425	4.3	38.4	11	64	9.9	5.4	6.0	1774	3.25	41.73	865	66	567
2001	27	1029	3.6	22.6	29	369	3.4	38.6	8	74	9.9	5.4	6.9	1450	2.60	41.76	821	66	539
2001	28	1347	2.3	28.0	22	356	3.6	39.9	8	65	9.9	5.4	6.0	1751	2.68	43.13	878	64	560
2001	29	1371	2.1	27.2	21	378	5.2	40.5	12	57	9.9	5.4	5.3	1787	2.73	44.81	729	64	469
2001	30	1039	2.4	25.8	19	313	2.4	41.9	4	43	9.9	5.4	4.0	1381	2.55	45.41	558	65	361
2001	31	1229	3.2	21.8	31	301	2.5	41.9	4	51	9.9	5.4	4.8	1559	2.49	44.20	677	64	433
2001	32	1240	3.9	32.1	33	277	5.2	41.3	8	51	9.9	5.4	4.7	1550	2.52	44.56	757	63	479
2001	33	1264	3.3	24.3	32	247	4.7	40.6	7	51	9.9	5.4	4.8	1539	2.65	43.57	810	64	517
2001	34	1324	3.2	24.2	32	253	5.6	40.4	8	46	9.9	5.4	4.3	1600	2.52	43.08	787	65	508
2001	35	1547	3.0	27.3	34	244	5.4	40.3	8	49	9.9	5.4	4.6	1818	2.65	43.17	873	63	553
2001	36	1625	3.0	24.0	37	263	5.6	40.0	9	86	9.9	5.4	8.1	1945	2.55	42.29	962	63	609
2001	37	1930	3.8	39.4	44	268	7.4	41.4	12	68	9.9	5.4	6.3	2256	2.53	42.56	884	64	562
2001	38	1732	2.9	30.6	35	293	6.0	41.3	10	72	9.9	5.4	6.8	2074	2.55	44.71	816	66	535
2001	39	1480	3.3	25.8	36	282	5.4	39.1	9	81	9.9	5.4	7.6	1814	2.47	44.06	925	66	610
2001	40	1425	2.5	26.9	26	232	5.5	39.4	8	72	9.9	5.4	6.7	1709	2.34	42.59	982	64	629
2001	41	1797	3.7	27.0	49	257	5.0	39.9	8	55	9.9	5.4	5.1	2080	2.31	42.59	1008	65	656
2001	42	1647	3.0	23.3	38	313	4.4	40.2	8	68	9.9	5.4	6.3	2000	2.33	42.51	989	66	656
2001	43	1738	3.1	22.4	42	322	5.6	39.9	11	66	9.9	5.4	6.2	2093	2.28	41.74	968	66	643
2001	44	1848	3.0	29.4	39	296	5.0	40.3	9	64	9.9	5.4	6.0	2187	2.23	41.37	959	65	627
2001	45	1340	4.0	25.0	36	291	3.7	37.9	11	85	9.9	5.4	7.9	1691	2.46	39.10	1034	65	671
2001	46	1384	3.9	22.0	42	352	5.0	39.4	11	62	9.9	5.4	5.8	1772	2.52	36.84	1036	66	686
2001	47	1593	3.8	23.2	46	299	6.0	39.2	11	75	9.9	5.4	7.0	1933	2.45	41.53	1070	66	706
2001	48	1496	3.4	21.5	40	330	6.0	38.8	12	77	9.9	5.4	7.2	1869	2.20	43.03	1059	67	707
2001	49	1700	3.3	23.3	43	345	6.0	38.0	13	82	9.9	5.4	7.7	2093	2.44	41.39	1126	68	763
2001	50	1623	3.3	23.0	41	338	5.8	37.4	12	89	9.9	5.4	8.3	2016	2.40	41.13	1073	68	730
2001	51	1474	3.3	25.0	36	309	4.7	37.9	11	89	9.9	5.4	8.4	1846	2.39	40.56	1007	66	661
2001	52	1233	3.3	25.0	36	305	4.7	37.9	11	20	9.9	5.4	1.8	1538	2.39	40.56	787	65	508
2002	1	1209	3.8	24.9	41	318	5.8	37.8	12	45	9.9	5.4	4.2	1548	2.39	40.56	799	67	534
2002	2	1588	2.7	22.8	33	315	6.1	35.5	12	55	9.9	5.4	5.2	1932	2.38	40.00	940	67	626
2002	3	1636	2.6	34.4	28	306	5.3	36.4	10	93	9.9	5.4	8.7	2023	2.23	40.30	951	66	628
2002	4	1544	4.0	34.6	40	304	5.8	34.0	12	77	9.9	5.4	7.2	1906	2.43	42.45	925	64	595
2002	5	1449	4.2	33.3	41	296	6.0	38.0	11	73	9.9	5.4	6.9	1798	2.66	43.07	974	65	635
2002	6	1394	4.1	27.7	41	321	6.2	37.7	12	77	9.9	5.4	7.2	1762	2.70	43.33	1067	64	686

		Primary sludge				Excess activated sludge				External organic matter				Digested sludge			Gas		
		Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	Dig. gas	Methane	
Year	w	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[Nm^3/h]	[%]	[Nm^3/h]
2002	7	1453	3.4	28.0	36	370	6.1	38.3	14	85	9.9	5.4	8.0	1882	2.51	43.63	1073	66	703
2002	8	1372	3.9	24.6	40	404	5.1	38.0	13	85	9.9	5.4	8.0	1828	2.62	44.36	1133	64	725
2002	9	1330	3.6	25.1	36	404	4.3	37.7	11	72	9.9	5.4	6.8	1779	2.71	43.52	1029	64	659
2002	10	1619	4.0	35.1	42	444	5.5	37.7	15	82	9.9	5.4	7.7	2126	2.66	43.05	1068	64	684
2002	11	1529	3.5	27.7	39	470	5.5	37.7	16	76	9.9	5.4	7.2	2047	2.66	43.43	1043	67	698
2002	12	1520	3.5	25.2	40	555	4.2	37.7	15	85	9.9	5.4	8.0	2128	2.66	43.81	1106	66	730
2002	13	1168	3.5	19.8	33	540	3.4	38.0	11	70	9.9	5.4	6.5	1750	2.61	43.61	1064	67	715
2002	14	1016	2.9	20.0	24	465	3.6	37.3	10	55	9.9	5.4	5.2	1514	2.50	43.23	994	67	669
2002	15	1419	3.8	21.2	42	396	3.6	36.6	9	86	9.9	5.4	8.0	1867	2.31	42.07	1055	67	702
2002	16	1370	4.8	18.9	53	328	4.4	35.5	9	83	9.9	5.4	7.8	1737	2.44	42.23	1105	67	738
2002	17	1532	4.0	20.6	49	299	5.6	35.1	11	75	9.9	5.4	7.0	1867	2.40	41.49	1060	65	692
2002	18	1670	4.7	24.9	59	322	7.2	35.3	15	63	9.9	5.4	5.9	2016	2.48	41.34	1110	65	725
2002	19	1632	3.4	24.8	42	339	6.4	36.6	14	104	9.9	5.4	9.8	2041	2.54	42.35	1137	67	761
2002	20	1527	4.8	22.8	57	340	6.1	36.4	13	77	9.9	5.4	7.2	1901	2.43	42.68	1104	65	718
2002	21	1202	3.8	22.6	35	354	6.2	36.5	14	39	9.9	5.4	3.6	1566	2.49	42.98	943	66	621
2002	22	1364	3.3	21.2	35	366	5.4	36.4	13	87	9.9	5.4	8.1	1784	2.51	42.22	1127	66	739
2002	23	1378	3.2	19.3	36	359	5.8	35.6	13	93	9.9	5.4	8.7	1795	2.41	41.08	1140	65	737
2002	24	1694	3.4	27.0	42	375	6.4	36.1	15	84	9.9	5.4	7.9	2125	2.18	40.24	1184	64	754
2002	25	1224	3.3	22.3	31	343	6.2	37.1	13	64	9.9	5.4	6.0	1603	2.56	42.36	964	64	621
2002	26	1289	4.4	41.2	33	327	6.6	38.8	13	55	9.9	5.4	5.1	1663	2.76	43.78	988	63	626
2002	27	1099	3.9	27.9	31	284	6.2	39.2	11	66	9.9	5.4	6.2	1425	2.76	45.06	958	64	612
2002	28	1056	4.7	27.6	36	273	6.1	40.0	10	47	9.9	5.4	4.4	1350	2.77	45.13	879	65	571
2002	29	1155	4.7	24.0	41	257	7.6	41.4	11	43	9.9	5.4	4.0	1424	2.68	44.30	823	65	531
2002	30	1338	5.3	33.6	47	261	7.4	42.1	11	35	9.9	5.4	3.3	1611	2.68	45.62	824	63	520
2002	31	1016	4.3	22.0	34	244	7.4	43.0	10	46	9.9	5.4	4.3	1276	2.57	46.48	752	65	487
2002	32	1156	5.9	19.9	55	254	7.3	42.1	11	58	9.9	5.4	5.4	1422	2.68	45.25	807	48	390
2002	33	1156	6.6	26.1	56	242	7.0	41.6	10	66	9.9	5.4	6.2	1426	2.64	44.99	930	64	597
2002	34	1345	7.2	22.1	75	190	5.5	41.0	6	68	9.9	5.4	6.4	1551	2.33	43.95	936	65	609
2002	35	1535	4.9	22.4	58	258	6.7	41.5	10	70	9.9	5.4	6.6	1820	2.48	43.66	1013	65	656
2002	36	1270	3.4	22.0	34	295	6.3	41.3	11	78	9.9	5.4	7.3	1613	2.63	42.90	1044	65	679
2002	37	1460	3.4	25.6	37	294	5.6	40.5	10	72	9.9	5.4	6.7	1799	2.54	42.73	1022	66	672
2002	38	1536	3.0	23.3	35	309	6.0	40.5	11	78	9.9	5.4	7.3	1894	2.48	42.27	1073	65	696
2002	39	1479	2.7	21.8	31	304	5.6	39.0	10	70	9.9	5.4	6.6	1825	2.23	41.96	1044	66	685
2002	40	1602	3.1	20.5	39	312	5.0	39.2	9	90	9.9	5.4	8.4	1970	2.33	41.47	1081	66	715
2002	41	1756	3.1	24.9	41	296	4.6	38.2	8	64	9.9	5.4	6.0	2089	2.29	41.03	1016	67	684
2002	42	1789	3.2	24.0	44	277	4.9	37.4	8	65	9.9	5.4	6.1	2101	2.20	40.68	1091	66	716
2002	43	2029	3.8	31.2	53	284	6.0	37.5	11	75	9.9	5.4	7.0	2362	2.17	41.16	1105	65	714

		Primary sludge				Excess activated sludge				External organic matter				Digested sludge			Gas		
		Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	Dig. gas	Methane	
Year	w	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[Nm^3/h]	[%]	[Nm^3/h]
2002	44	1375	2.9	18.5	32	361	5.9	36.6	14	65	9.9	5.4	6.1	1769	2.15	40.79	999	66	659
2002	45	1279	3.6	20.8	36	344	5.6	35.6	12	67	9.9	5.4	6.3	1659	2.23	41.51	1052	66	697
2002	46	1750	3.1	23.2	42	330	6.2	34.9	13	82	9.9	5.4	7.7	2130	2.29	39.69	1170	65	759
2002	47	1625	3.1	20.8	40	316	6.3	34.6	13	76	9.9	5.4	7.2	1984	2.21	39.59	1180	66	784
2002	48	1734	2.7	26.6	34	341	6.4	34.9	14	73	9.9	5.4	6.8	2124	2.05	40.01	1218	67	819
2002	49	1674	2.7	22.6	35	340	6.2	34.7	14	78	9.9	5.4	7.3	2061	2.34	40.43	1202	68	823
2002	50	1704	2.8	21.1	38	303	5.6	34.5	11	81	9.9	5.4	7.6	2056	2.28	40.02	1165	68	795
2002	51	1717	3.8	24.9	41	288	5.8	37.8	12	81	9.9	5.4	7.6	2055	2.09	39.59	1156	67	772
2002	52	1731	3.8	24.9	41	247	5.8	37.8	12	11	9.9	5.4	1.1	1963	2.09	39.59	876	67	588
2003	1	1746	3.6	24.4	30	231	3.8	37.5	9	39	9.9	5.4	3.7	1989	2.09	39.59	855	66	562
2003	2	1497	2.8	20.8	33	269	6.4	34.4	11	65	9.9	5.4	6.1	1802	1.90	39.15	901	67	600
2003	3	1473	3.7	25.3	41	293	6.5	34.6	12	74	9.9	5.4	6.9	1812	2.00	39.33	1154	65	754
2003	4	1347	3.6	24.4	37	342	6.1	35.2	14	82	9.9	5.4	7.6	1743	2.23	40.38	1202	66	798
2003	5	1323	2.1	22.6	22	326	6.2	36.5	13	72	9.9	5.4	6.8	1699	2.32	41.33	1217	66	801
2003	6	1369	3.5	21.3	38	287	5.8	36.4	11	73	9.9	5.4	6.9	1698	2.46	40.89	1162	67	773
2003	7	1502	4.0	26.3	44	287	5.9	36.2	11	72	9.9	5.4	6.7	1832	2.38	41.15	1126	69	773
2003	8	1467	3.6	24.7	40	244	5.6	36.3	9	62	9.9	5.4	5.8	1746	2.03	41.01	1092	68	742
2003	9	1397	3.2	23.8	34	245	5.2	36.1	8	56	9.9	5.4	5.2	1672	2.28	41.00	992	68	671
2003	10	1443	3.6	25.8	39	312	3.6	35.9	7	75	9.9	5.4	7.0	1805	2.26	40.64	1126	67	754
2003	11	1295	4.6	30.7	41	350	6.0	35.6	14	84	9.9	5.4	7.8	1705	2.30	41.04	1121	68	758
2003	12	1060	3.6	23.3	29	384	5.6	35.6	14	93	9.9	5.4	8.7	1509	2.42	42.12	1200	68	820
2003	13	1107	4.5	23.6	38	345	4.6	36.2	10	100	9.9	5.4	9.3	1522	2.36	41.92	1254	67	837
2003	14	1277	4.3	21.2	43	375	5.4	35.4	13	93	9.9	5.4	8.7	1708	2.46	41.62	1292	66	855
2003	15	1308	3.3	24.6	33	484	3.5	35.8	11	87	9.9	5.4	8.1	1854	2.52	41.71	1218	67	816
2003	16	989	3.6	20.5	28	396	5.4	35.9	14	51	9.9	5.4	4.8	1410	2.42	41.69	1160	69	796
2003	17	1074	3.9	19.8	34	351	2.8	36.7	6	56	9.9	5.4	5.2	1455	2.50	42.01	1057	66	693
2003	18	1338	4.0	33.0	36	418	5.1	36.4	14	54	9.9	5.4	5.1	1794	2.45	41.25	1201	64	769
2003	19	1314	3.1	24.5	31	384	5.4	37.6	13	98	9.9	5.4	9.2	1768	2.64	42.79	1174	65	765
2003	20	1185	3.2	20.6	30	369	3.6	37.8	8	80	9.9	5.4	7.5	1607	2.35	42.51	1124	65	729
2003	21	1327	3.0	20.1	32	300	3.1	37.7	6	74	9.9	5.4	6.9	1675	2.42	41.76	1184	64	760
2003	22	1154	4.3	32.2	34	241	4.8	37.7	7	48	9.9	5.4	4.5	1425	2.52	44.59	1118	65	726
2003	23	1095	3.5	20.7	30	235	2.8	38.2	4	83	9.9	5.4	7.8	1387	2.60	43.47	1126	65	728
2003	24	1109	3.7	23.7	31	225	3.8	37.7	5	59	9.9	5.4	5.5	1370	2.53	43.46	1034	64	661
2003	25	1123	3.4	25.0	29	446	2.6	38.8	7	59	9.9	5.4	5.5	1609	2.10	42.36	1102	64	708
2003	26	1123	3.4	26.9	28	476	2.6	39.0	8	68	9.9	5.4	6.4	1650	2.44	42.65	1015	65	658
2003	27	1143	3.2	25.6	27	478	3.2	39.7	9	58	9.9	5.4	5.5	1661	2.55	43.27	1027	64	661
2003	28	1337	3.0	23.2	31	465	2.0	39.8	6	51	9.9	5.4	4.8	1834	2.41	42.99	908	65	589

		Primary sludge				Excess activated sludge				External organic matter				Digested sludge			Gas		
		Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	Dig. gas	Methane	
Year	w	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[Nm^3/h]	[%]	[Nm^3/h]
2003	29	1267	3.0	25.2	28	409	2.2	41.5	5	44	9.9	5.4	4.1	1701	2.44	44.18	773	65	498
2003	30	1261	5.0	35.0	41	400	2.9	41.5	7	32	9.9	5.4	3.0	1678	2.43	44.75	819	64	522
2003	31	1181	2.7	22.0	25	337	2.8	42.4	5	52	9.9	5.4	4.9	1550	2.37	46.81	792	64	509
2003	32	1224	3.6	22.2	34	365	2.1	41.2	5	47	9.9	5.4	4.4	1612	2.29	45.11	798	65	517
2003	33	1242	4.4	25.2	41	401	3.1	41.0	7	56	9.9	5.4	5.2	1673	2.27	44.03	1010	63	640
2003	34	1255	3.4	22.7	33	459	2.5	41.1	7	65	9.9	5.4	6.0	1754	2.36	44.27	996	64	639
2003	35	1524	3.4	28.2	37	522	2.1	40.0	7	67	9.9	5.4	6.3	2093	2.30	43.64	1029	64	658
2003	36	1426	3.5	24.8	38	557	1.9	39.8	6	83	9.9	5.4	7.8	2043	2.00	42.91	1070	66	706
2003	37	1648	3.4	30.1	39	499	2.1	38.7	6	80	9.9	5.4	7.5	2207	2.35	42.19	925	65	602
2003	38	1727	4.3	21.6	58	374	2.1	37.1	5	68	9.9	5.4	6.4	2131	2.36	40.97	1099	65	709
2003	39	1390	3.1	23.6	33	589	2.0	39.8	7	77	9.9	5.4	7.2	2035	2.09	41.21	1221	65	796
2003	40	1592	3.5	24.1	42	533	2.0	37.4	7	73	9.9	5.4	6.8	2172	2.28	40.88	1136	65	737
2003	41	1725	3.6	24.6	47	409	2.6	37.4	7	81	9.9	5.4	7.6	2187	1.68	40.63	1077	65	699
2003	42	1734	3.2	22.2	43	405	2.0	37.2	5	80	9.9	5.4	7.5	2190	2.25	40.51	1116	68	758
2003	43	1972	3.0	23.7	45	400	2.4	36.6	6	60	9.9	5.4	5.6	2404	2.16	40.15	1060	67	708
2003	44	1694	3.4	19.2	47	448	2.9	36.8	8	61	9.9	5.4	5.7	2170	2.03	39.07	1042	65	680
2003	45	1428	3.6	22.1	40	621	2.5	36.5	10	82	9.9	5.4	7.7	2105	2.15	39.70	1093	69	750
2003	46	1639	3.6	20.5	47	646	2.0	35.8	8	69	9.9	5.4	6.5	2324	2.05	39.45	1014	68	685
2003	47	1525	3.5	22.6	41	567	2.8	34.9	10	36	9.9	5.4	3.4	2102	2.23	39.72	1177	66	775
2003	48	1470	4.4	31.6	44	481	4.4	35.0	14	108	9.9	5.4	10.1	2038	2.42	39.38	1343	67	895
2003	49	1360	3.4	24.7	35	469	3.2	36.1	10	100	9.9	5.4	9.4	1904	2.44	40.59	1251	68	851
2003	50	1541	3.7	23.9	43	422	3.8	35.5	10	78	9.9	5.4	7.3	2011	2.40	41.21	1273	66	844
2003	51	1600	3.6	24.4	30	475	3.8	37.5	9	94	9.9	5.4	8.8	2138	2.32	42.30	1223	66	812
2003	52	1821	3.6	24.4	30	436	3.8	37.5	9	30	9.9	5.4	2.8	2256	2.32	42.30	1059	66	703
2004	1	1509	3.6	27.5	40	398	4.6	38.3	11	38	9.9	5.4	3.6	1922	2.32	42.30	1000	68	684
2004	2	1586	3.6	27.5	40	362	4.6	38.3	11	57	9.9	5.4	5.3	1980	2.32	42.30	1063	67	715
2004	3	1521	3.0	26.5	34	371	5.0	38.1	11	96	9.9	5.4	8.9	1961	2.23	43.38	1100	66	727
2004	4	1255	3.5	24.1	33	409	3.3	38.2	8	80	9.9	5.4	7.5	1719	2.37	42.79	1153	67	774
2004	5	1419	3.2	24.6	34	393	2.9	37.6	7	79	9.9	5.4	7.4	1866	2.48	42.48	1185	65	773
2004	6	1665	3.2	30.9	37	377	6.2	37.9	15	92	9.9	5.4	8.6	2112	2.45	42.22	1261	66	830
2004	7	1393	3.3	24.6	35	353	6.2	37.6	14	88	9.9	5.4	8.3	1804	2.57	43.70	1215	67	819
2004	8	1352	3.7	26.9	37	320	5.1	37.9	10	93	9.9	5.4	8.8	1738	2.39	43.63	1190	67	801
2004	9	1375	2.8	23.0	30	378	4.2	37.3	10	80	9.9	5.4	7.5	1807	2.59	42.90	1175	66	774
2004	10	1496	3.0	22.6	35	368	3.3	36.6	8	109	9.9	5.4	10.2	1944	2.59	42.70	1226	68	831
2004	11	1586	3.2	24.4	38	344	4.4	36.4	10	99	9.9	5.4	9.2	1997	2.56	42.61	1137	69	789
2004	12	1774	1.8	31.1	22	386	8.0	37.0	19	85	9.9	5.4	7.9	2225	2.59	42.76	1355	66	900
2004	13	1326	3.8	28.0	36	351	7.0	38.0	15	85	9.9	5.4	7.9	1733	2.48	43.89	1279	67	863

		Primary sludge				Excess activated sludge				External organic matter				Digested sludge			Gas		
		Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	Dig. gas	Methane	
Year	w	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[Nm^3/h]	[%]	[Nm^3/h]
2004	14	1248	4.6	25.4	43	298	5.4	37.8	10	62	9.9	5.4	5.8	1576	2.72	44.64	1131	69	777
2004	15	1268	3.9	25.8	37	259	5.3	37.7	9	66	9.9	5.4	6.2	1566	2.70	44.12	1069	67	716
2004	16	1297	4.1	26.2	39	362	4.8	37.6	11	73	9.9	5.4	6.8	1703	2.67	43.35	1085	68	735
2004	17	1780	4.1	25.6	54	417	2.8	36.8	7	73	9.9	5.4	6.8	2235	2.60	43.36	1257	68	854
2004	18	1825	3.1	25.0	42	416	3.7	36.7	10	74	9.9	5.4	6.9	2286	2.59	42.23	1112	68	752
2004	19	1893	2.5	24.8	36	451	3.4	36.4	10	80	9.9	5.4	7.5	2398	2.09	41.66	1104	65	719
2004	20	1560	4.0	24.9	47	428	3.1	36.4	8	64	9.9	5.4	6.0	2024	2.55	40.07	1083	65	706
2004	21	1598	4.2	23.9	51	443	3.1	37.6	9	60	9.9	5.4	5.6	2071	2.49	39.63	1159	65	750
2004	22	1775	3.4	30.8	42	440	5.0	38.4	14	104	9.9	5.4	9.8	2296	2.61	41.56	1156	66	760
2004	23	1560	4.0	25.9	46	448	4.3	38.5	12	63	9.9	5.4	5.9	2042	2.55	41.50	984	66	648
2004	24	1967	6.4	44.8	69	489	5.2	39.1	15	82	9.9	5.4	7.7	2535	2.74	43.30	1094	65	716
2004	25	1765	3.8	33.4	45	458	5.1	39.7	14	89	9.9	5.4	8.3	2288	2.83	44.53	1063	64	684
2004	26	1689	3.9	29.2	47	450	4.9	39.5	13	76	9.9	5.4	7.1	2184	2.78	44.53	1033	65	672
2004	27	1750	4.1	34.7	47	416	5.7	40.5	14	70	9.9	5.4	6.6	2212	2.57	45.45	972	65	633
2004	28	1619	3.1	34.0	33	397	4.4	41.1	10	57	9.9	5.4	5.4	2057	2.95	44.32	883	65	577
2004	29	1378	3.5	32.0	33	420	3.7	41.5	9	50	9.9	5.4	4.7	1830	2.50	45.57	826	65	536
2004	30	1185	4.3	29.4	36	391	2.1	42.0	5	49	9.9	5.4	4.6	1605	2.44	46.16	740	66	490
2004	31	1345	4.3	28.6	41	342	2.8	41.8	6	61	9.9	5.4	5.7	1723	2.44	45.92	770	66	509
2004	32	1292	4.9	29.9	44	333	3.2	41.0	6	62	9.9	5.4	5.8	1664	2.50	44.43	799	66	526
2004	33	1327	4.8	28.5	46	320	3.6	40.6	7	64	9.9	5.4	6.0	1685	2.50	44.11	844	65	550
2004	34	1164	3.5	24.9	31	343	4.8	39.9	10	69	9.9	5.4	6.5	1551	2.63	44.30	924	64	589
2004	35	1513	4.5	27.4	49	357	5.0	39.0	11	77	9.9	5.4	7.2	1915	2.63	42.97	1024	65	666
2004	36	1583	3.8	29.7	42	333	5.6	38.6	11	93	9.9	5.4	8.7	1982	2.63	43.48	965	66	638
2004	37	1836	3.0	29.4	39	360	5.1	38.1	11	96	9.9	5.4	9.0	2266	1.98	43.13	961	67	641
2004	38	1917	3.2	28.4	44	430	4.6	37.8	12	69	9.9	5.4	6.5	2391	2.53	41.65	1044	65	683
2004	39	1301	4.0	26.3	38	371	5.2	39.6	12	58	9.9	5.4	5.5	1705	2.44	42.37	920	65	595
2004	40	1582	3.2	25.2	38	389	5.4	39.3	13	127	9.9	5.4	11.9	2067	2.61	42.54	1079	67	725
2004	41	1694	2.6	24.7	33	422	5.4	39.4	14	88	9.9	5.4	8.2	2176	2.43	41.88	1168	68	790
2004	42	1679	3.3	25.2	41	381	4.2	38.5	10	87	9.9	5.4	8.1	2117	2.59	41.41	1112	69	762
2004	43	1915	3.2	29.3	43	214	6.0	39.3	8	81	9.9	5.4	7.6	2188	2.59	40.80	1151	66	759
2004	44	2013	3.2	30.3	45	407	5.5	38.2	14	85	9.9	5.4	7.9	2480	2.30	41.37	1168	67	787
2004	45	1577	2.9	27.0	33	446	4.6	37.7	13	82	9.9	5.4	7.7	2082	2.47	41.11	1105	67	745
2004	46	1527	3.8	25.2	43	540	2.9	37.7	10	84	9.9	5.4	7.9	2125	2.44	41.03	1161	68	791
2004	47	1425	3.2	20.8	36	458	4.8	36.8	14	81	9.9	5.4	7.6	1931	2.50	41.47	1140	67	758
2004	48	1647	3.1	22.1	40	400	4.0	36.2	10	90	9.9	5.4	8.4	2105	2.34	41.55	1183	68	799
2004	49	1750	3.2	25.5	42	428	5.4	35.8	15	80	9.9	5.4	7.5	2230	2.30	39.63	1192	67	798
2004	50	1661	2.9	32.6	32	386	3.6	36.7	9	88	9.9	5.4	8.2	2118	2.43	41.84	1113	68	759

		Primary sludge				Excess activated sludge				External organic matter				Digested sludge			Gas		
		Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	Dig. gas	Methane	
Year	w	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[Nm^3/h]	[%]	[Nm^3/h]
2004	51	1473	3.9	25.8	43	437	4.6	36.6	13	103	9.9	5.4	9.6	1982	2.53	41.28	1280	67	853
2004	52	1577	3.6	27.5	40	464	4.6	38.3	11	56	9.9	5.4	5.3	2071	2.59	42.21	1138	67	758
2004	53	1463	3.6	27.4	36	451	4.0	37.4	11	75	9.9	5.4	7.0	1965	2.59	42.21	1170	67	788
2005	1	1616	3.6	27.4	36	451	4.0	37.4	11	59	9.9	5.4	5.5	2099	2.65	43.15	1157	66	764
2005	2	1591	3.8	41.6	35	370	5.8	38.6	13	91	9.9	5.4	8.5	2043	2.68	43.74	1103	68	745
2005	3	1525	3.3	28.5	36	371	5.8	37.9	13	98	9.9	5.4	9.2	1966	2.65	44.41	1175	66	773
2005	4	1402	3.6	25.1	38	403	5.6	37.8	14	82	9.9	5.4	7.7	1856	2.61	43.57	1208	68	822
2005	5	1307	3.6	23.2	36	457	4.6	37.3	13	73	9.9	5.4	6.8	1808	2.68	43.18	1138	68	774
2005	6	1374	3.9	30.9	37	430	5.0	37.2	13	77	9.9	5.4	7.3	1858	2.73	43.35	1230	67	824
2005	7	1471	3.4	26.4	37	425	5.1	37.2	14	80	9.9	5.4	7.4	1949	2.70	42.51	1330	67	894
2005	8	1409	3.0	23.8	32	438	4.8	36.8	13	101	9.9	5.4	9.4	1919	2.65	42.29	1304	69	895
2005	9	1285	3.0	24.0	29	443	3.8	35.9	11	78	9.9	5.4	7.3	1782	2.53	41.49	1168	67	784
2005	10	1274	4.1	24.7	39	400	3.8	36.1	10	74	9.9	5.4	6.9	1721	2.53	41.40	1166	66	772
2005	11	1498	4.5	24.0	51	454	4.1	35.2	12	91	9.9	5.4	8.6	2008	2.54	41.25	1255	67	846
2005	12	1847	3.4	29.2	44	505	3.6	35.0	12	67	9.9	5.4	6.3	2394	2.57	42.12	1208	68	825
2005	13	1126	3.5	26.9	29	451	6.0	36.3	17	66	9.9	5.4	6.2	1620	2.48	41.97	1085	69	748
2005	14	1353	4.0	27.4	39	432	5.8	35.9	16	88	9.9	5.4	8.2	1845	2.47	41.35	1183	67	791
2005	15	1460	3.5	25.9	38	468	4.8	36.3	14	84	9.9	5.4	7.9	1984	2.44	41.64	1160	67	778
2005	16	1429	3.6	23.8	39	502	4.5	36.2	14	91	9.9	5.4	8.5	1990	2.50	41.12	1163	67	784
2005	17	1368	3.4	23.9	35	539	3.6	36.2	12	84	9.9	5.4	7.9	1966	2.44	40.48	1141	67	766
2005	18	1684	4.5	33.9	50	550	3.6	36.1	13	54	9.9	5.4	5.1	2267	2.70	42.64	1114	66	735
2005	19	1527	3.8	29.4	41	574	3.4	36.6	12	79	9.9	5.4	7.4	2156	2.50	42.10	1041	66	688
2005	20	1421	3.4	27.2	35	631	3.0	37.1	12	98	9.9	5.4	9.2	2129	2.41	41.03	1050	65	687
2005	21	1481	3.6	25.1	40	658	2.5	36.9	10	66	9.9	5.4	6.2	2180	2.39	41.45	1045	65	682
2005	22	1631	4.8	32.3	53	488	3.3	36.8	10	82	9.9	5.4	7.7	2178	2.52	41.76	1163	65	753
2005	23	1412	3.5	24.0	38	425	3.9	36.7	11	81	9.9	5.4	7.6	1890	2.65	42.08	1096	65	716
2005	24	1460	3.0	30.8	30	393	4.4	37.9	11	95	9.9	5.4	8.9	1929	2.65	42.08	1391	66	922
2005	25	1411	4.3	32.7	41	377	4.9	37.7	12	58	9.9	5.4	5.4	1825	2.63	43.73	1344	66	890
2005	26	1423	3.3	27.2	34	398	4.2	38.0	10	85	9.9	5.4	7.9	1880	2.55	43.49	1053	65	690
2005	27	1117	4.0	25.9	33	470	2.6	39.0	7	75	9.9	5.4	7.0	1641	2.48	42.90	960	66	631
2005	28	1205	3.4	24.3	31	493	1.4	39.3	4	55	9.9	5.4	5.1	1735	2.53	42.48	887	65	574
2005	29	1389	3.1	30.6	30	480	3.2	39.5	9	59	9.9	5.4	5.5	1909	2.68	45.26	923	64	590
2005	30	1037	4.4	44.4	25	385	5.2	41.8	12	67	9.9	5.4	6.2	1481	2.73	46.83	823	65	537
2005	31	1263	3.6	27.7	33	322	3.8	42.2	7	65	9.9	5.4	6.1	1628	2.70	46.44	936	65	609
2005	32	1212	3.8	32.9	31	361	4.7	41.8	10	58	9.9	5.4	5.5	1612	2.71	46.64	921	64	591
2005	33	1061	3.5	27.2	27	394	3.8	41.6	9	63	9.9	5.4	5.9	1498	2.65	46.06	932	66	611
2005	34	1305	4.2	27.2	40	431	4.0	40.5	10	98	9.9	5.4	9.2	1806	2.70	44.76	1162	65	756

		Primary sludge				Excess activated sludge				External organic matter				Digested sludge			Gas		
		Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	VS	Flow	DM	ROI	Dig. gas	Methane	
Year	w	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[tonne/d]	[m^3/d]	[%]	[% of DM]	[Nm^3/h]	[%]	[Nm^3/h]
2005	35	1116	3.5	25.0	29	489	3.1	39.6	9	77	9.9	5.4	7.2	1661	2.67	43.58	1078	67	718
2005	36	1300	3.4	29.8	31	411	3.1	38.2	8	74	9.9	5.4	6.9	1767	2.64	43.14	1008	66	664
2005	37	1195	3.8	26.3	33	416	3.7	37.0	10	76	9.9	5.4	7.2	1665	2.64	41.92	1057	66	694
2005	38	1194	3.6	22.8	33	506	3.2	37.2	10	78	9.9	5.4	7.4	1754	2.60	41.46	1056	67	708
2005	39	1547	3.0	24.7	35	535	2.8	36.7	9	84	9.9	5.4	7.9	2143	2.51	40.74	1147	66	762
2005	40	1642	2.7	22.7	34	612	2.8	37.0	11	94	9.9	5.4	8.8	2323	2.29	40.21	1159	68	785
2005	41	1603	3.0	21.8	38	400	1.8	36.8	5	88	9.9	5.4	8.2	2065	2.10	39.85	1119	68	757
2005	42	1611	3.1	23.2	38	757	1.9	36.8	9	76	9.9	5.4	7.1	2420	2.08	40.49	1119	67	748
2005	43	1401	3.2	28.9	32	788	2.1	36.1	11	84	9.9	5.4	7.8	2253	2.11	42.87	1090	67	735
2005	44	1518	3.5	27.8	38	589	2.1	36.2	8	85	9.9	5.4	7.9	2173	2.16	39.71	1168	67	788
2005	45	1489	3.2	26.4	35	377	3.6	36.0	9	75	9.9	5.4	7.1	1920	2.20	39.31	1126	68	761
2005	46	1503	3.4	20.9	40	368	3.9	35.8	9	73	9.9	5.4	6.8	1914	2.20	39.42	1124	66	744
2005	47	1634	3.0	21.9	38	376	4.3	35.4	10	88	9.9	5.4	8.2	2069	2.22	39.13	1185	67	796
2005	48	1776	3.2	25.0	43	416	5.0	36.0	13	70	9.9	5.4	6.5	2234	2.19	39.15	1191	66	785
2005	49	1539	3.7	35.1	37	411	6.1	35.6	16	99	9.9	5.4	9.3	2033	2.49	40.75	1195	68	809
2005	50	1326	3.8	26.9	37	458	5.5	37.1	16	100	9.9	5.4	9.3	1858	2.49	40.75	1280	66	847
2005	51	1215	3.6	27.4	36	523	4.0	37.4	11	100	9.9	5.4	9.3	1817	2.49	40.75	1225	67	826
2005	52	1362	3.6	27.4	36	532	4.0	37.4	11	71	9.9	5.4	6.7	1944	2.49	40.75	1177	68	798