From Sludge to Energy

FRA SLAM TIL ENERGI

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i. Abstract

Two primary municipal sewage sludges from the same source wastewater, but different separation technologies, were collected and fed to two pilot scale (20 L) anaerobic digesters to investigate differences in the biogas output and quality. The sludges compared were sampled from the Nodre Follo Resnseanlegg South of Oslo, Norway, which is also where the digesters were situated. Sedimentation sludge was collected via the plant's sedimentation basins, and sludge from the Salsnes Filter SF1000 was collected by treating wastewater just prior to entry to the sedimentation basins. The Salsnes Filter sieve sludge was collected at two different influent flowrates (sieve rates) into the filter; for the first half of the experiment the sieve rate was 100 and then 50 m^3/m^2hr for the second half. The sieve sludge and sediment sludge were measured for volatile solids, and then diluted accordingly with raw wastewater to match volatile solids content; this to enable more direct comparison when fed equally to the respective digesters. Gas volume and gas quality (CH_4 and CO_2) measurements were collected continuously with the Dolly Digester system by Belach Bioteknikk. Results showed that the quality of the biogas was similar for both reactors, at close to 60% methane. For the first phase, when the sieve rate was 100 m^3/m^2hr for the Salsnes Filter, the sediment reactor produced 0.547 m^3CH_4/kgVS-destroyed compared to 0.527 m^3CH_4/kgVS-destroyed for the Salsnes fed reactor. However, in the second phase with a sieve rate of 50 m^3/m^2hr, the sediment reactor produced 0.567 m^3CH_4/kgVS-destroyed to the Salsnes 0.570 m^3CH_4/gVS-destroyed. These results are supported by BMP experiments that were also conducted in the experiment, showing that the methane potential of the sieve sludge is somewhat dependent on sieve rate.

ii. Preface

This past summer of 2012 I had the opportunity to work for Salsnes Filter as an intern in Namsos, Norway. Here I worked for a good part of the summer directly with the filters, as well as in treatment plants all around Nord Trøndelag and Midt-Norge. I went on service calls with very experienced technicians, participated in R&D meetings with the engineers, drove thousands of kilometers around the extraordinarily beautiful countryside taking samples at various plants, and I certainly saw my fair share of Salsnes Filter sludge. This was a special experience for me, and I really got to know how Salsnes Filters work, and what they are capable of.

This research is somewhat a continuation of my experience, putting my learned knowledge of how the filters operate to good use. I have now had the opportunity to explore some of the phenomena that I witnessed firsthand, and this thesis will hopefully represent that.

Figure 1: Salsnes SF6000s at Tiendeholmen Renseanlegg in Namsos, Norway.

iii. Acknowledgements

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And finally, to all my friends and acquaintances in Norway, for making the last 18 months an experience that I will never forget.

iv. Abbreviations

AS – Activated Sludge
BOD – Biological Oxygen Demand
CH_4 – Methane
CO_2 – Carbon Dioxide
COD – Chemical Oxygen Demand
FOG – Fats, oils, and grease
GC – Gas Chromatograph (specific to gas quality analysis)
HRT – Hydraulic retention time
Sediment/sediment sludge – sludge obtained via sedimentation basins using gravity
SF – Salsnes Filter
Sieve sludge – sludge obtained via Salsnes Filters
SRT – Solids retention time
TS – Total Solids (dried solids)
TS% - mass percent total solids in a given sample of wet sludge
TSS – Total Suspended Solids
VOA/VFA – Volatile Organic Acid / Volatile Fatty Acid (used interchangeably)
VS – Volatile Solids (organic, 'combustable' solids)
VS% - mass percent volatile solids in a given sample of wet sludge

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1. Introduction

The scope of this thesis project is quite large, and there is a lot of background information that must be explained for full understanding of the methodology. Some information might seem out of place, but every attempt was made to make the background for this project as concise as possible.

The Sludge to Energy project is a research study commissioned by Salsnes Filter AS of Namsos, Norway. Salsnes Filter manufactures rotating belt sieves for removal of suspended solids in water, which were initially developed by Audun Fosseng for the treatment of waste created by the aquaculture industry. It was soon realized that the filters had more potential than in just the aquaculture industry, and soon the product was developed and marketed to other industries, most notably the wastewater industry. Since 1991, the filters have undergone much development, and Salsnes filters can now be found all across the globe.

The main market for the filters is replacement of traditional primary wastewater treatment, typically sedimentation basins. The filters have a drastically smaller footprint than sedimentation basins, and research shows that they can perform as well at removing suspended solids, if not better. There are also other potential benefits of Salsnes Filters, and the current research is concerned specifically with investigating these potentials.

1.1 Background

This project is called 'Fra Slam til Energi,' or in English 'From Sludge to Energy' and it means just that: turning what would otherwise be a product to be disposed of into biogas that can be combusted to produce usable energy. While many substrates can be used for digestion, this project focuses on municipal wastewater or sewage. Municipal waste has a relatively low COD concentration in the raw influent, but there is an *ample* supply and the facilities already exist to treat such waste. Treatment of this water must be done economically, so perhaps there are ways to utilize more of the resources that are for most, thought of simply as a waste product.

The Sludge to Energy project is based on the idea that municipal sewage waste contains a large amount of energy in the form of organic waste that is not fully utilized. Anaerobic digestion is a common practice at waste water treatment facilities, especially larger facilities, but the question is: are the digesters being used at their full potential? It is already known both waste activated sludge (biomass from aerobic treatment) and primary treatment sludge can be digested to produce methane (Appels et. al., 2008), but research shows that sludge that is captured before any bioprocess, i.e. primary sludge, has higher potential to produce biogas (Ucisik & Henze 2008). This is logical as aerobic processes make use of substrate and extract much of that energy for growth and respiration. It follows that if more solids could be removed before biological processes, the net energy gain in terms of methane production would be higher with a higher proportion of primary treatment solids, in addition to removing those solids before aerobic processes requiring oxygen. However, different primary treatment processes may have different potentials when it comes to their digestability and methane potential, so this needs to be investigated.

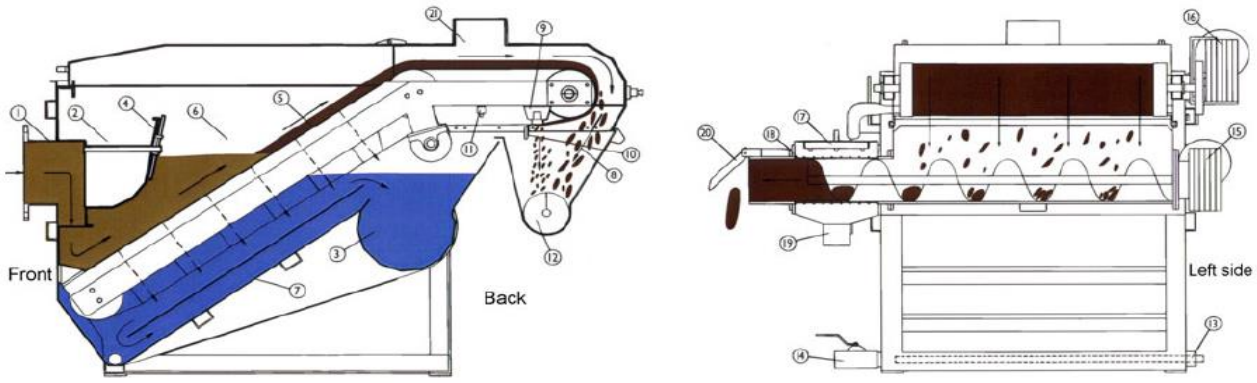
The current project is the second phase of the, Sludge to Energy project. The first phase was preliminary research carried out by Aquateam AS, in which the differences between sedimentation sludge and sludge obtained via Salsnes Filters from wastewater treatment plants around Norway were compared. In the first phase of the project, sieve sludge from 19 different plants operating Salsnes filters for the primary treatment and 10 plants operating sedimentation alone were sampled. Solids testing (TS/VS), COD, calorific value, and methane potential tests were conducted on the different sludges.

The results from the first phase showed that SF sieve sludge typically has ~10% higher VS/TS ratio on average (91.6% vs. 80.8%) which is supported by other research (Paulsrud, 2005), however the COD/VS ratio was found to be slightly lower for sieve sludge at 1.3 gCOD/gVS compared to 1.6 gCOD/gVS for sedimentation sludge (however results from the current research found more equal values). No significant difference was found for the calorific value of each of the sludges when normalized for VS%. The most interesting finding in the first phase of the project is that when normalized for VS%, the methane potential was found to be higher for the Salsnes sieve sludge. This last point is the motivation to go ahead with the second (current) phase of the project.

The second phase of Sludge to Energy is to see if the same methane potential results can be demonstrated in pilot scale digesters, that is, if sieve sludge has a higher methane yield in a larger scale reactor. For the experiment, two anaerobic digesters were run concurrently, one being fed sludge obtained via sedimentation alone and the other being fed sludge obtained from a Salsnes Filter SF1000. The goal of the project is to see if there is any significant difference in volume of biogas production, biogas quality (%CH_4), volatile solids reduction, and some other minor parameters.

1.2 Salsnes Filter

Salsnes Filter is a company based out of Namsos, Norway. They produce rotating belt filters with a fine mesh to effectively sieve the water, removing suspended solids (TSS). Numerous sizes of these filters are available, currently ranging from the SF1000 to the SF6000 which can filter raw wastewater at up to 150 L/s (salsnes-filter.no). There are also larger and smaller filters in development – the SF500 filter was to be used for this project, but the filter is currently still under development. Instead, the SF1000 filter was used for this research, fitted with a filter mesh of 0.35mm.



a) Cut from the right side b) Cut from behind

Figure 1. The fine mesh rotating belt sieve.

Key:

1 Inlet
2 Overflow
3 Outlet
4 Level indicator
5 Wire cloth
6 Wastewater
7 Filtered water
8 Sludge compartment
9 Air-knife cleaning device
10 Rubber scraper
11 Hot water nozzles
12 Screw
13 Cold water pipe for settled waste removal
14 Drain valve for settled waste
15 Gear/motor for screw press
16 Gear/motor for wire cloth
17 Hot water nozzles for cleaning press cylinder
18 Press cylinder
19 Reject from press cylinder
20 Spring-loaded lid
21 Ventilation

Figure 2: Diagram of Salsnes Filer rotating belt sieve (from Nussbaum et.al., 2006)

Salsnes rotating belt filters (Figure 2) work by passing raw water through a fine mesh sieve. The filter belt, similar to a conveyor belt, is mounted between two rollers with cogs to allow turning of the filter. The filter itself is a plastic mesh that can have pore sizes in many different sizes, ranging from 0.015 mm to 1 mm, but the most common for municipal wastewater is 0.35 mm. The pores of the filter get clogged by solids in the influent water, lowering flux through the filter, causing the water level to rise. A pressure transducer measures the water height of the reservoir, and when the water height crosses a threshold, the belt turns and reveals clean filter mesh at the bottom of the inlet. As the filter rotates, it builds up a filter mat and collects solids even finer than the nominal mesh size. When solids on the filter reach the top (see Figure 3 next page), an 'air knife,' using compressed air, blows the solids that have collected on the mesh into a trough, cleaning the mesh so that it is able to return to return and filter again. The solids in the trough are moved out of the machine via a screw and can be pumped to a dewatering screw for further water removal. However, before dewatering, the dry solids concentration can be up to 6%, similar to traditional

primary sedimentation with a much lower footprint. The removal of suspended solids can range between 50-90%, and the BOD reduction is in the range of 40-70% (Sutton et. al., 2007). As much as 80% of influent cellulose is removed (Ruiken et. al., 2012), but all of these removal rates can vary depending on the mesh size, sieving rate, and influent water characteristics. In comparison, removal via sedimentation removes between 50-60% of suspended solids and 25-40% BOD (Metcalf & Eddy, 2003).

Figure 3: SF1000 used in experiment showing air knife cleaning the filter

Currently, there exists a knowledge gap about the quality of the filtered solids obtained with Salsnes technology; that is, typical values for TSS and COD are not fully known and will vary depending on location and flowrate (sieve rate) through the filter. Furthermore, it is known that Salsnes filters can remove a higher proportion of cellulose than simple sedimentation, mainly due to toilet paper content – something that is more difficult to remove with primary sedimentation due to density). Toilet paper alone can account for 35% of the suspended solids of the influent for municipal waste and this can account for up to 79% of the total mass in the sievings at high rates (Ruiken, et al., 2012). This may be of particular concern when looking at downstream processes, especially aerobic bioprocesses, as cellulose is a slowly biodegradable substrate and special conditions must be met to degrade it fully (Puhakka et. al., 1988). Another unknown is the ability of the filter to remove fats from influent wastewater, empirical evidence exists and is typically seen by plant operators (see Figure 4) as a problem of fouling, but specific research has not been done on the topic.

Figure 4: Salsnes Filter SF6000 with waste attached before airknife. Note that toilet paper is visible on the filter, and fats are visible on the screw.

1.3 Separation Theory

Sedimentation Theory

Conventional primary treatment can be defined as gravity sedimentation, where raw wastewater is allowed to flow into large basins with relatively long retention times. Particles in the water will settle following Stoke's Law, which is dependent on the density and size of the particulate. After the water has been allowed to settle, the effluent of this process is removed of particles that were dense enough to be retained. Removal rates are dependent on retention time of the water, but typical rates are ~60% SS removal and ~35% BOD removal with two hour retention time (Greely, 1938, via Metcalf & Eddy, 2003).

The basic principle behind Stokes law is that a particle will have a settling velocity v_p which must be greater than the overflow velocity of the sedimentation basin v_c (Metcalf & Eddy, 2003).

$$v_p = \frac{g(\rho_p - \rho_w)d_p^2}{18\mu}, \text{ and } v_c = \frac{Q}{A},$$

where g is acceleration of gravity, ρ is the density of the particle and water respectively, d is the particle diameter, and μ is the dynamic viscosity. Q is the volumetric flowrate into the sedimentation basin, and A is the surface area of the sedimentation basin surface.

Sedimentation is very common because of the simplicity, but the removal rates are essentially dependent on the surface area of the sedimentation basin surface area, and diminishing returns I removal rates limit removal (Metcalf & Eddy, 2003). Sedimentation without chemical flocculation will not remove very small colloidal particles, nor will it remove particles that are less dense than water – most importantly to the current research fats, oils, and grease (FOG).

Filtration Theory

Filtration, on the other hand, is not dependent on settling velocity of particles, but rather on the nominal pore size of the filter. Theoretically, any particle larger than the pore size of a filter will be retained. However, another phenomenon is also at work – the development of a filter mat. A filter mat is an accumulation of particles on the surface of a filter, where particles larger than the pore size block the filter's pores, effectively reducing the nominal pore size (Cheryan, 1998). The new *effective* pore size is smaller, which allows for capture of smaller particles that build up on top the blocked pores, and continue to reduce the effective pore size. A filter mat on the surface allows capture of smaller and smaller particles at the cost of reduced flux rates and higher pressure drops through the filter (Rusten & Ødegaard, 2006).

Research by Rusten & Ødegaard suggests that if a filter mat is allowed to form, the nominal pore size of a filter does not influence treatment efficiency of the filter (i.e. similar TSS removal with 55 micron and 350 micron). The problem is that sufficiently low flow rates are necessary to develop a filter mat, and at high hydraulic loading, even very small pore sizes may fail treatment requirements. With sufficiently low sieve rates (m^3/m^2 sieve cloth area/hr), TSS removal can be as high as 80% and is relatively independent of nominal pore size of the filters (similar removal for 0.05 and 0.35 mm mesh).

For the SF1000 that was used in the experiment, the sieve rate was run at sieve rates of ~50 and ~100 m^3/m^2hr, translating into 300 and 650 m^3/day which for previous testing showed ~67% and ~60% TSS removal efficiencies respectively in batch testing and ~67% removal with 350 micron screen at a sieve rate of close to 100 m^3/m^2hr full scale (Rusten & Lundar, 2006). Obviously it is not feasible to have sieve rates much lower than this despite higher removal efficiencies as it would be cost prohibitive in the amount of filters required. To meet effluent requirements of greater than 50% TSS removal, sieve rates below 200 m^3/m^2hr are required for most applications (Rusten & Ødegaard, 2006).

1.4 Anaerobic Digestion

Anaerobic digestion is a fermentation process in which bacteria break down COD in the absence of oxygen, releasing methane, carbon dioxide, water, and leaving behind inorganic constituents. This process is actually a combination of four processes: Hydrolysis, in which complex material is broken down into simple soluble compounds; Acidogenesis, where the dissolved compounds are converted by bacteria into volatile fatty acids (VFAs), alcohols, acids, and gasses; Acetogenesis, in which VFAs are converted to acetate and gasses; and Methanogenesis, where acetate, alcohols, hydrogen and carbonate, and formate, are converted into methane and CO_2 (Henze, et.al., 2008).

The processes described above work in a synergistic manner. Different bacterial communities are responsible for different steps in the processes, which include fermentative bacteria, hydrogen producing acetogenic bacteria, H_2 consuming/CO_2 reducing methanogens (~30% of methanogenesis), and acetoclastic or acetate consuming methanogens, (~70% of methanogenesis) (Henze, et. al, 2008). Each is dependent on the other to produce methane, and there is a relatively delicate balance of alkalinity, VOA concentration, and pH that must be maintained or methanogenic bacteria will be inhibited (See Section 4.2). The fermentative bacteria are responsible for hydrolysis, and hydrolysis is typically the rate limiting substrate in an

anaerobic digester – more than anything due to relatively low surface area of the solids in a feed (Henze et. al., 2008; Ferreiro & Soto, 2003; Chyi & Levine, 1992; many others). Figure 5 shows the breakdown of various substrates and the pathways that are taken to produce methane.

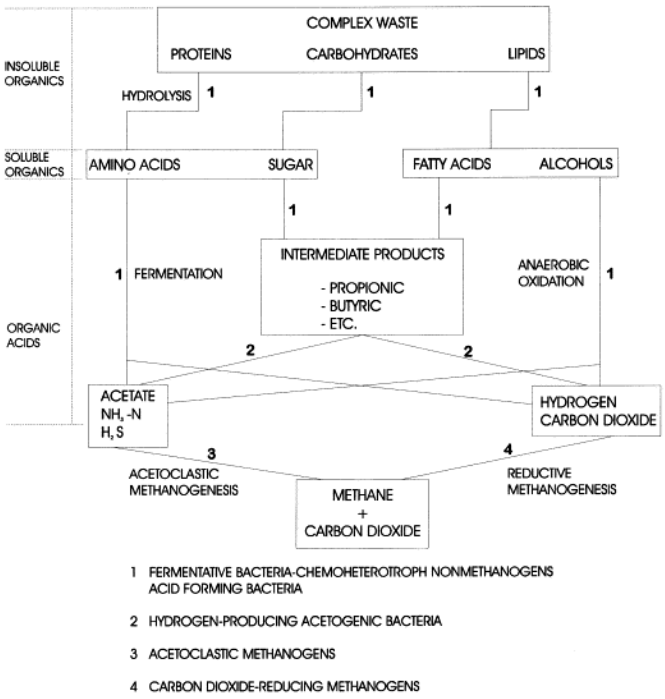


Figure 5: Anaerobic digestion pathways (Massé & Droste, 2000)

Methane production depends on the substrate being fed to the digesters, that is, different materials have different stoichiometries. Fats most readily break down into fatty acids, and will therefore produce the most methane (>70%). Cellulose on the other hand, has about 50% methane and 50% CO_2 production (Kirch et. al., 2005). Sludge from wastewater is somewhere in the middle as it is a combination of many different things – see Figure 6.

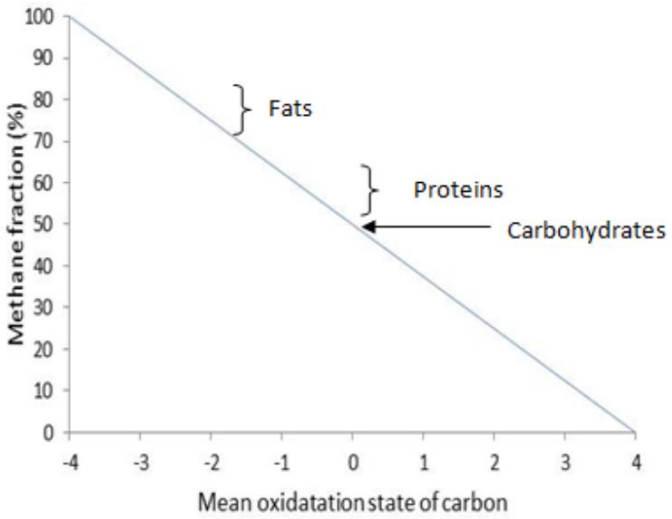


Figure 6: Methane fraction formed in anaerobic digestion of different substrates (Horan et. al., 2011).

Methanogenic bacteria are very slow growing and very sensitive to conditions, so overfeeding can be a problem as VOA concentration can rise faster than the Methanogenic bacteria are able to grow and consume VOAs produced (Kurian et. al. 2012). An overabundance of VOAs in a digester, with low alkalinity will reduce pH and inhibit the bacteria. Overfeeding without retaining solids can cause a washout of the methanogenic bacteria which will cause VOAs to accumulate (Lee, Parameswaran & Rittman, 2011). The bacteria can be inhibited with high VOA concentrations even before the pH begins to drop, which means that pH is ***not*** a good parameter to follow for digester care (Storhaug, 2012, Brambilla et. al., 2012). Basically, the SRT must be high enough for Methanogenic bacteria to be in abundance and the VOA/alkalinity ratio must be low enough to provide a good environment for the methanogens (Hatzigeorgiou et. al., 2006).

Due to the low redox potential, COD is broken down more slowly than would be with an aerobic bioreactor, but has some major benefits. According to Henze et. al., 2008, this process converts 100 kg of COD to 70 m^3 biogas (60-70% methane), 5 kg of sludge, and 10-20kg of COD in the supernatant. By comparison with aerobic reactors, the same 100 kg of COD will produce 30-60 kg of sludge (which can also be digested), and 10-12 kg of COD that must be recycled back into the reactor, not to mention energy input in the form of aeration. The biogas from anaerobic digestion can produce about 1.5 kWh of electricity per kgCOD (Henze et. al., 2008).

1.5 Motivation

So the question is: why would there be more biogas production from SF sludge than for sedimentation sludge? Both come from the same influent water containing the same material. What is it about the Salsnes Filter that would make the sludge more potent? The theory would be that Salsnes filters are able to trap material that would otherwise not settle out in a sedimentation basin (suggesting density less than water, and therefore likely organic). Despite the mesh size typically used for wastewater, 0.35 mm, the filter has demonstrated that it can capture much smaller particles, and perhaps more importantly, fat (which is supported by both direct observation and Salsnes plant operators). Fats are especially important because they have high energy density, and can produce a better quality biogas than other substrates (see Section 1.4).

So this sounds great – let's take out all of the solids possible before the bioreactor and put them into a digester and produce as much energy as possible! Well, it is not exactly that simple. The most common solid removal process is by gravity sedimentation, and the basins require on average two hours of retention time. Also, solids removed in this manner are at concentrations too low to put into digesters, so they must first be thickened – again, typically in another gravity settler. Sedimentation alone removes only 50-60% of suspended solids (Metcalf & Eddy, 2003), which leaves 40-50% suspended solids that could otherwise be digested. This is not to say 100% can be removed economically by any process, but we can probably do better.

There is much that is yet known, but there is some promising evidence that Salsnes Filter (SF) has a product that can remove a higher proportion suspended solids from influent streams than conventional sedimentation (Rusten & Lundar, 2006, Ruiken et. al. 2012). In the same step, the filters remove enough water from the sludge to a point that is nearly acceptable for introduction into anaerobic digesters, all in one process. The Salsnes technology also does this with a fraction

of the space requirements of conventional sedimentation technology. Several studies have shown that the Salsnes filter can do as well or better than conventional technologies in solids removal Rusten, 2002, Rusten & Ødegaard, 2006, Nussbaum et. al., 2006), but it is possible that the quality of the sludge produced with the filters have a different quality than sedimentation sludge.

There are many benefits for the removal of COD (the energy found in VS) from the influent stream via primary treatment. According to Metcalf & Eddy, 2003, primary sludge typically produces about twice as much biogas as an equal amount of waste activated sludge (WAS), so removal of as much COD from the influent stream as practically possible can theoretically provide anaerobic digesters with the highest proportion of primary sludge possible. The removal of suspended solids reduces the load on biological reactors be reducing the amount of slowly biodegradable COD from the influent (Ruiken et. al., 2012), increasing capacity of the biological reactors by reducing the oxygen requirements for aerobic degradation. The latter is also important because the sludge production from anaerobic reactors can be up to 90% less than with aerobic treatment (Henze, et. al, 2008) which reduces costs associated with sludge disposal. This last point is due to the low amount solids produced via growth of anaerobic bacteria vs. the amount grown with aerobic processes with the same substrate.

The motivation, then, is to see if Salsnes filters can produce a better substrate for feeding digesters, while removing at least as much solids as conventional treatment. If so, it might be more economical for municipalities to replace the primary step of their treatment processes in favor of Salsnes filters. Additionally, due to the smaller footprint, Salsnes filters can feasibly increase the capacity of existing treatment plants jut by reducing the slowly biodegradable load to bioprocesses (Ruiken et. al., 2012), and by allowing conversion of sedimentation basins into bioreactors to increase capacity of existing plants.

1.6 Project Scope

The basic principle of this project was to measure gas output of two anaerobic digesters that were fed different substrates; somewhat confusingly, these different substrates are from the same source wastewater. Primary sludge was collected from Nodre Follo Renseanlegg (WWTP), by two different methods – one from sedimentation, one from a Salsnes filter – the influent wastewater for each is the same. This sludge was then fed to its respective digester. Digestion performance was measured by gas volume output as well as quality. Samples of the digestate were taken daily and these samples were measured as well to provide insight into the VS reduction by the digesters. This would then allow a mass balance of the reactor to be calculated. The gas quality measurements were supposed to be measured by integrated sensors, but unfortunately, the sensors were being repaired throughout most of the experiment, so only limited data exists. Gas Chromatograph analysis was completed once for both digesters by a local laboratory once at the end of the experiment due to lack of trust of the gas sensors used.

To complete this project in a fair manner, several procedures were necessary develop and to follow. It was desired to feed each reactor as closely as possible with respect to VS content to allow a more direct comparison – this because of the assumption that the volatile solids (organics) are what will be consumed by bacteria. The SF sieve sludge was always higher in solids content than the collected sedimentation sludge, so dilution was necessary to attempt to normalize the

volatile solids loading. This turned out to be a difficult task, but typically the digesters were fed ±5% of volatile solids content, and all feedings were kept track of diligently. Visibly it was clear that the sludges were different, and Figure 7 below shows the sludges after dilution, so VS% is almost the same – notice the larger particles in the SF sludge.

Figure 7: Salsnes Filter sludge (left) and Sedimentation sludge (right) after dilution to normalize VS%. Note the difference in consistency.

In addition to the sludge collection and digester feeding, several other tests were completed to give a better understanding of the characteristics of the feed sludges and digestate. Calorific value was tested on both feed sludge and digester sludge. Capillary suction time (CST) was performed on digestate to determine differences in dewaterability. Alkalinity and VOA tests were performed to monitor digester performance. Additionally, two AMPTS tests were run on 8 different feedstocks to measure methane potential differences to be compared with results from phase 1. There were many variables that needed to be considered, as each sludge had different characteristics, COD, VS, TS, etc.

2. Literature Review

This section will attempt to provide justification for the current experiment with evidence from other researchers. There is currently a knowledge gap in the literature concerning Salsnes Filters sludge, and further study is warranted as there is promising evidence in the literature that *is* available. This section will first focus on the Salsnes Filter and its capabilities, and then will provide evidence that anaerobic digestion of primary treatment sludge is beneficial to gas production and sludge handling. This section will be relatively short, but it will provide a solid foundation for the investigation at hand.

Salsnes filters are a fundamentally different primary treatment technique than conventional sedimentation treatment. The basic premise for both is to remove a large portion of suspended solids from the wastewater, reducing COD and turbidity. In Norway it is common for water to be discharged to sea immediately after primary treatment. Currently the law states (reference the law) that >50% TSS must be removed along with >20% BOD_5 (Rusten & Ødegaard, 2006) However, laws are rapidly changing and treatment facilities are being required to further treat the water before disposal – this is already a requirement for larger treatment facilities and is also a requirement in countries other than Norway.

Filtration for removal of suspended solids reduces the COD/BOD of the wastewater, which must have an effect on downstream processes. One benefit to the organic material reduction is that downstream biological processes will require less oxygenation due to the lower BOD (Henze et. al., 2008, Metcalf & Eddy, 2003). The introduction of Salsnes Filters as primary treatment can increase the capacity of an existing treatment plant in two ways. First, since the filters are able to remove suspended solids equal to or better than sedimentation, biological processes will require less oxygenation for the same level of treatment (Ruiken et. al., 2012) – especially if no primary treatment is currently used (Rusten, 2002). Due to a significantly smaller footprint, filters can be feasibly installed to replace sedimentation basins. Subsequently to increase capacity, existing sedimentation basins could then feasibly be converted to biological treatment tanks.

It has been shown that the Salsnes technology can remove a higher proportion of cellulose (from toilet paper) than sedimentation (Ruiken, 2012). It can easily be seen when looking at the solids removed from a Salsnes filter that a very high proportion is toilet paper (see Figure 7 in last section). Ruiken et. al., 2012, reported that toilet paper is a major constituent in the wastewater, with thermographic measurements showing 79% of total mass and 84% of organic mass in sievings as cellulose – though sieve rate was very high at 200 m^3/m^2hr. At lower sieve rates, the cellulose is being caught, but there is a much higher proportion of other material (Ruiken et. al. 2012).

Cellulose is known to be the rate limiting substrate in anaerobic digesters, and it can take up to 18 days to solubilize 75% in a digester (O'Sullivan et. al., 2005). However, it has been shown that degradation of cellulose is only 60% in aerobic conditions after 4-5 *weeks* (Verachtert, 1982) – whereas complete degradation can occur in as little as 8 days under anaerobic conditions at 30°C (Ruiken, et. al., 2012). The best environment in the digesters for maximum digestion must be investigated, as waste with high cellulose content tends to need higher temperatures to degrade quickly (Puhakka et. al., 1988, Keating et. al., 2013) as well as enzyme activity (Chyi & Levine,

1992). A benefit of using thermophillic digesters is that class A biosolids are produced, which can be used as commercial fertilizer (Iranpour et. al., 2006).

There is one other significant piece of information that is best suited to be included here, although no research could be found to support the following claims. However, personal communication with Salsnes Filter, treatment plant operators especially in Orkanger where they had a big problem, as well as personal experience while as an intern for Salsnes, give leverage to the following claim. One major constituent in influent wastewater is fat. Fats can account for about 10% of the influent organic contaminants in municipal wastewater, and can vary depending on industry in the area (Ellis, 2004). Fats do not readily settle due to density, and many plants have scum skimmers installed in sedimentation basins for this reason. With Salsnes filtration, all wastewater must pass through the filter, and much of that through the developed filter mat. Fat will bind to other water insoluble material when given the chance, as it has a lower free energy (Course notes, MLJ600 UiS). That means that a portion of influent fats will end up stuck in the filter mat material, or on the filter itself – also referred to as fouling (Cheryan, 1988). In fact, the Salsnes filters have a hot water rinse function to remove fats from the filter. This is important, specifically for this research, because fats are a highly digestable and produce high quality biogas (Kabouris et. al., 2009; Alanya et. al., 2013). There is evidence of fats in the Salsnes sludge in the Results section relating to COD as well as in Figure 4. However, other sources say that too much fat can prevent the release of biogas in a digester, but typically at concentrations far higher than of any concern for municipal waste (Kurian et. al., 2012)

It is already known that primary sludge has higher VOA production potential than AS (Ucisik & Henze, 2008), and this regardless of which plant that sludge is collected from. VFAs are used by Methanogenic bacteria to produce methane, so logically, primary sludge produces more methane than activated sludge.

At the time of this writing, the most relevant source of information on this topic is from an unpublished paper prepared at the conclusion of the first phase of the Waste to Energy project, by Paulsrud, Rusten, and Aas. The research compared Sludge obtained from Salsnes filters in 19 different plants, and sedimentation sludge from primary clarifiers at 9 different plants. Samples were analyzed and it was reported that the Salsnes sludge was much higher in TS (total solids) and VS than sediment sludge; Salsnes filters have an integrated dewatering press, so this finding is somewhat irrelevant as sedimentation sludge does not get dewatered via presses. However, what is of note is that the average VS/TS ratio for Salsnes sludge was 91.6% and only 80.8% for sedimentation sludge – this, despite only 5 of the 19 Salsnes plants having grit removal prior to the filters. The VS% of TS findings are also supported by Paulsrud, 2005, and in the current battery of research.

In the same study, COD content, an indication of the energy potential of the sludge, was found to be slightly lower for Salsnes when normalized for VS content at 1.6 gCOD/gVS for sediment sludge and 1.3 gCOD/gVS for Salsnes. This may be for a number of reasons such as sieve rate, but could also be due to experimental error, as the high cellulose content in the sludge make it quite difficult to measure (See method for COD for better explanation). An automatic methane potential test (AMPTS) was run for 4 of each of the sludges. It was found that the sieve sludge

produced 20% more methane than the sediment sludges after normalizing for VS%. This interesting finding is the basis for moving forward

There are a number of findings that can give clues as to why the gas production for the sieve sludge may be higher than for the sediment sludge. Assuming then that cellulose is a large portion of the sludge, the Methanogenic potential should not be as high as the study by Rusten, Paulsrud, and Aas. The stoichiometry of cellulose digestion produces 50% CO_2 and 50% CH_4. $C_nH_{n-2}O_{n-1} + nH_2O \rightarrow ½\ nCH_4 + ½\ nCO_2$ (Kirch et. al, 2005). But, there is a higher percentage of methane produced in these digesters, so there must be other material responsible for the difference. Fat would be a good candidate, and there is empirical proof that sieve sludge contains this. Studies show (Kabouris et. al., 2009; Alanya et. al., 2013) that digesting waste with FOG added to the feed increases biogas quality. The Alanya study showed that adding clarifier skimmings (mostly fats) could improve specific methane yields by 29%, while also increasing VS. The Kabouris study also showed an increase in biogas quality with FOG addition. The thing to keep in mind with this is that lipid hydrolization does not typically occur without methanogenesis and a SRT (same as HRT in this experiment) must be kept above 10-15 days and ideally longer for sufficient hydrolyzation of lipids (Zeeman & Sanders, 2001).

Essentially what is being said here is that the Salsnes Filters are able to produce sludge at higher concentrations of volatile solids and especially cellulose. At high sieve rates, the cellulose content is very high (Ruiken et. al., 2012), but removal rates are lower (Rusten & Lundar, 2006). At lower sieve rates, there more fine material, and evidence that a lot of this could be fat. The stoichiometry of methanogenesis is only 50% methane for cellulose (Kirch et. al. 2005), but much higher for fats (Horan et. al., 2011). As long as the temperature is high enough (Fierreiro & Soto, 2003), stirring si kept to a minimum (Stroot et. al., 2000) and there is a high enough SRT (Zeeman & Sanders, 2001), there will be a breakdown of the cellulose and fats to produce methane (Ruiken et. al., 2012). The only thing that is not really known is what effect the sieve rate has on the solids produced by the Salsnes Filter. If the filter has a high sieve rate, we would expect a lot of cellulose, but not much else because the filter won't catch small particles. This would lead to digesters producing 50% methane or slightly more according to stoichiometry. However, if the sieve rate is kept low, we would expect a high removal rate, lots of fine organic material that solubilizes well, and also some fats, which would presumably produce a higher quality biogas.

3. Instrumentation

3.1 Salsnes Filter SF1000

Description and overview of Salsnes filters is found in the introduction, this section will focus on the specific filter used for the research.

The Salsnes Filter SF1000 is the smallest filter currently sold by the company, though a smaller filter is development. Peak capacity is 10 L/s for normal wastewater, but they are typically run at a lower average flow. Technical specifications taken from the Salsnes filter website are shown below.

Technical specifications SF 1000 (Salsnes-filter.no)
Hydraulic capacity normal wastewater – 250 mg per litre Up to 10 litres per second
Hydraulic capacity clean water Up to 20 litres per second
Cloth mesh size 0.05 – 4 mm
Separation efficiency; SS at 0.3 mm mesh 40-85%
Separation efficiency; SS at 1 mm mesh 20-30%
Dry substance in dewatered sludge exiting SF 20-40% DS
Length – including air blower 1223 mm
Width – including air blower 1046 mm
Height – including air blower 1294 mm

Figure 8: Salsnes Filter SF1000 used in the experiment.

Figure 910: Salsnes filter with and without filter in place.

The filter was sent to Nodre Follo Renseanlegg and installed over a four day period in early February. There were problems during installation unrelated to the Salsnes unit, and the filter was finally up and running by the third week of February. It was decided the placement of the filter was the only suitable place to put the machine considering the source water and discharge of filtered water and solids. The unit is supplied by raw wastewater (after degritting) via submersible pump and 3" hose – the wastewater source is from the influent into the sedimentation basins.

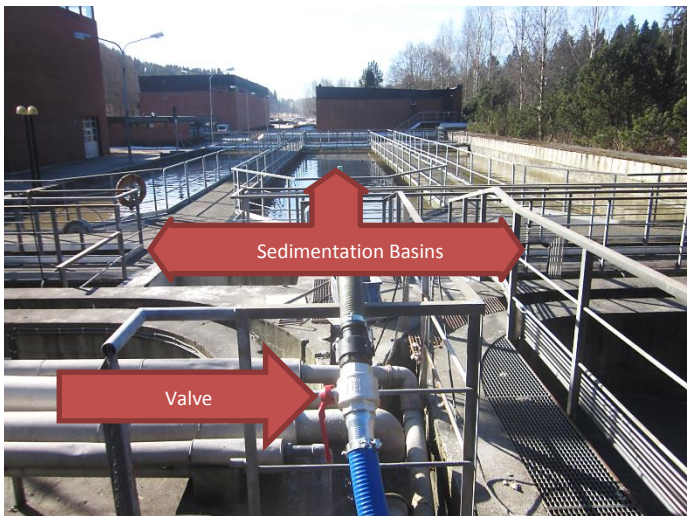


Figure 9: Influent water taken just prior to entrance to sedimentation basins.

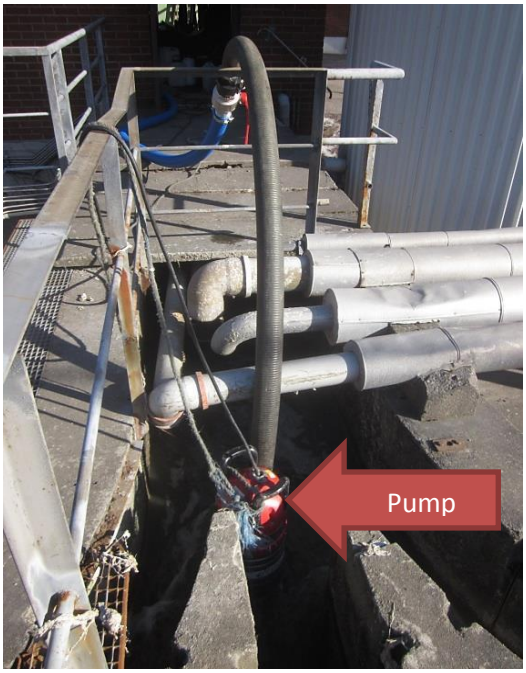


Figure 11: Submersible pump used to pump wastewater to filter.

Once the pump is hooked up, the pump is turned on and the flow is throttled to the chosen rate by the valve shown and by checking with the flow meter. The filter begins to fill up, and the blower, filter cloth, and the solids screw will begin to turn automatically. The control interface is used to

change variables such as the water level, cloth speed. There are many different functions that can be chosen for filter behavior, but that will not discuss here. Basically the water level is chosen and the filter will turn automatically to maintain that water level (see Figure 12).

Figure 12: Clockwise from top left: 1. Wastewater influent being filtered. 2. Solids being blown off into trough by air knife. 3. Solids being transported out of trough via screw. 4. Solids exiting the filter (normally where the dewatetering unit is attached).

Solids accumulate on the filter and are rotated out of the water – they remain adhered to the filter cloth. As the solids rotate into the discharge area, they are blown off by an 'air knife,' cleaning the filter before the newly cleaned cloth rotates around to filter more solids. The solids are blown off into a trough below the air knife, and transported out of the trough via the screw conveyor.

In Norway, especially at smaller plants, it is common to dispose of the solids offsite (no anaerobic digestion), so normally there is a dewatering unit installed to reduce the cost of transportation. The dewatering unit was removed from the experimental filter; the rationale behind this was that solids were already dewatered enough for the requirements of the experiment without dewatering. Also, dewatering would make it more difficult to dilute to match VS% with sedimentation sludge (solids were typically around 4% TS without dewatering). Dewatering unit is shown below, **NB! Dewatering screen removed for the current project (See below for dewatering unit).**

Figure 12: Dewatered sludge from SF6000 in Bangsund, Norway. Solids content ranges from 25-40%. The black color is not due to wastewater but from a charcoal addition experiment to see if dewatering was affected – typical solids look are brown or gray and lighter in color.

Figure 11: Dewatering unit screen that was removed for this project.

Filter Settings

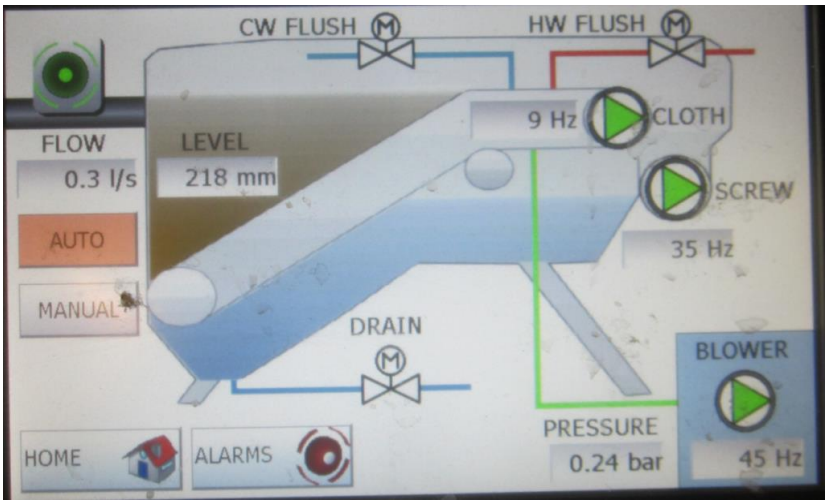


Figure 13: Salsnes Filter main control window.

The filter itself is controlled via a touchscreen attached to the electronic instrument housing. This is where all of the settings can be changed. The system is quite easy to use, for example, by touching the green arrow next to the cloth, the cloth can be set to automatic or manual, and off or on. This is the main screen that an operator would use for maintenance of the filter. If the home button is pressed, more options are available.

Many of the options are to compensate for irregular flow, such as the start level and stop level in the figure – these were not needed in the experiment because flow was controlled and steady. The other options available on the filter have to do with the controlling of the filter behavior. It is possible to have a combination of many different regimes that the filter can follow, such as acceleration/deceleration, delay, variable flow compensation (forward/backwards gain), and many other settings that only a technician could explain. When the filter arrived, it was behaving differently than I had ever experienced in the past, in that the filter cloth would accelerate very quickly once the setpoint was reached, and then would stop with wholly clean filter submerged (my apologies, it is very difficult to explain without seeing it). After long discussions with a technician, the filter was programmed to work more continuously. That is, when the water level rose to the 'start filter cloth level' the cloth would begin to move slowly, exposing new filter at the bottom. The water would still continue to rise to the setpoint, and once reached, the filter cloth would then move only as fast as was needed to keep the setpoint constant. This provided a much

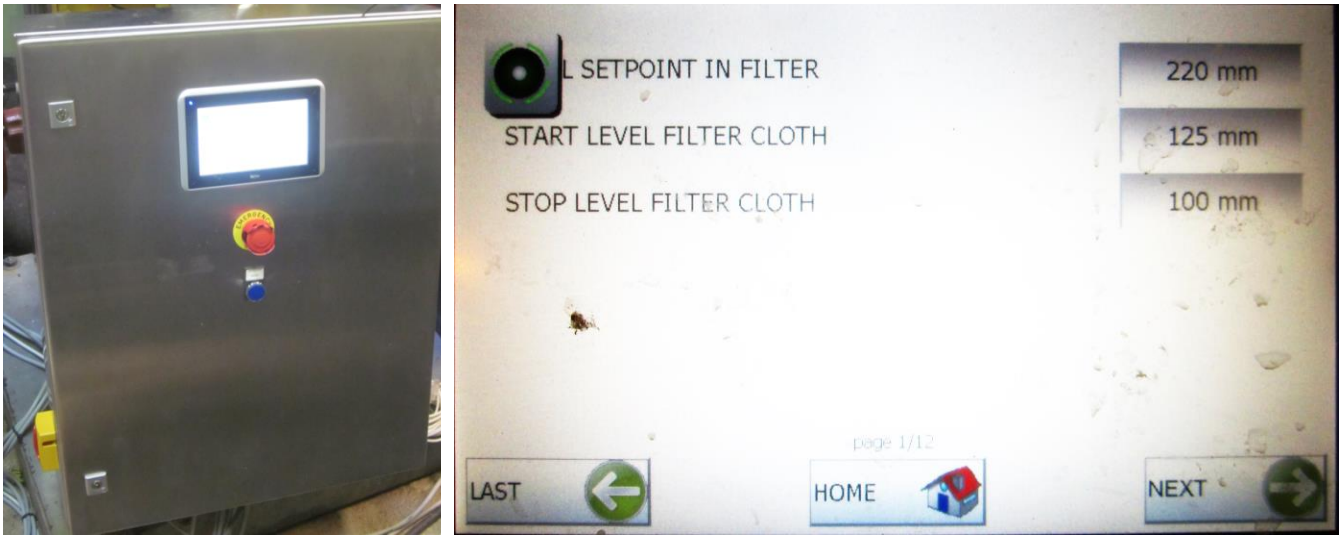


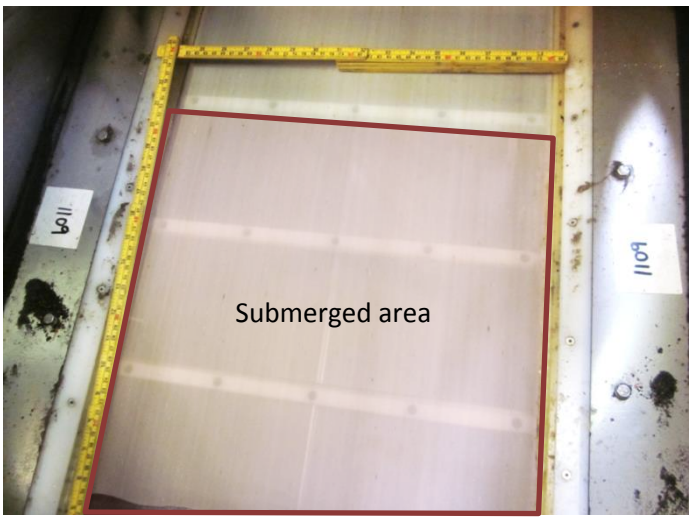
Figure 14: Left is the control unit with touchscreen. Right, one of the many settings screens, this showing the water level setpoint.

more continuous filtration, and allowed for filter mat growth. This way, no matter the water flow rate, the water level kept constant – the filter would move to compensate for the flow.

Flowrate and Sieve Rate

The inlet wastewater was throttled to two different flowrates during the experiment. During the first phase, the flowrate was set at 7.5 L/s, or a sieve rate of about 100 m^3/m^2 sieve area per hour. The digesters subsequently soured due to over feeding or flushing of bacteria (as described by Lee, Parameswaran & Rittman, 2011). There was very little noticeable difference in the gas production from the digesters when using solids from this flowrate, so it was decided when the digesters needed to be reseeded that the flow rate be dropped to ~3.75 L/s, or sieve rate ~50 m^3/m^2hr. There were several differences observed between the two flow rates, notably the filter mat formation was greater, solids content higher, and it was apparent that fats were present with the lower rate.

Figure 15: attached magnetic flux flow meter



Measurement of sieve area in SF100 at setpoint.

Sieve rate is a calculated value which combines the flowrate with the submerged filter surface area. The flowrate is known via a magnetic flux flow meter (note that at low flowrates the value is variable, 3.75 L/s was target). Filter area was measured by marking the water level at the setpoint, and measuring the submerged area of the filter. The unit for sieve rate is m^3/m^2hr, where the m^2 is the submerged filter area. The benefit to this unit is that it is directly comparable to overflow rates for sedimentation processes.

$$\text{Sieve Rate} = \frac{Q_i}{A_{filter}},$$

where Q_i is the influent flowrate in m^3/hr and A_{filter} is the submerged filter area in m^2.

The settings on the filter were left constant for the two sets of experiments beside one difference. Via communication with Bjørn Aas, it was stated that at a lower flowrate the set point water level should be lowered because the pressure difference with the filter mat formation would cause up-concentration before the filter, so the water level was changed from 250mm to 220mm in order to avoid this. However, for this particular filter and wastewater, the only apparent difference was water content of the solids between the two setpoints

Since no solids removal testing was done for this experiment, the knowledge of the sieve rate is important because data exists for removal rates with respect to sieve rates at various treatment plants around Norway – though very little full scale data exists at this time. Much of the reason for the lack of data is that there have been problems with sampling – that is, water sampled just before the filter (in the filter basin) tends to have an up-concentration of solids, so removal percentage will appear to be higher than the actual removal rate. The figure below shows removal rates from Nodre Follo using a batch scale filter developed by Bjørn Rusten.

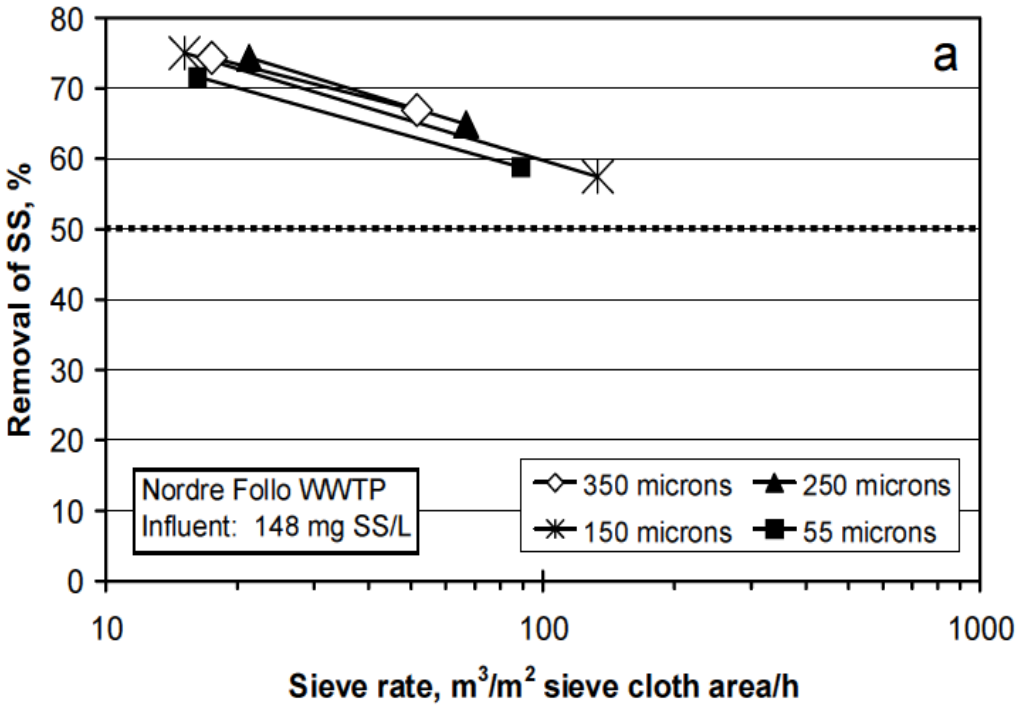


Figure 16: Removal of SS versus sieve rate for a batch of wastewater from the Nodre Follo WWTP (Rusten & Lundar, 2006)

3.2 Dolly Digester

The Dolly by Belach Bioteknikk is an all-in-one anaerobic digester system. It consists of two reactor vessels with attached equipment and access ports. Each is independently equipped with volumetric gas flow 'gas clocks,' gas condensers, heating bands and temperature sensors, stirring motors and blades, and pH meters. Gas sensors are independent of the Dolly, but are also (supposed to be) connected to the system.

The data from each of the sensors (gas sensors independent) is relayed into a control panel on the back of the dolly. It is then relayed to a computer via cat5 cable, and can be interfaced in the Phantom software provided by Belach (See below). Each of the variables can be controlled and/or monitored with the software – temperature, stirring speed, gas flow data, pH, etc. The system collects data continuously, and it is reported immediately in the software.

Figure 17: Dolly digester system

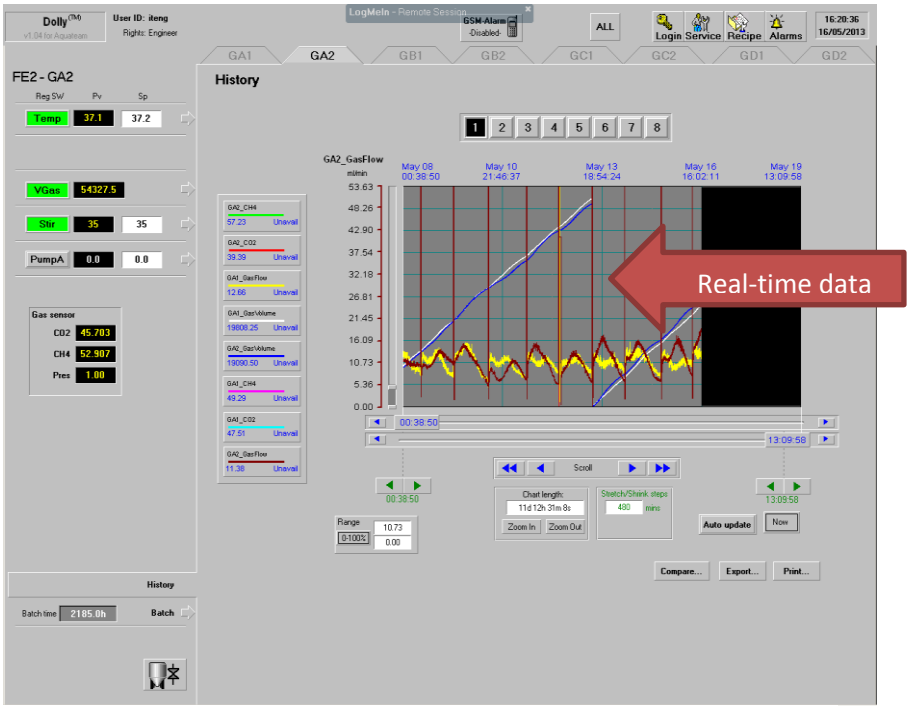


Figure 18: Real time data acquisition and graphing by Phantom software

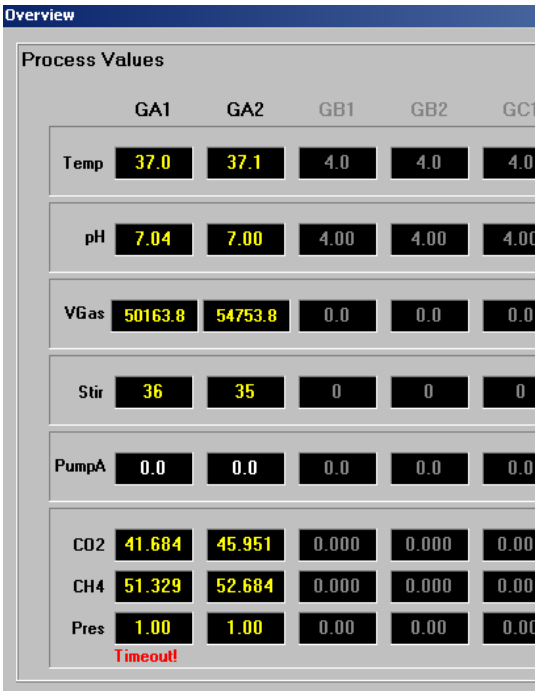


Figure 19: 'Vitals' or overview of the digester variables

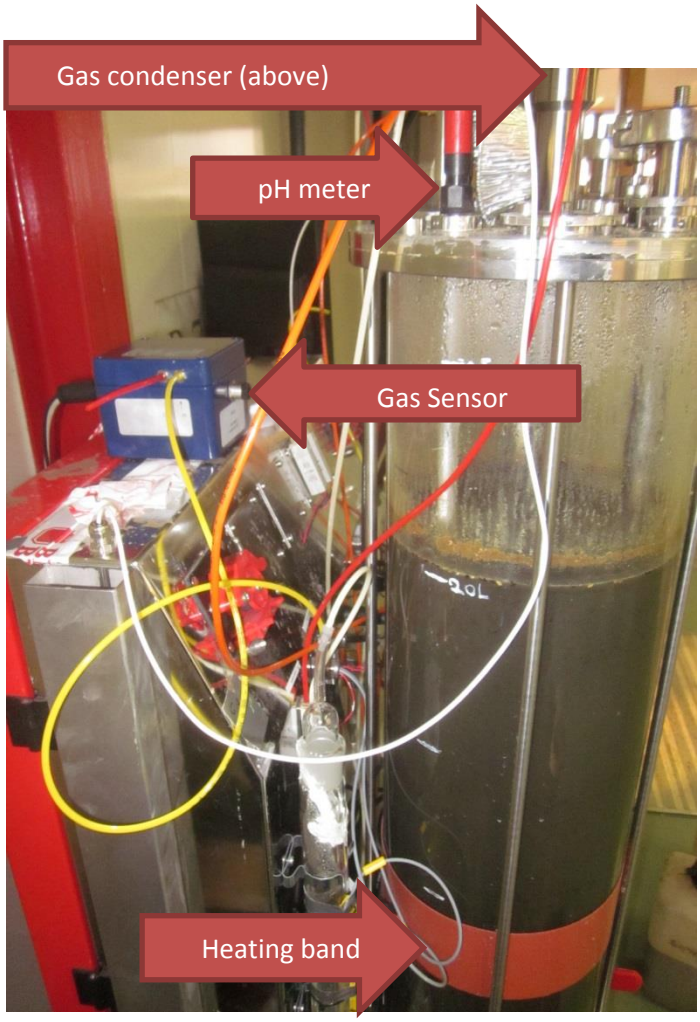


Figure 20: Dolly Digester from side with attached as sensor

On the outside of each Dolly digester, there are four access ports that can be opened to access the liquid, each serving a different purpose (see feeding section for more pictures). There is a drop stem on the top with a tube that drops down below the fluid level for feeding (which serves as an airlock to keep in gas while feeding). There are three ports on the bottom, for removal of sludge. One is a small ¼" pipe and valve for taking small samples – this clogged easily and was never used. Another is a pipe that reaches to the top of the fluid level for assumedly for scum removal – it too was never used in this project. The last port is a 2" ball valve, which is used for emptying the digester, and was used for removal of sludge during feeding (see feeding section for pictures and use).

Gas flow and volume data was collected continuously by a 'gas clock' – a flow meter that works by displacement of water. Gas flows out of the reactor via a gas port and through a condenser – cold water is continuously pumped through the condensers to cool off the gas and remove water vapor. The flow meter, shown below, is a glass tube with a glass cylinder that drops down the middle. Gas flows down through the cylinder and displaces water up the outside of the tube, volumetrically equaling 3.5ml/cm on the tube. The yellow capacitive sensors sense the water through the glass and control and switch the valves when the water level has reached the threshold. Once the water level rises to the top sensor, the inlet valve is closed and the outlet valve (to BlueSens sensor) is opened and flows out. The water level then drops, pushing gas out, and once it reaches the lower sensor threshold, the valves switch again and the tube begins filling again. From the experience I had, these must be calibrated on a regular basis because the capacitive sensors tended to be finicky and residue collected on the interior surface of the glass. Some error in the gas measurements might propagate from this falling out of calibration, but calibrations were done weekly and typically did not need much adjustment – error is likely in the ±5% range, but there is no way to measure this.

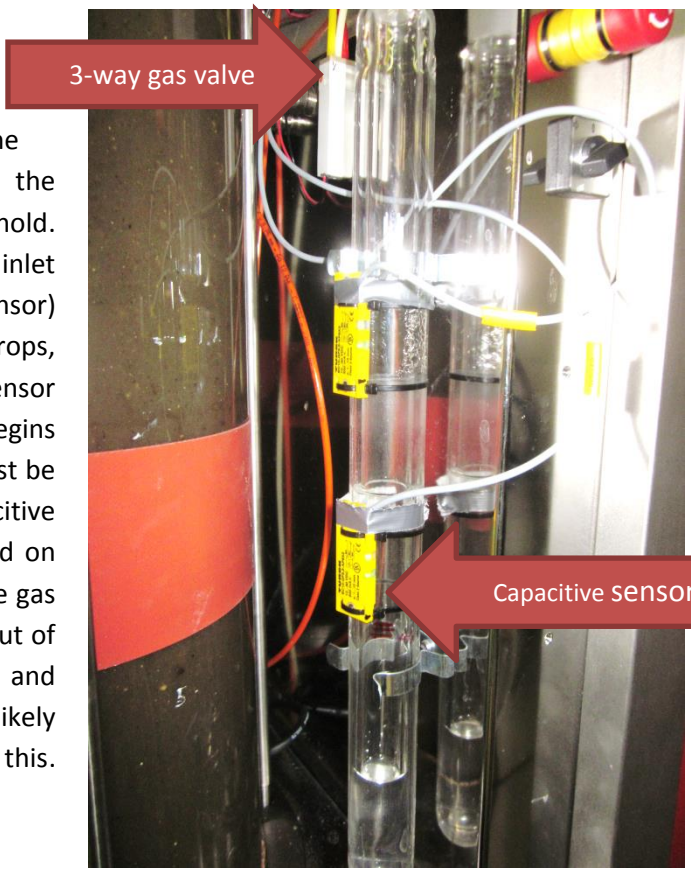


Figure 21: close up of gas clock, capacitive sensors and 3-way valve for gas flow.

Specifications for the stock Dolly Digester are shown below. The digester used for this experiment was custom, with several differences. Each bioreactor is 20L, heating element is 240W, and importantly, the gas sensors are 0-100% CH_4 and 0-50% CO_2.

Technical specifications for Dolly Digester (Belach.se)

BIOREACTOR
Volume 2x2-6 L
Vessel Material Stainless steel lid with Duran Glass vessel

CONTROL SYSTEM
BioPhantom

VOLUMETRIC GAS MEASUREMENT
Outgoing gas is measured with a gas clock

TEMPERATURE
Temperature Sensor Pt 100
Measuring Range 0-100°C
Regulation Range 10-60°C
Regulation Proportional-time-regulator for heat and cool (DB±0.1°C, PB±0.3°C)
Heating Element 100W or 150W (24V) heating band
Cooling Element Tap water (max 12°C) in cooling finger probe

STIRRER
Speed Ranges 20-250 rpm
Regulation Transistor regulation
Motor 24VDC motor
Location Top

CONNECTIONS
Extra Input signals 6 free input signals 0-10V
Extra Output signals 4 free output signals 0-10V, 6 free digital output signals

MEDIA
Power supply 230V AC±10V or 110V AC 60Hz
Water Tap water

DIMENSIONS
Height / Width / Diameter 1500 / 600 / 600 mm
Weight 70 kg

OPTIONS INTEGRATED IN BIOPHANTOM SOFTWARE
pH Glass electrode w. gel pH 2-12
Level / Foam sensor (conductivity)
Level probe 0-100%
Gas Analyzer CH_4 and CO_2 0-80% CH_4 0-20% CO_2 Biogas
Feed pump Peristaltic pump 0.5-200 rpm
DO control Bioethanol 0-100%

Gas Sensors

Gas quality sensors were provided by a German company called BlueSens (BlueSens.de). They manufacture a large number of real-time inline sensors for gas measurements. The particular sensor is a special sensor used just for biogas measurements, and they are supposed to measure CH_4 and CO_2 in the same sensor. There were two sensors; one of each was to be hooked up to each of the digesters for the duration of the experiment. However, after initially hooking the sensors up, the gas readings were showing percentages of around 105% total concentration, which was wrong without question. After a long discussion with the company and remote connection to the sensors, it was decided that they should be sent in for maintenance and repair. The turnaround time was said to be about 3 weeks maximum, but unfortunately they were in repair for much, much longer. One sensor was sent back in the middle of April, and the other I finally received the day I got back from the final feeding of the digester. So, for the time that one sensor was available, it was switched between the two digesters, which can easily be tracked by the nature of the data collection. Sensor data for the duration the data was collected will be discussed in detail in the discussion.

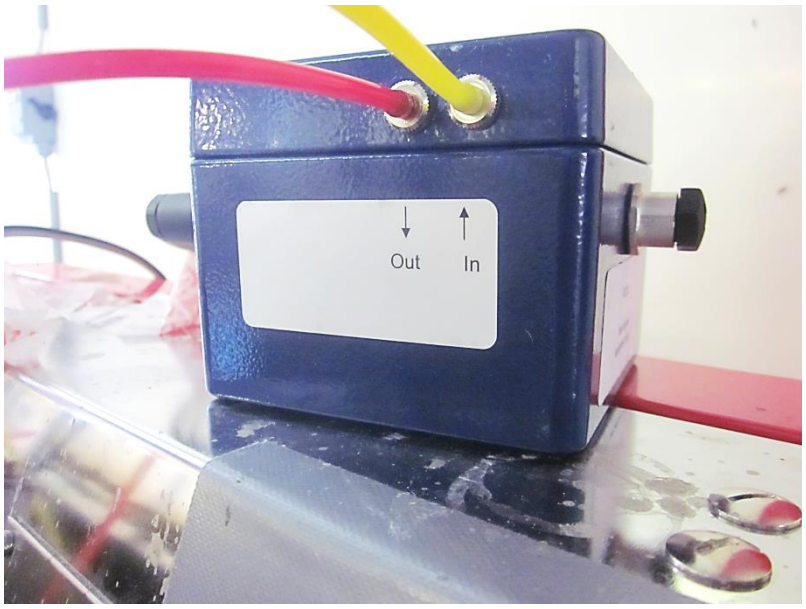


Figure 22: BlueSens Biogas sensor. Measures 0-50% CO_2 and 0-100% CH_4

The initial seeding of the reactors was done by collecting mesophillic anaerobic sludge from the Søndre Follo Renseanlegg in Vestby Kommune. The sludge was collected in two 25L containers and brought back immediately to Nodre Follo to fill the digesters up. Volume was measured out in a two liter graduated cylinder and then poured into the reactors via the orange funnel and the feeding port on the top.

Figure 23: Re-seeding of the digesters in April

The picture to the above was taken during the reseed of the digesters while mixing new seed sludge with wastewater and 20% of the failed digesters' contents. The VS of the seed sludge from Søndre Follo was known from the initial first seeding, the seed sludge was diluted with raw wastewater and 20% of each reactor. This made it possible to keep the VS levels in the digesters near the pre-re-seed concentration, while also introducing the acclimated good bacteria back into the system that had been flushed out from over feeding in the first phase. This was a very messy job to say the least.

Once the digesters were seeded, the Dolly system was turned on and allowed to run. Besides the seeding process, the reactors run quite well on their own without the need for interaction, other than the daily feeding and regular calibrations of the gas clock.

4. Methods

4.1 Total and Volatile Solids

Background

Total and volatile solids are the most important measurements that were carried out during this project. This is the measure of percentage of solid material that is present in a given sample of wastewater, sludge, or anything. The basic principle is total solids are the ratio between the dry weight and wet weight of a sample. Volatile solids are the ratio between the volatilized (ash) weight and the wet weight. For this project the volatile solids are of the utmost importance because it allows the calculation of a mass balance in the system. Knowledge of these variables are necessary to make comparisons between the systems.

The method involved in this measurement is performed as per the standard method (Standard Methods 2540), however the majority of this section will explain the preparation of the samples for measurements.

The samples collected from both the Salsnes filter, but also the sedimentation solids, are very thick and tend to clump up. Not only that, the sludges tend to have very large particles, much toilet paper, etc., so it was realized quite quickly that special preparation was necessary to accurately measure the solid percentage of the sludges. The sludge taken directly from the filter was typically quite thick, especially after the flowrate was changed to a lower setting in the second phase, so it became necessary to dilute the sludge prior to measurement (to make it easier to pour and blend with the Ultra Turrax). This was done by pouring raw wastewater into the collected sludge before measurement – even with this procedure, it was still necessary to further dilute the sieve sludge every preparation.

Materials

Mass balance capable of at least 1/100 of a gram
Aluminum dishes (roughly 60 ml capacity)
Ultra Turrax mixer
Drying oven set at 100° C
Volatilization kiln set at 550° C
500 ml beakers
Glass stirring rod

Method

First label the required amount of aluminum dishes and label by indentation with a ballpoint pen (number for duplicate/triplicate). Weigh each dish and record. Fill the dishes with the respective sludge and weigh and record. Place the dishes in a drying oven set to 105° C and allow to dry overnight. Once dry, weigh the dishes and record. Place samples in kiln, turn on, and set temperature to 550° C – leave in kiln for at *least* 30 minutes once the temperature has reached 550° C. After 30 minutes, take out of kiln and weigh samples and record. The determination of the total solids and volatile solids are based upon the weights of the sample in each stage.

Sample Preparation

Because the sludge samples tended to be very thick and heterogeneous, they had to be first homogenized. This is done by blending with an Ultra Turrax high shear mixer. First take a 500 ml beaker and fill with ~300 ml of sludge immediately after the sludge has been vigorously shaken for at least 15 seconds. Place the beaker under the Ultra Turrax mixer, lower mixer into beaker about 1/2 - 2/3 of the way, and turn on to around 20,000rpm. Placement of the mixer head seems to effect the mixing efficiency, so it may be necessary to move the beaker or mixer around until the sludge is mixing effectively. Allow to mix like this for 3-4 minutes. There is a fine line between mixing enough and too much, because the mixer will cause the samples to become very hot, which will draw fats out of the sample and cause them to deposit on the side of the glass, so remove prior to temperature getting too high.

Once emulsified, take the mixer out and stir with glass rod. Once stirred, the sample should be pourable. Quickly pour into aluminum dishes until nearly full.

Equations

Equations to determine total solids and volatile solids percentage are as follows:

$$TS\% = \frac{M_{dry} - M_{dish}}{M_{wet} - M_{dish}} \qquad VS\% = \frac{M_{volatilized} - M_{dish}}{M_{wet} - M_{dish}}$$

where M is the respective mass of each phase as labeled,

and percentage of volatile solids of total solids is:

$$VS\% \; of \; TS = \frac{VS\%}{TS\%}$$

Figure 24: Wet, dried, and volatilized samples. The difference in weights determine the total and volatile solids content

4.2 Alkalinity and Volatile Organic Acid (VOA)

Background

The measurement of alkalinity and volatile organic acids are together very important for the operation and especially startup of anaerobic digesters. A whole bacterial community is responsible for the production of the target end-product methane, so all must be able to survive and flourish, which makes the measurement of these two factors so important. Methanogenic bacteria will feed on VOAs to produce methane, specifically acetic acid, but also to a lesser extent butyric and propionic acids. However, an overabundance of these acids without the presence of alkalinity as a buffer will cause the digester to 'sour,' a lowering of pH from roughly neutral to potentially catastrophic failure. A common rule of thumb is to keep the VOA/Alk ratio to equal or less than 0.3 mol/mol while keeping an alkalinity above 25 mmol/l (Hatzigeorgiou et. al., 2006, Kurian et. al., 2012). The pH can be used as an indicator that the digester is in dangerous territory, however because of the buffering capacity of the alkalinity, by the time the pH drops into dangerous territory, it is likely too late to take corrective action (which was the case in the first part of this experiment).

Corrective actions can be taken if the ratio of VOA/Alk becomes close to the 0.3 limit, which include reduction in the feeding and addition of an alkaline solution such as Na_2CO3. IF the VOA number continues to rise after corrective measures have been taken, the likely cause is due to over feeding (essentially the flushing of the slow growing bacteria).

The main reason that these two parameters are presented together is due to their direct relation to the other in the proper operation of an anaerobic digester. These tests also require much of the same equipment and sample preparation.

Materials

Coarse filter paper (I used coffee filters)
2 Funnels
2 200 ml beakers
2 50 ml beakers
Pipettes, 50-1000 µl and 1-10 ml
COD incubator capable of 100°C
Spectrometer with barcode reader
Distilled water
Dr. Lange LCK 365 test kit for VOA
Dr. Lange LCK 362 test kit for alkalinity

Figure 25: Filtering of digestate for alkalinity and volatile acid testing.

Method

Begin by collecting a fresh sample of sludge from an anaerobic digester. The samples were collected every day at feeding, and placed in a 2L sealed container for transport to the lab. The measurements should be done as soon as possible as the volatile organics are quickly consumed and/or volatilize. Take a coarse filter paper and place it into a funnel and place the funnel inside of a clean flask. Pour sludge into the filter until it reaches the top of the filter, then allow the filtrate to flow through the filter and funnel into the flask until ~2ml at least is available.

Alkalinity test

Pipette 0.5 ml of the filtrate into a small 50 ml beaker. Dilute 1:10 by pipetting 4.5 ml of distilled water (that has not been exposed to CO_2). Further dilution may be necessary, but this was enough for the range of values expected.

Take a cuvette from the LCK 362 test kit for alkalinity and label. Place 2 ml of reagent A into each cuvette, followed by 0.5 ml of the respective diluted sample. Close the lid, shake the sample, and wait for 5 minutes. After 5 minutes, place cuvettes in spectrophotometer and record result. The alkalinity will then be reported in mmol/l – make sure to correct for dilution ratio.

Volatile Organic Acid test procedure

Take cuvettes from the test kit, label, and pipet 0.4 ml of reagent A in each and then 0.4 ml ***un***diluted of the respective sample into the cuvette, replace cap, and shake. Place the cuvette into the reactor at 100°C and heat for 10 minutes. After 10 minutes, allow cuvettes to cool to room temperature. Pipet 0.4 ml of reagent B into the cuvette, replace cap and shake. Pipet 0.4 ml of reagent C into the cuvette, replace cap and shake. Pipet 2 ml of reagent D into the cuvette, replace cap and shake. Wait 3 minutes for bubbles to migrate out of solution. After 3 minutes are up, place in spectrophotometer and record results. The volatile organic acids are reported in meq/l CH_3OOH (mg/l equivalent acetic acid) divide by 60 to obtain mmol/l.

4.3 Chemical Oxygen Demand

Background

Chemical Oxygen Demand (COD) is the measure of the amount of oxygen required to fully oxidize the organic compounds contained in a known volume of sample. This is measured in mgO_2/l, in other words, the mass of oxygen required to oxidize the compounds in a sample of water. This is a slightly different measurement than biological oxygen demand (BOD) in that all compounds that can be oxidized are oxidized, rather than what can be oxidized by bacteria. COD is commonly used as a variable to calculate a mass balance in a wastewater treatment plant, or certain processes like anaerobic digestion, and can be used to predict biomass generation and oxygen requirements for biological processes.

COD tests were performed for every feedstock that was fed to the digesters. This test proved to be difficult due to the high concentration of the sludge, and also due to the abundance of very large particles in the sludge, especially cellulose. Cellulose is not soluble in water, so attempts to homogenize the samples fully proved very difficult.

Materials

Two 500 ml beakers
100 ml Graduated cylinder
50 ml graduated cylinder
Ultra Turrax high shear mixer
1-10 ml Pipette (smaller pipette be used, but this particular pipette has a larger diameter inlet)
Hach-Lange LCK 014 test kits for COD, 1000-10,000 mgO_2/l range
Cuvette incubator capable of 148°C with 2 hour timer
Hach-Lange spectrophotometer
Flask filled with water and NaOH solution to rinse Ultra Turrax between uses
Glass stirring rod

Figure 26: Hach-Lange LCK014 COD test kits, COD incubator, Hach-Lange spectrophotometer.

Method

Each step is done once for each feedstock. First take 500ml beaker and fill with ~300 ml of sludge immediately after it has been vigorously shaken for at least 15 seconds. Take the beaker and place under Ultra Turrax mixer, lower mixer into beaker about 1/2 - 2/3 of the way, and turn on to around 20,000 rpm. Placement of the mixer seems to affect the mixing efficiency, so it may be necessary to move the beaker or mixer around until the sludge is mixing effectively. Allow to mix like this for 3-4 minutes.

After the sludge has been thoroughly emulsified, take mixer out of sludge and place the mixer in the cleaning flask and turn on for about 30 seconds (this must be done quickly because the mixer will be very hot and it is much easier to remove particles remaining on the mixer before they dry). Take the mixed sludge and stir well with glass stirring rod. Pour 20 ml of the sludge into the 50 ml graduated cylinder as carefully and as accurately as possible – the sludge will adhere to the sides, so be as accurate as possible. Once the 20 ml has been filled into the cylinder, pour the remainder of the sludge down the sink, rinse and dry the beaker. Pour the 20 ml sludge back into the clean beaker. Fill the 100 ml beaker with 100 ml of distilled water, and pour some into 50 ml beaker to rinse out – pouring all 100 ml into the beaker. Add 80 ml more of distilled water to the beaker, completing a 1:10 dilution.

Once the sludge has been diluted, place back under the clean Ultra Turrax mixer and allow tomix for another 3 minutes. Once the diluted sludge is properly emulsified, take out from the mixer and allow to stand for 3-4 minutes, stirring with the glass rod every so often to remove air bubbles that will cause particles to float, similar to a DAF tank.

After 3-4 minutes, take cuvettes from the test kit, shake well, label, and open the lids. Take the 1-10ml pipette and dial it to 0.5 ml – this is done because the diameter of the inlet is much larger than the 50-1000 µl pipettes. The particles left in the water will easily clog the pipette, despite the larger diameter (this is where I think the most error in these measurements comes from). Stir the diluted sludge well, and pipet 0.5 ml from 2/3 depth. If the air bubbles have been removed, most of the larger suspended particles will be floating freely and not at the top, so this *should* provide a fairly representative sample.

Figure 27: Emulsification with Ultra Turrax, dilute 1:10, Ultra Turrax again with diluted sample, pipet into test cuvettes.

Place the 0.5 ml into the respective COD cuvettes and replace the lids (duplicates were typically done, but later in the experiment triplicates were used). Place the cuvettes in the COD incubator and set temperature to 148°C and set time to 2 hours.

Once the cuvettes have been allowed to digest for 2 hours, remove and allow to cool to room temperature. Wipe off the cuvettes with linsen paper, and place in the spectrophotometer. Record results – multiply by 10 for dilution.

4.4 Capillary Suction Time (CST)

Background

Capillary suction time is a measure, perhaps more appropriately an indicator, of the dewaterability/filterability of a given sludge. This is an important variable for waste sludge, because eventually it must either be transported or disposed of in another way. Long CST times can indicate a need for polymer addition to aid in dewatering (Vestilind, 1988). This test can be used for any type of sludge.

A hollow small steel cylinder is placed upon a special piece of paper used for the test. The cylinder is held in place by a piece of acrylic that has electrodes placed a certain distance from the center of the cylinder. The basic idea is that when the cylinder is filled with a sludge, the water contained in it will radiate through the filter paper at a certain rate, depending on its dewaterability. Once the water hits the first two electrodes, it completes a circuit and a timer will start counting in seconds. The water will continue to radiate out of the center, and once it reaches the third electrode, the timer will stop. The time taken for the water to travel between the first two and third electrode is called the CST, measured in seconds.

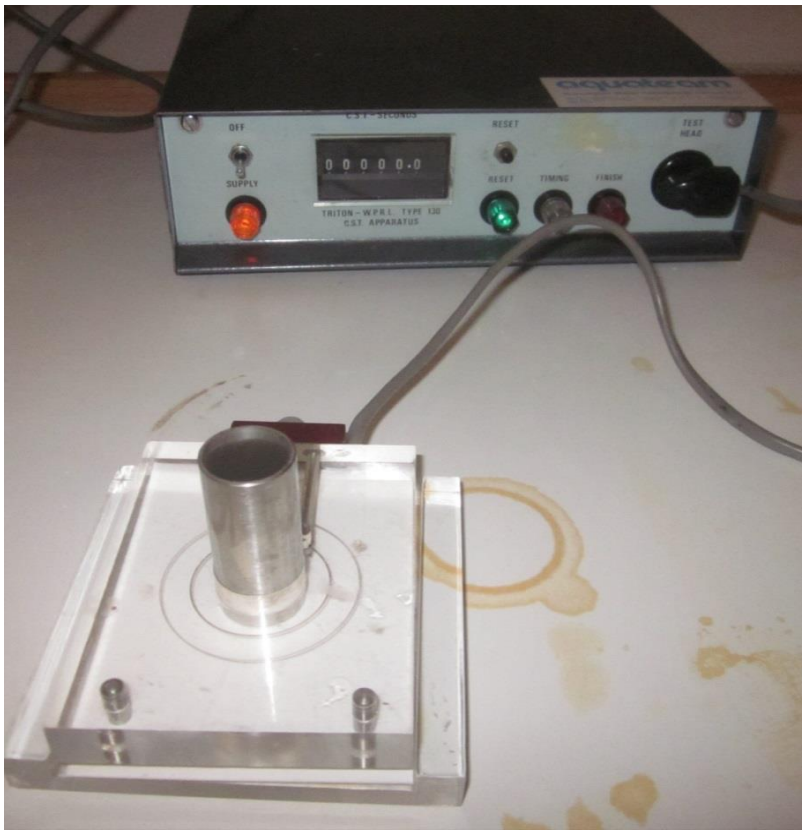


Figure 28: Capillary Suction Time device

Method

This test is very simple, but some care must be taken in the setup to obtain good results. First take the CST machine, turn it on and press reset to zero time. Take a filter paper and insure that the 'rougher' side is up and place this on the acrylic base. Place the electrode piece on top of this, making sure good contact is made with the paper and electrodes. Put the clean and dry cylinder inside of the electrode piece, and make sure everything is secure. Take a small sample of well mixed

sludge and pour into the cylinder until it is full to the top, taking care not to spill down the side of the cylinder. Once this is complete, wait for results and record time.

4.5 AMPTS (Automatic Methane Potential Test System)

Figure 29: AMPTS system from Bioprocess Control.

The Automatic Methane Potential Test System (AMPTS II) is a device used to determine the biogas potential of particular substrates compared to a control. The system is nearly fully automatic and requires only careful set-up of the machine and some minor maintenance in the first week of the test The simple operation makes it easy to compare several substrates at once with exactly the same conditions.

The machine was developed by the company Bioprocess Control from Lund, Sweden. It consists of 15 digestion vessels (shown on left above), or 5 triplicates, that can be run simultaneously - which was the case for the current battery of tests. Each digestion vessel is connected via Tyvek tubing to the CO2 absorption bottles (shown center), which are filled with a 3M NaOH solution and an indicator. These are connected to the gas measurement or flow cell array (shown right), where gas is collected under levers submerged in water – the buoyancy of the gas lifts the lever, the gas is released and metered. The digestion vessels are submerged in a water bath which is held at a constant temperature, and each digestion vessel has an attached motorized stirring rod which stir each vessel simultaneously. The idea is that each digestion vessel will experience the exact same conditions, so theoretically the differences in measured methane volumes are due solely to the different substrates used.

In order to compare different substrates in the array of vessels, there must be an equal ratio of volatile solids for each reactor; in the case of the current tests this ratio is 2:1 inoculum to substrate. This is done by doing simple TS/VS testing (triplicate average). Furthermore, to control for gas produced by the inoculum, there are 3 control vessels filled with inoculum only, and the inoculum in *every* vessel is the same, using the lowest inoculum mass as determined by the ratio –

since the substrate VS% are slightly different for each stock. This way the inoculum gas production can be subtracted from the totals to determine how much methane production is due to the substrate itself.

Method

Inoculum for these tests was taken from Søndre Follo Reseanlegg, the same place that the inoculum for the experimental digesters was taken. The feed stocks from two different feed preparations (two of each) were used as the substrates – and will be referred to as substrates from now on in this section.

Before running the AMPTS, the volatile solids of both substrates and the inoculum must be determined. Due to the small volumes needed for the test, precision in the VS determination is very important. For this reason, the Ultra Turrax emulsifier was used on samples of one liter taken from feed stocks prepared on two different days, mixed until the consistency was as uniform as possible, typically around 3 minutes. Triplicate TS/VS tests were run on each sample and the inoculum, and VS% was determined.

Once the VS% for each substrate was determined, calculations were done to determine how much to put in each vessel. The VS% of the inoculum (g/g) is divided by the VS% of each inoculum satisfying two conditions: the ratio of VS% inoculum:substrate is equal to 2, and the total mass is equal to 400 grams. This is done for all four substrates, but the lowest inoculum mass necessary to satisfy these conditions is used for all 15 reactors. That is, for control, the same inoculum amount is placed into each reactor including the control vials containing inoculum only. The other three triplicates are recalculated using the lowest inoculum mass, which means the total mass is slightly less for those vials. The equations used to calculate these values are as follows:

$$\frac{M_{inoculum} * VS\%_{inoculum}}{M_{substrate} * VS\%_{substrate}} = 2 \quad \text{and,} \quad M_{inoculum} + M_{substrate} = 400g$$

The table following is presented to provide clarification of the method.

Table 1: Volatile Solids measurement and masses for addition to each reactor vessel.

Dish (g)	Sample +Dish (g)	Dried Sample +Dish (g)	Volatized Sample + Dish (g)	TS%	VS%	VS% of TS	Avg VS%	Mass Subst. (g)	Mass Inoc. (g)	VS% Ratio	Total Mass (g)
Salsnes Feedstock 24/4											
1.868	64.0391	3.6205	2.009	2.82%	2.59%	91.93%					
1.863	52.313	3.2888	1.9766	2.83%	2.60%	92.05%					400.0
1.861	50.3609	3.1826	1.9671	2.72%	2.51%	91.98%	2.57%	107.7	292.3	2.00	
Sediment Feedstock 24/4											
1.857	45.9102	3.1637	2.0514	2.97%	2.52%	85.12%					
1.858	43.1969	3.1294	2.0462	3.08%	2.62%	85.21%					399.2
1.857	51.1796	3.378	2.0833	3.08%	2.62%	85.09%	2.59%	106.9	292.3	2.00	
Salsnes Feedstock 26/4											
1.886	57.3789	3.4488	1.9856	2.82%	2.64%	93.60%					
1.865	57.0972	3.4428	1.9653	2.86%	2.68%	93.63%					396.0
1.865	66.0443	3.7054	1.982	2.87%	2.69%	93.62%	2.67%	103.7	292.3	2.00	
Sediment Feedstock 26/4											
1.859	58.3098	3.6726	2.1174	3.21%	2.75%	85.75%					
1.864	51.728	3.4319	2.0861	3.14%	2.70%	85.83%					393.3
1.842	57.3756	3.625	2.0951	3.21%	2.75%	85.82%	2.74%	101.0	292.3	2.00	
Inoculum											
1.865	55.5768	3.7626	2.7319	3.53%	1.92%	54.31%					
1.865	54.019	3.703	2.7502	3.52%	1.83%	51.85%	**1.89%**	0.00	292.3	#N/A	292.3
1.871	53.687	3.7194	2.7195	3.57%	1.93%	54.09%					

As can be seen from the table, the masses for all inoculum masses are the same; however the substrate masses change depending on the substrate - the ratio always remains 2:1. This means that the total mass of VS is the same in each reactor vessel – this is the most important variable to control.

Prior to any run, a solution of 3M NaOH was prepared with an alizarin indicator. 80 ml was poured into each CO_2 capture vessel along with a small magnetic stirrer. These were covered with their respective rubber stoppers and then connected to the corresponding flow measurement port – all are labeled and correspond to reactor vessels as well. The stirring plate was set for 400 rpm to insure proper capturing of CO_2. If at any time the indicator changes (from red to yellow) both sides of tubing are clamped, then removed; the fluid is poured out and refilled with more solution and replaced.

For the first experiment run, inoculum and solids were measured out one by one and placed in the reactor vessels. It was decided that measurement with volumetric methods was extremely difficult due to the nature of the substrates, so a mass balance was used to measure out mass of all the substrates. Inoculum was poured into each reactor vessel and then substrate was added. This proved difficult because some of the solids would adhere to the side of the beaker used to weigh, so a rubber spatula was used to remove as much solids from the beaker as possible.

In the second run, it was decided that it would be more accurate to measure out the total inoculum for all three vessels, as well as the substrate. This was mixed together and stirred well with the rubber spatula. The substrate/inoculum mixture was then poured into a beaker resting on a scale to the total mass that was needed. This proved to be much easier, seemed to provide more accurate measurements, and the results seem to reflect this change.

Once all of the reactor vessels were filled, they were covered with the rubber stopper and stirring mechanism. Before placing them in the water bath, each reactor was connected to the corresponding tubes (connected to CO_2 trap, and flow measuring device). At this point, Nitrogen gas was connected to the reactor vessels via the access port in each. Nitrogen gas was then flushed through each bottle (which in turn flushes all the way to the flow measurement) for 1 minute each. Once all of the vessels were flushed, they were placed in the water bath, which has a temperature control, set at 37° C. Each flow meter lever was raised to allow any gas pressure remaining in the system to evacuate.

With everything set up and ready to go, the experiment can then be started. This is done by connection to the bioprocess control software specific to the equipment. Before starting the experiment (and before filling the reactors) the experimental data must be placed into the program. This is simply done by entering the corresponding VS% of the inoculum and substrate and chosen ratio. The software will correct for any differences in the headspaces in the reactor vessels. The experiment is then started, and data will be automatically recorded and graphed by the software.

Data Analysis

The AMPTS software does most of the legwork when it comes to the data analysis. As long as the bottles are filled correctly, the program will do the rest. The data that is provided is a spreadsheet of gas volume (assumed to be CH_4 after CO_2 scrubbers) and gas flow. The total flows are given of all reactors are given, including the inoculum blanks. Since all reactors hold the same inoculum, blanks can be averaged and directly subtracted from the experimental reactors. This will give gas volumes based upon the feed VS alone.

With triplicate experimental reactors, the gas volumes are averaged and then the average inoculum is subtracted from this. The resulting gas volumes are then divided by the volatile solids content in grams, giving units of Nml CH_4/gVS, or normal milliliters of methane per gram volatile solids – the 'normal' meaning at atmospheric pressure and temperature. This method makes the data directly comparable with respect to the substrate used, hence why it is called a methane potential test.

4.6 Calorific Value

Calorific value is basically a measure of the amount of energy that can be produced by combustion of a dried sample of sludge. The reason for this analysis is to see how much both the feed sludge from each primary treatment and waste sludge (after digestion) has for energy recovery. This analysis requires special equipment, so it was done by an outside laboratory, the Skog og Landskap department at the university of Ås.

Samples were collected from both the digester and from different feedstocks. The samples were dried in the same way as for a TS analysis. The dried samples were collected and placed in vials to be sent to the laboratory. Sludge was poured into aluminum dishes the same way as doing a TS/VS analysis, but there was no need to weigh the samples beforehand. The samples were dried in a drying oven, and then sent to a local lab for analysis. Results for the analysis are given in MJ/kg*TS (dried), meaning joules of energy per kilo dried solids.

5. Digester Operation

5.1 Feed Preparation

Sludge Collection and Dilution

One of the main challenges for this project was feeding of the digesters. The two primary treatment substrates are not alike, despite coming from the same source, so simply adding them to the digesters without some alteration was not possible. Samples collected from each source had drastically different solids compositions, but one of the goals was to feed each digester the same volatile solid loading each day. In order to do this, it was necessary to measure solids content and then dilute the substrate as necessary to obtain feedstock sludges with equal volatile solids loading. The following section will explain the feedstock preparation procedure that was developed and additionally the feeding procedure of the digesters.

Figure 30: Sedimentation basin sludge collected ~1.2% solids

The first step (day -1) in preparing the feedstocks for the digesters is to collect a sample of sedimentation sludge, which is obtained in the basement of the sedimentation building at Nodre Follo. The sludge that is scraped off of the bottom of the sedimentation basins flows through a pipe to the thickening process – there is a sampling port where sludge can be taken (shown on left). There are pumps that run on a timer at 5-25 minute intervals (depending on the program running at that time). When pumps turn on and the sludge begins to flow through the pipe, after roughly 30-45 seconds it becomes dark opaque – which is close to the 1.2% total solids that the PLC is set for. When the pumps starts, a 25 L container with a large funnel is placed below the sampling port, and the valve is opened to fill the container – it was important to make sure that the water was very opaque and dark while filling to maximize the solids collected. Once full, the container was taken upstairs to where the Salsnes filter was located, and allowed to sit undisturbed overnight. This provided additional thickening of the sludge (shown on next page).

The next day (day 0) the Salsnes Filter was run. A large submersible pump was carried outside of the sedimentation building, lifted over a rail, and placed into the inlet flow to the sedimentation basin (after grit removal). Once the pump was in place, a three inch hose and valve was connected to the pump. The pump is then turned on, and the filter starts working automatically as it is designed to do (see section 3.1 for full description). Flowrate was adjusted by the ball valve, and the filter is allowed to run for at least 15 minutes before any sample

Figure 31: Collection of Salsnes sieve sludge

is taken. Typically once the filter began running and before a sample was taken, other tasks were completed. The solids were collected by placing the outlet pipe into a 10 L container, which was allowed to fill to at least 6 L of volume (which took roughly 10-20 minutes depending on flow rate).

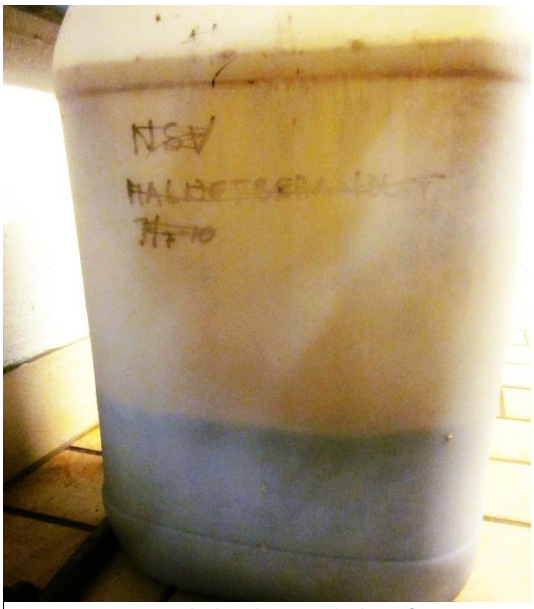


Figure 32 Settled sediment sludge after sitting overnight, note distinct line of separation.

While the filter was running (day 0), the sedimentation sludge that has settled over night has a distinct line between the sludge and supernatant. A siphon was used remove the supernatant from the sludge with the goal of removing as much supernatant as possible while leaving as much of the solids as possible. Once the siphoning was done, the large container was shook to mix the solids well and transferred into a smaller container. In later preparations, in order to achieve higher solids %, the sludge was allowed to further settle in the smaller container and supernatant was poured off. **NB!** Once any measurements were begun, no further alterations were ever made to the sludge.

The Salsnes sample and the sedimentation sample were then taken to the lab for solids testing. Due to the nature of the substrates (especially the SF sludge), pouring into any small container proved difficult and messy, and solids testing provided highly variable results. After a few trials, solutions to this problem were developed. Solids were first shaken vigorously for around 10-15 seconds and 300-400 ml immediately poured into a beaker (in order to have the most representative sample possible). The Ultra Turrax mixer was then used to emulsify the solids as well as possible. Total and volatile solids testing procedure was followed for solids measurement.

Figure 34: Salsnes sludge being emulsified with Ultra Turrax mixer

Figure 33: Wet solids in aluminum dishes prior to drying for TS/VS analysis.

It became necessary to predilute the sieve sludge sample after the flowrate (sieve rate) was lowered on the filter. The solids were so thick coming out of the filter that the Ultra Turrax would not blend the SF sludge to a homogenous and pourable consistency. The rationale of doing this was that the samples were to be diluted anyway, and the same dilution water was used. Basically once the Salsnes sample was taken, about 1L of raw wastewater was poured into the sample. It was still necessary every time to dilute the Salsnes sludge despite prediluting with no determined measurement.

The next day (day 1), the dry solids were taken from the drying oven, weighed, and then volatilized (See section 3.1). Once the volatile solids measurements were made, the data was placed in a spreadsheet and the VS ratio between sediment and Salsnes sludge was calculated. The ratio (which was always below 1, typically around .67 – See Feedstock TS/VS in appendix) was then multiplied by the desired feedstock volume to give Salsnes sludge volume to add, the remainder of the volume was diluted with raw wastewater (with the assumption of 0% VS). During a normal feed preparation, 5-6 L of Salsnes feedstock was prepared; if the ratio between the two is 0.67, for example, 3.35 L of the Salsnes sludge is measured and poured into a new container, and 1.65 L of raw influent was added to make 5 L of feedstock. This proved to be a particularly effective method, which provided solids within 5% VS or within 1g VS per feeding.

Figure 35: Salsnes sludge torn in half after drying, note the cardboard-like appearance signifying high cellulose content.

When the feedstocks were prepared, the digesters were fed with the one prepared that day (day 1). Solids testing had not yet been completed for the diluted Salsnes feedstock yet – the solids content is not known until the next day (day 2) because the TS/VS testing requires the samples to be left overnight to dry. The diluted feedstock was treated the same way as the raw substrate and sediment stock, using the Ultra Turrax mixer to emulsify and make duplicate/triplicate samples as homogenous as possible. COD testing was done at the same time as the TS/VS measurement for the prepared sludge. It is important to note that the feed sludge was always left in a cooler at 4°C when not being used.

5.2 Feeding

This process changed during the experiment for a couple of reasons, but this will be discussed after the explanation. The feeding was quite straightforward, but there were some complications due to the design of the digesters. Automatic continuous feeding of the digesters was desired, but this proved to be impossible with equipment available – any pump that could accurately measure such a small amount of sludge clogged immediately, so continuous feeding was abandoned before the experiment started. Rather, feeding for the duration of the experiment was completed semi-continuously, with a feeding once per day, six days per week (This varied somewhat towards the end of the experiment due to holidays and other reasons – see appendix for feeding schedule). The feeding volume was reduced after the digesters failed and were reseeded, from 1.5 L/day to 1 L/day –SRT/HRT of ~15 days changed to ~23 days.

First Phase Feeding

Figure 36: Measurement of sludge into graduated cylinder (1.5L/day in part 1)

Each day feeding was completed around the same time around 12:00 ± 2 hours, with exact timing clearly visible in the data. During the first phase before reseeding, the stirring mechanism on the digesters was turned to 150rpm and allowed to stir the digesters until the gas flow nearly stopped (this can be clearly seen in the data daily with large spikes in gas flowrate). The respective feedstock was shaken thoroughly and 1.5 L was measured out in a graduated cylinder. The gas outlet valve was then closed manually in order to maintain gas pressure in the digester, before the feeding port was opened. The stirring mechanism was then removed (zero stirring), and a funnel was placed in the opening. The feedstock was then poured into the funnel, but due to the pressure in the headspace, it would not flow into the reactor. The cylinder was quickly rinsed out after pouring the feedstock in the funnel, and then was placed at the outlet and filled to the same volume as fed. Once completed, the feeding port was closed, stirring motor replaced, and valves were turned back to operating mode.

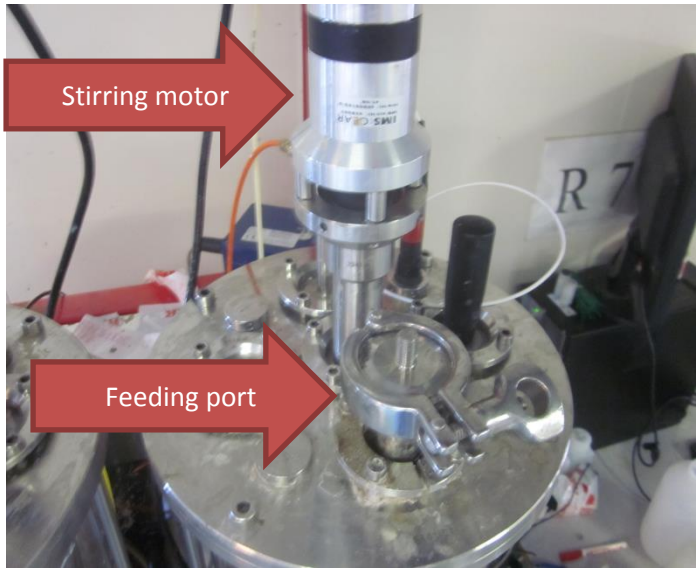


Figure 37: Digester feeding port and removable stirring motor

The feeding procedure for the first part had flaws for a few reasons. Since the stirring mechanism was removed, solids in the digester were able to settle prior to the actual feeding – which would cause undigested solids to flush out of the system (not fully mixed) and lead to washing out of bacteria needed for digestion. The second issue with this was that when the port at the bottom of the tank was opened without stirring, it would cause solids from the feed funnel to migrate directly down to the outlet port, so much of what was being fed could have entered the outlet immediately – however the amount is not known and was certainly variable. After discussion with my advisor, it was decided to attempt a different approach.

Second Phase Feeding

For the second half of the experiment, the feeding was completed with the stirring motor attached and running at maximum speed the entire time (200 rpm). This was done to combat the two issues described above. Solids would not have a chance to settle with the motor on, allowing for a more representative sample and preventing washout of bacteria that might settle when the

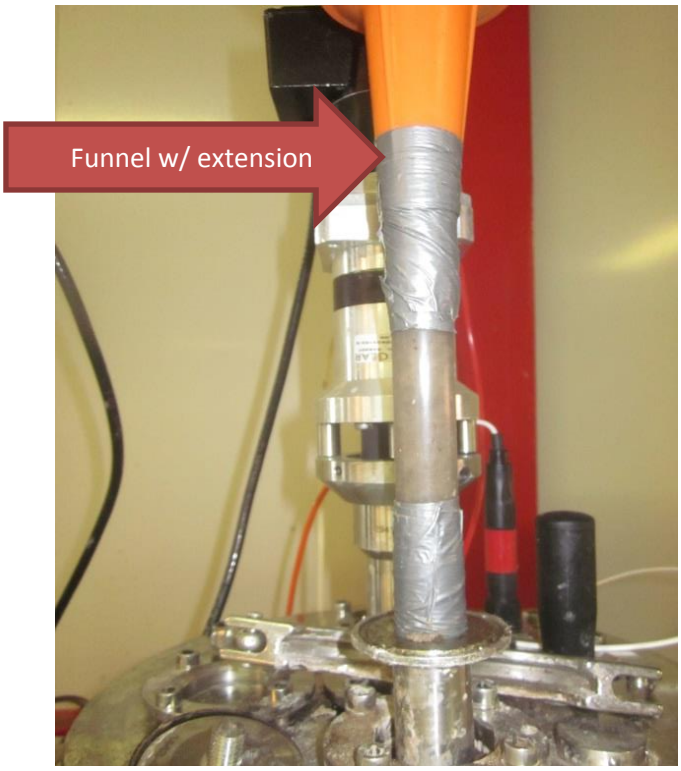


Figure 38: Second phase feeding solution, funnel extension allowing motor to stay attached.

motor was removed. Also, with the stirrer on at full speed, any solids that enter during the feed would presumably be mixed in quickly as if it were a completely mixed tank reactor – which does not allude that no feed solids were removed during feeding, but that it was a more complete mix. If the Dolly Digester is run in future experiments, this is a major issue that must be addressed.

The feeding for both phases was completed in the manner described because it was desired to keep headspace pressure up. When the valve removing solids was opened, it caused a vacuum in the feed funnel, sucking them into the digester. Ideally feeding would have been completed via a draw-fill regime, by first removing the digestate followed by addition of the feed after, but this was not possible without introduction of atmospheric air into the digester headspace – this is the main reason for the feeding procedure described.

Once the feeding is completed for the two digesters, the digestate from the respective reactors are measured for TS/VS as well. Twice weekly, the digestate is subject to Alkalinity and Volatile Organic Acid tests as well (See section 4).

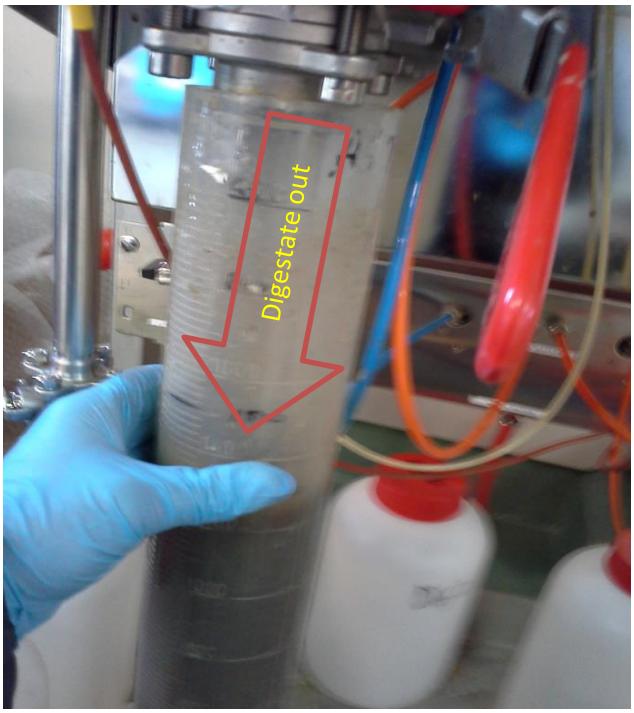


Figure 40: Removal of digestate solids from digester

Figure 39: Digester outlet for removing solids. When onpened, fluid flows into cylinder and creates vacuum in funnel completing feed.

6. Results and Discussion

There is some difficulty in presenting the results to the experiment without discussion simply due to the nature of the experiment. This section is broken down into four sections. The first deals with the sludge properties and feedstock preparation. The second deals with the digester health and variables surrounding the operation and maintenance. The third deals with the data collected from the digesters, gas production, quality, and mass balances for the two experimental windows that data was viable. The last discusses the AMPTS results.

Figure 41: Raw Salsnes Slude (left), Salsnes and Sediment Sludge (middle), Sediment Sludge (right)

6.1 Sludge Properties and Feedstock Preparation

The first set of data to be presented is the feedstock preparation for subsequent feeding into the digesters. Settled sedimentation sludge and raw Salsnes sieve sludge were measured for their volatile solid content and then the sieve sludge was diluted to attempt to match the sedimentation sludge. Note Figure 42, as this shows why the sieve sludge had to be diluted.

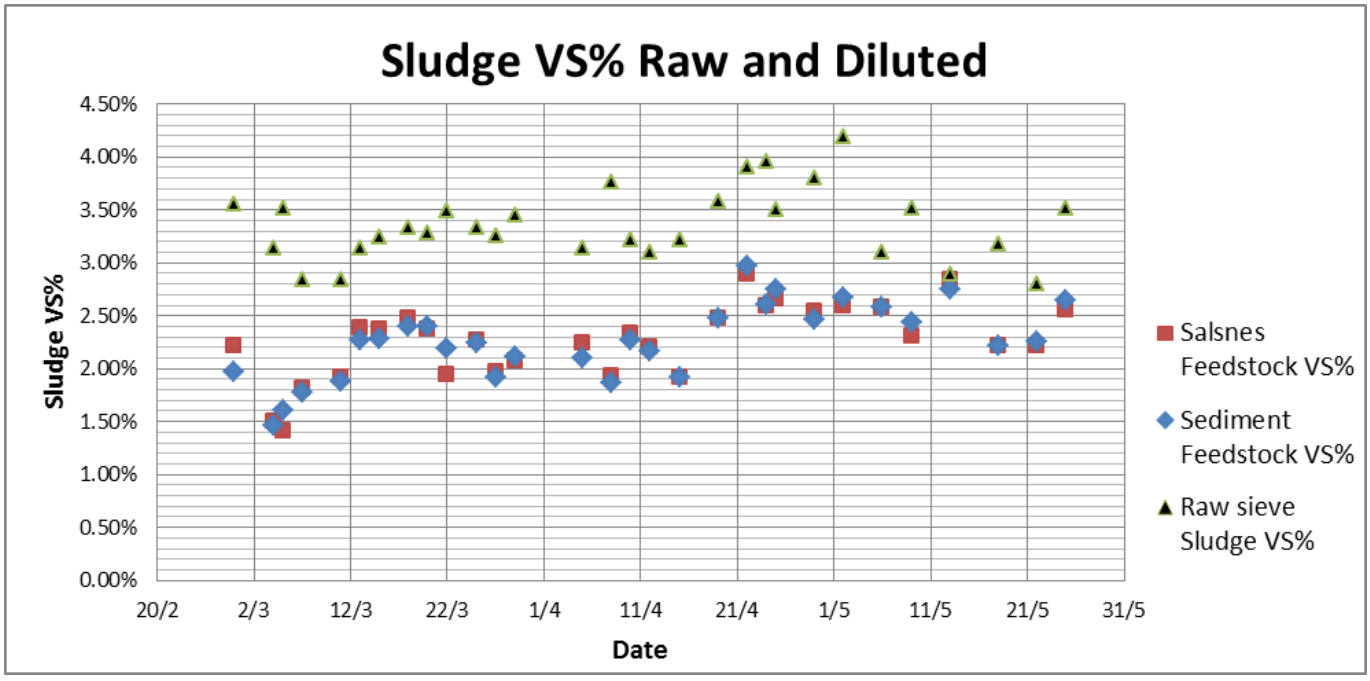


Figure 42: VS% of the respective sludges.

For the sludge that was collected, there were several differences. The consistency of the sludge was quite different, with the Salsnes sludge having notably larger particles than the sediment sludge, which was had much finer particles as a whole. This was not measured directly, but was clear upon inspection (Figure 41). Other differences were in the color, where the sieve sludge was lighter in color, likely due to containing less inorganic material like fine dust/gravel. It follows that for the total solid percentage of the respective sludges, in general the sieve sludge was significantly higher in volatile solids as a fraction of total solids, which can be seen in the graph in Figure 44.

This regression curve is to show how close the feedstock preparations were to each other. Since it was desired to feed the digesters as similarly as possible, the raw sludge needed to be diluted. The rationale was to make it easier and more direct comparison of gas output, as feeding the same amount makes any residual sludge from previous feedings less significant. Feedstocks were, except for a few cases at the beginning of the experiment, within ±5% of VS%.

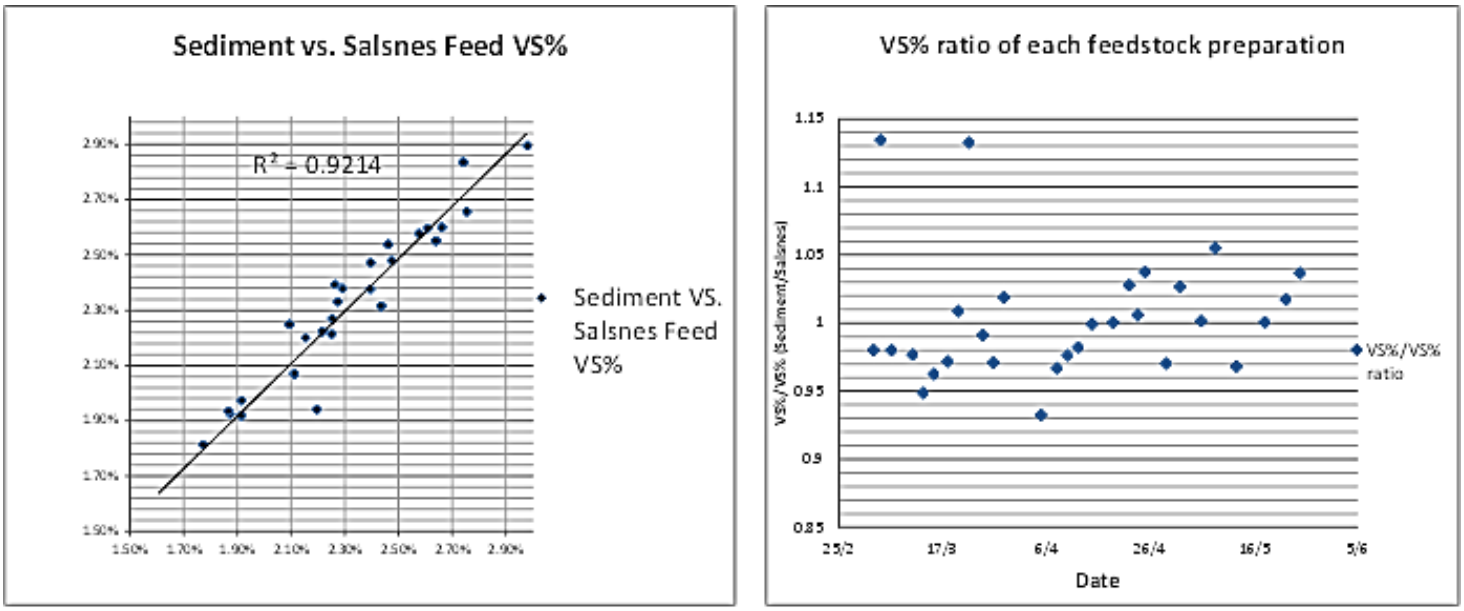


Figure 43: Regression and VS/VS ratio for each feed preparation to show closeness of dilutions.

As can be seen in Figure 43, the volatile solids content of each of the feeds were quite close after dilution of the raw sieve sludge to make the feedstock. There were some poor dilutions at the beginning of the experiment, but that was solved after experience was gained in dealing with the sludge. At first, the Ultra Turrax was not used to emulsify the solids, which caused the Salsnes sludge to be measured inaccurately, as the sludge would tend to clump during pouring and measurements were highly variable between samples.

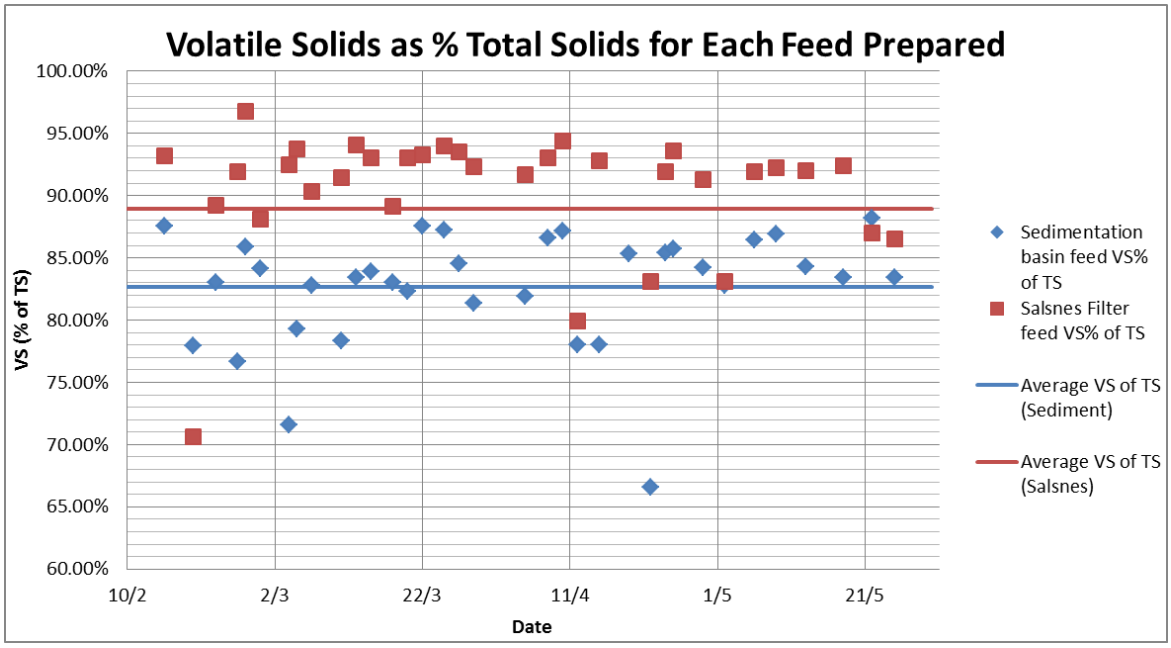


Figure 44: Feedstock VS% and average VS% of the duration.

The above graph shows the percentage of volatile solids with respect to total solids in the feed. For a majority of the feeds, the sieve sludge was significantly higher in VS% of TS, with an average of 88.9% compared to 82.7% for the sediment sludge. The average was affected by a number of outliers, for when the total solids were very high. One case of this in February was due to the local water treatment plant dumping a large amount of clay and other fine inorganics into the wastewater when flushing their filters. The low VS% cases in April and May were during wet weather days during the melt period in Norway – there was a large amount of small gravel in the wastewater from the streets that were flushed in spring rainstorms. The typical range for the VS% of TS for the Salsnes sludge was around 91-94% during dry weather flow.

The really interesting thing about the VS% of TS is the question of why this is the case. There are two possibilities that I can think of, either the filters are allowing very fine inorganics to seep through the filter and not be caught, or the filter is simply capturing much more of the total influent volatile solids that would otherwise not settle. The latter is most intriguing because if the filter is capturing more of the suspended solids, those solids are not moving on into downstream processes. It has already been discussed that cellulose is slowly biodegradable at low temperatures and without enzyme activity, so aerobic processes (if in place) would subsequently have the burden of that load, which increases the oxygen demand and therefore energy/money.

Feedstock COD

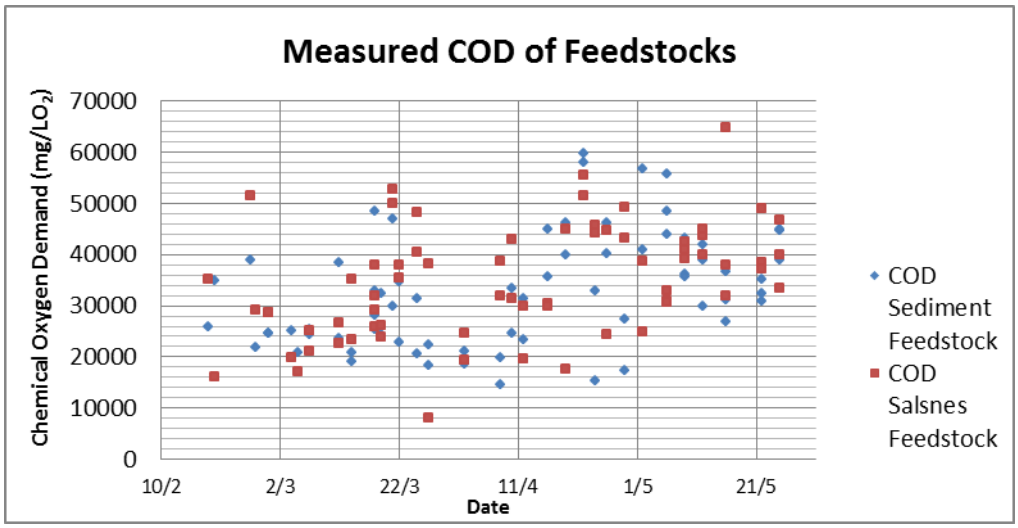


Figure 45: Measured COD of feedstocks, note the high variability between samples.

Each feedstock was tested for Chemical Oxygen Demand, which proved to be difficult with the high solids content, and especially with the cellulose content of the sludges. Some minor variations in the testing method made for more consistent measurements later in the experiment, but even then there were sometimes very large variations between triplicate measurements. For example, with a dilution of 1:10 (to be within range of the test kits), one sample might read 6800 mg/l O_2 while the next sample in a triplicate using the same sample would read 3100 mg/l O_2. The reasons for this were likely due to cellulose blocking the pipette used to take the sample, basically acting as a filter. In later trials, to attempt at higher consistency of the results, duplicate sampling was replaced by triplicate sampling (budget was of concern for beginning with triplicates). The other change that improved consistency was using a larger pipette for the sampling, which provided a larger opening for larger particles to enter (large 1-10 ml pipette shown below). Averaging of the results provided values for the COD to be within range of the literature, however, the ranges between triplicates were still quite high.

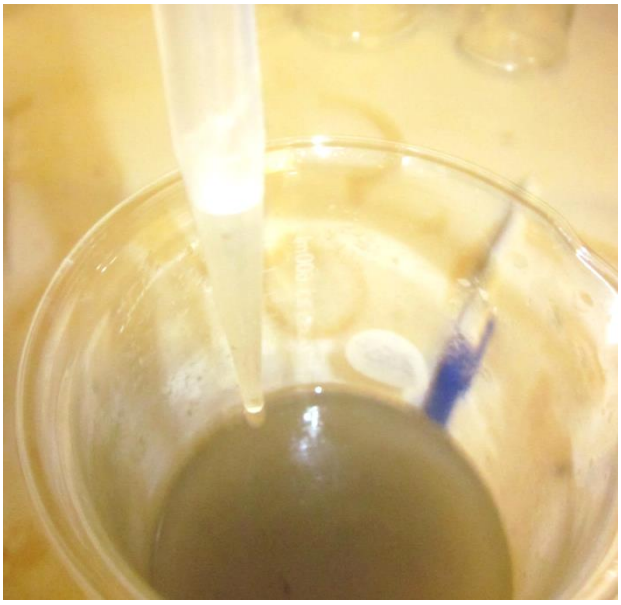


Figure 47: Sampling for COD testing, showing possible blockage of pipette.

Figure 46: 1:10 Diluted Salsnes feedstock for COD analysis with large particles even after emulsification.

COD/VS Ratio

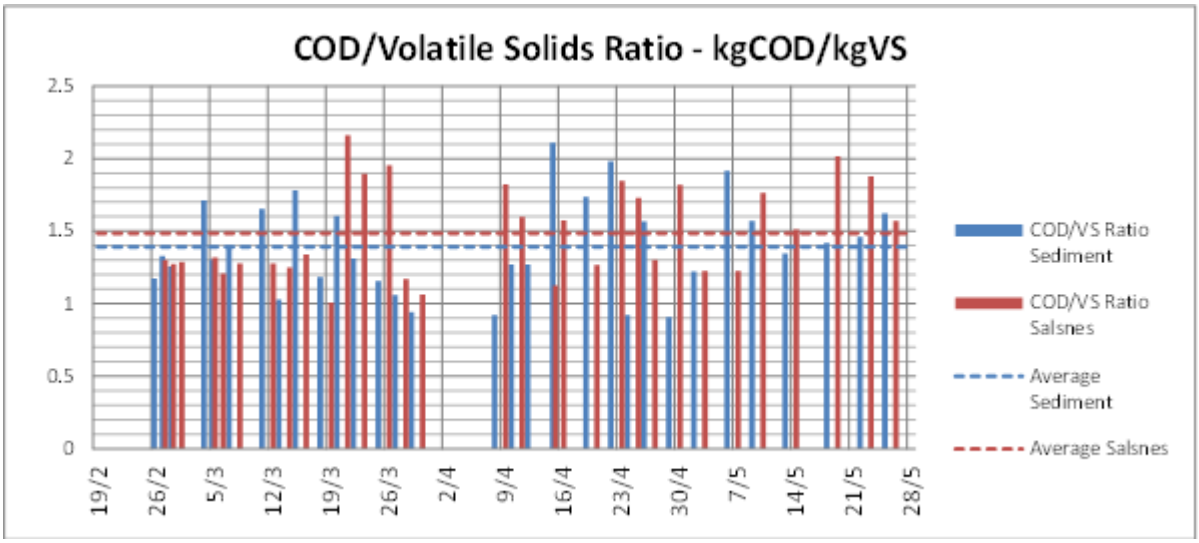


Figure 48:COD/VS ratio in kgCOD/kgVS for the duration of the experiment (COD data was missing for April 4)

The value that is of most interest for the operation of a digester and for comparison with literature concerning the 'strength' of the sludge is the ratio between the volatile solids and the COD. Typical wastewater is 1.42 gCOD/gVS with the generic chemical formula of $C_5H_7O_2N$ (Metcalf & Eddy, 2003). The measured results for the entire duration of the experiment were within range of this with the sediment sludge with an average value of 1.39 gCOD/gVS and the sieve sludge 1.49. For the first half of the experiment when the sieve rate was higher for the filter, and before the protocol change, the values were slightly lower with 1.33 and 1.39 for the sediment and sieve sludge respectively.

With the new techniques in place in the second half of the experiment, *and* the slower sieve rate, the averages for the COD/VS ratio were slightly higher at 1.45 gCOD/gVS for sediment sludge and a significantly higher 1.58 gCOD/gVS for the sieve sludge (April 8-May 29). There are several possibilities for this change, one being the larger pipette used for the sampling. However, there was one very notable difference in the sieve sludge that had not been noticed before the flowrate to the filter was lowered (sieve rate 50m^3/m^2hr) for the second half of the experiment – clear evidence that fatty material was abundant in the sieve sludge.

Figure 49: Empty beaker covered in fat residue after emulsification of sieve sludge.

After emulsification of the sieve sludge for solids analysis with the Ultra Turrax, it was noticed that the sides of the beaker became covered in a fatty residue. This could not be rinsed out with water, but rather needed soap to be cleaned from the beaker. The same phenomena was never noticed for the sedimentation sludge, therefore it is clear that the Salsnes filter is capturing the fats along with the other solids. The increase in COD/VS ratio in the second half of the experiment may be due to the fat content in the sludge and not due simply to a change in procedure. What

is of special concern regarding this fat content, is that fats are gram for gram higher in COD than cellulosic material, and also produce a higher percentage of gas per gram than other lower energy volatile solids (shown on Figure 6 in Section 1).

Figure 50: Fats floating in SF6000 prior to filter in Tiendeholmen Renseanlegg in Namsos.

Figure 50 is simply to show that this is not the first time fats are seen captured in the filters. The fats that are floating here do end up making it out of the filter when the flow stops. However, this is seen as a big problem due to the fouling that it causes, plugging up the pressure transducers and causing errors in that way – maintenance must be done often by hand (it was kind of fun the first few times…). The fats will also plug the screws for the solids in the trough. With most Salsnes Filters using dewatering screw presses, this is even more of a problem because the fats will clog lines in very hard to reach places.

Calorific Value for Feedstocks and Digestate

Samples from three days of feedstock preparations were prepared for calorific value measurements. Digestate from two days were also analyzed. The lab Skog og Landskap lab at the University of Ås performed the analysis.

Table 2: Calorific Value for feedstock and digestate samples.

Type	Sample Label	Moisture content %H20	Calorific Value of Dried Sample (MJ/kg*TS)	Average (MJ/kg*TS)	Sample VS%	VS% of TS	Average VS of TS	Average (MJ/kg*VS)
Digestate	DG1 7/5	2,08	12.04		0.97%	57.69%		
Digestate	DG1 13/5	2,08	12.95	12.54	0.98%	58.18%	57.90%	21.66
Digestate	DG1 15/5	2,08	12.64		0.94%	57.83%		
Digestate	DG2 7/5	2,08	13.25		0.92%	58.12%		
Digestate	DG2 13/5	2,08	13.07	13.33	0.95%	58.07%	58.83%	22.65
Digestate	DG2 15/5	2,08	13.66		1.00%	60.31%		
Feedstock	Sediment 25/4	2,08	17.55		2.75%	85.79%		
Feedstock	Sediment 6/5	2,08	17.88	17.72	2.58%	86.79%	86.91%	20.39
Feedstock	Sediment 22/5	2,08	17.74		2.25%	88.16%		
Feedstock	Salsnes 25/4	2,08	18.73		2.66%	93.61%		
Feedstock	Salsnes 6/5	2,08	18.38	18.43	2.58%	91.97%	90.85%	20.28
Feedstock	Salsnes 22/5	2,08	18.17		2.21%	86.98%		

With regard to the feedstocks, note that the calorific values for the sieve sludge was slightly higher than the sediment, however, the sediment had a higher inorganic content. This is of course logical if there is a higher portion of non-volatile solids in the waste. When normalized for VS, the values become almost equivalent. What should be taken away from this is that the Salsnes filter is able to produce sludge with a lower inorganic content, which means that gram for gram, it has a higher calorific value than sediment sludge.

Regarding the digestate samples, the energy left in the sludge after digestion could potentially be combusted for energy. However, this is dependent on the ability for that sludge to be dewatered. If dewatering is difficult (see CST results), then it is somewhat of a moot point (however the dewaterability would be better with a higher solids loading than this experiment used). Differences between the two digesters are slight, but somewhat higher in the Salsnes reactor – this likely due to cellulose content and lower inorganic solids.

6.2 Digester Maintenance and Health

Anaerobic digestion is a process that needs to be carefully controlled and monitored, as slight changes can affect the bacterial community in major ways. It was very important to monitor the 'vitals' of the digester on a regular basis, especially during the startup, as at this time bacteria are trying to acclimate themselves to a new environment. Knowledge of the inner workings of the digester are not only important to keep the community alive, but also gives data for calculation of the factors of interest, mainly the reduction of solids that subsequently produce the biogas that is desired.

The results in this section will show the status of the digester throughout the experiment and also provide characteristic values for the management of the sludge. The failure of the digesters in the first phase will be discussed as well as the probable reasons for that occurrence.

Digester Feeding

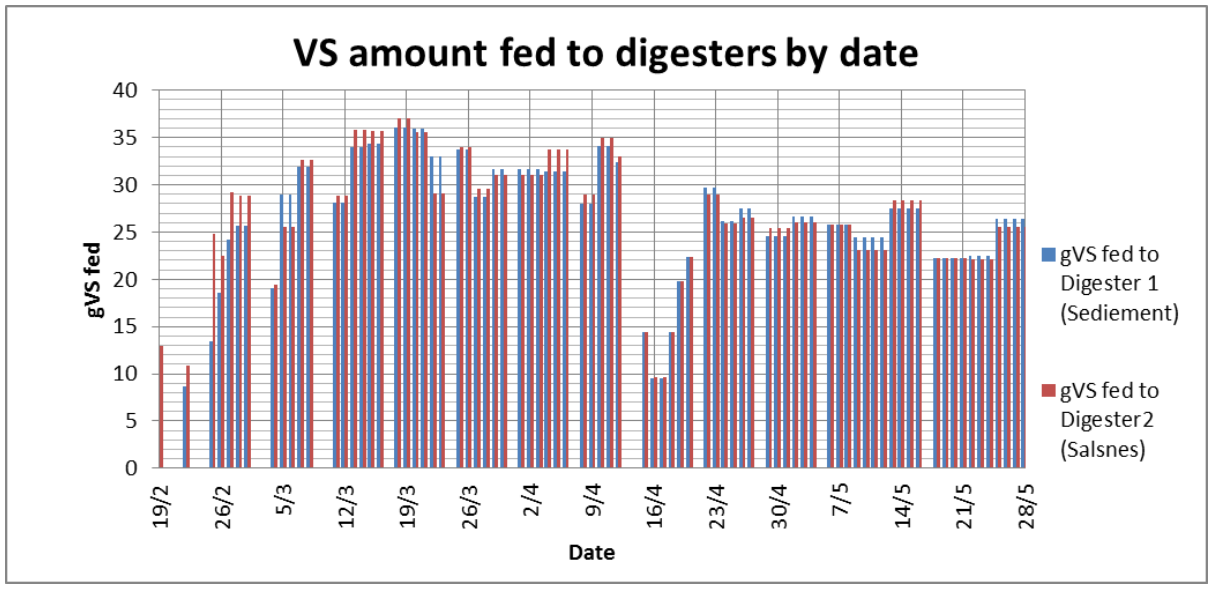


Figure 51: grams of volatile solids fed to digesters by date

Before the 16th of April, the HRT/SRT was maintained at ~15days. At this time, feeding occurred on 5 days out of the week, and then was changed to 6 days per week – which meant a feed amount of 1.5 L/day. As can be seen by the graph above, the total VS feed amount in the first phase was typically higher than after April 16, with a lower HRT. This proved to be problematic, as too much was being fed to the digesters, but more importantly, too much being drawn from the digesters, flushing out much of the bacteria.

In the second phase, after April 16th, the feed was reduced to 1 L/day, but there was an attempt to increase the VS% of each feed, as it was thought that flushing of the bacteria was more of a problem than the mass of solids itself.

The overall goal was to reach a steady state in the reactor, where the VS% in the reactor would remain constant over a period of time. Due to the nature of anaerobic digesters, and the relatively short time period in which this experiment was conducted, the reactors were actually

fairly close to being steady state – especially for the time periods in which the gas data was analyzed.

Total and Volatile Solids in the Digesters

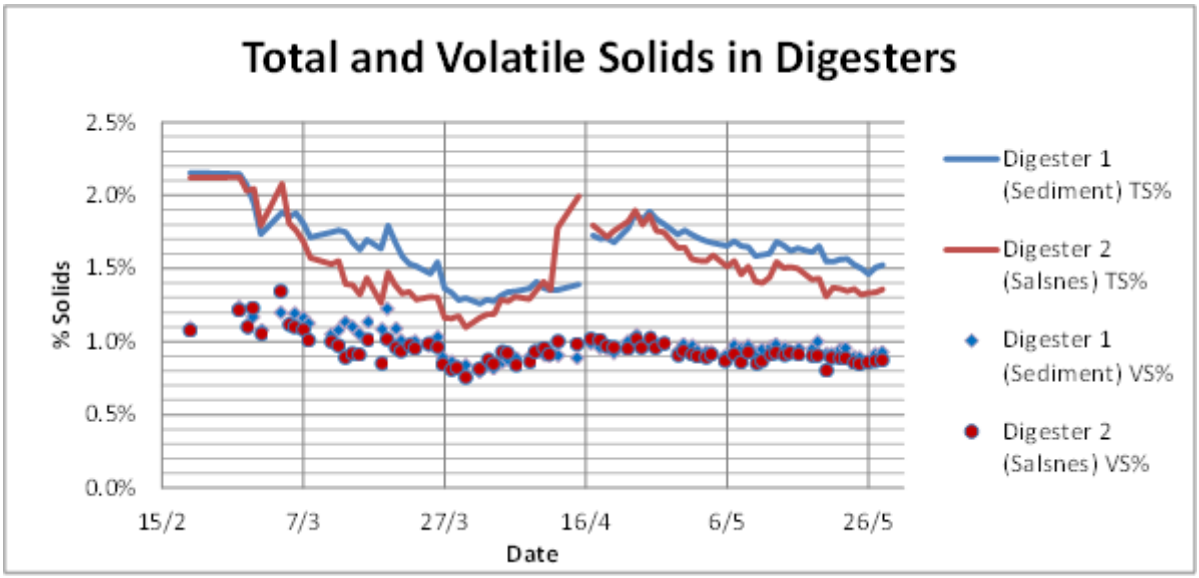


Figure 52: Total and volatile solids in the digesters for the duration of the experiment.

The figure above shows the state of the digester through the entire duration of the experiment. After seeding, the solids content of the digesters dropped quickly from feeding and volatilization of solids. After a time, the volatile solids stabilized between 0.9% and 1%, signifying that the digesters were close to steady state operation.

The slight dip around the 27th of March was due to the change in feeding protocol, where the sludge was kept completely mixed during the feeding (as opposed to mixing immediately before and removing the stirring motor to accommodate the funnel used to feed). This changing of the feeding procedure, had it occurred earlier in the experiment, may have saved the digesters from souring by not allowing bacterial solids to settle after the mixer was disconnected - subsequently flushing them out.

The spike in the total solids concentration just before 16/4 in Digester 2 was from addition of Na_2CO_3 as well as digester activity ceasing (solids not being digested). This addition was to combat the rise in volatile acids, in attempt to keep the ratio below a 0.3 Alkalinity/VOA (see Alkalinity and VOA for more discussion).

After the reseed, the volatile solids remained relatively constant, hovering around 0.9% VS, but note that the total solids dropped during this time for both reactors, with the Salsnes reactor falling much faster – this was due to feeding a higher VS% of TS percentage, i.e., less inorganic solids were being fed to the reactor. At true steady state, it would be expected that the total solids would be the same as the average total solids being fed to the reactor – something around 10-12% higher than the volatile solids concentration.

Volatile Solids Reduction

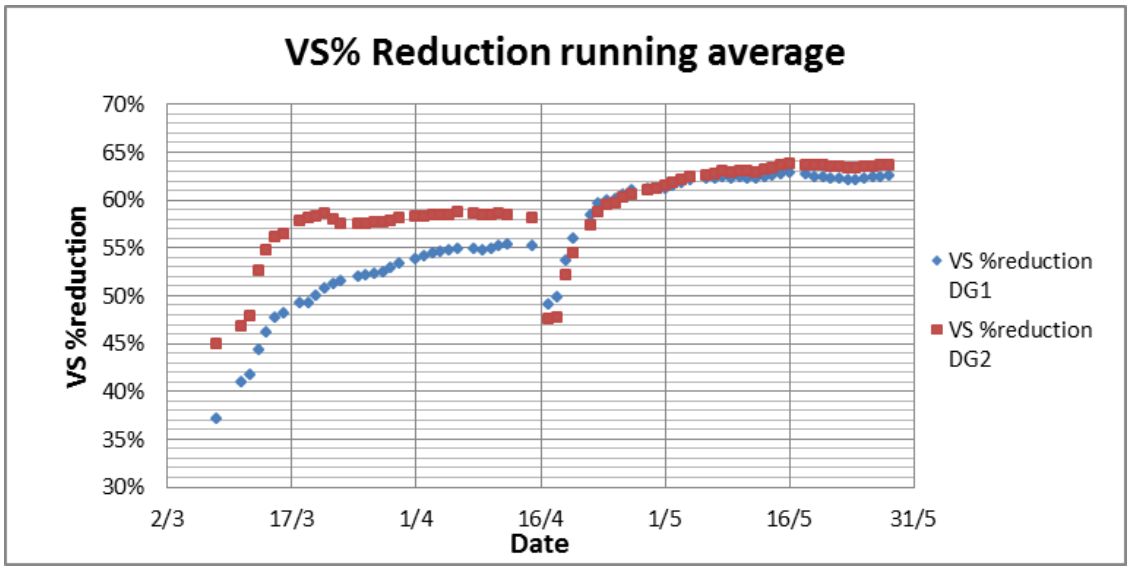


Figure 53: Volatile solids reduction for each phase of the experiment

The volatile solids in the digestate are a direct measure of the volatile solids in the digesters under completely mixed conditions. This allows knowledge of the digesters performance in breaking down the organic matter and converting it to gas. The difference between volatile solids fed and the volatile solids removed is used to calculate the volatile solids reduction, a pseudo mass balance of the system (pseudo since it does not take into account total mass of solids fed, but rather assumes a constant feeding volume, which was the case). Essentially, anaerobic digestion converts a portion of the solids to gas (which too was measured), and the difference between what is fed and what the content in the digesters is, equals the reduction of solids. The equation for calculation is shown below. A running average of this over the duration of interest provides the average volatile solids reduction over the period.

$$\frac{VS\%_{in} - VS\%_{out}}{VS\%_{in} - (VS\%_{in} - VS\%_{out})}$$

The average VS% in minus the average VS% out, divided by the difference in VS% in and VS% destroyed.

Alkalinity and Volatile Acids

The most important parameters to keep track of in the digester are the alkalinity and the volatile acid concentrations to monitor the health of the digester. The ratio between the two should be kept below a ratio of 0.3. This may seem straight forward, but if close attention is not paid, souring can occur very quickly.

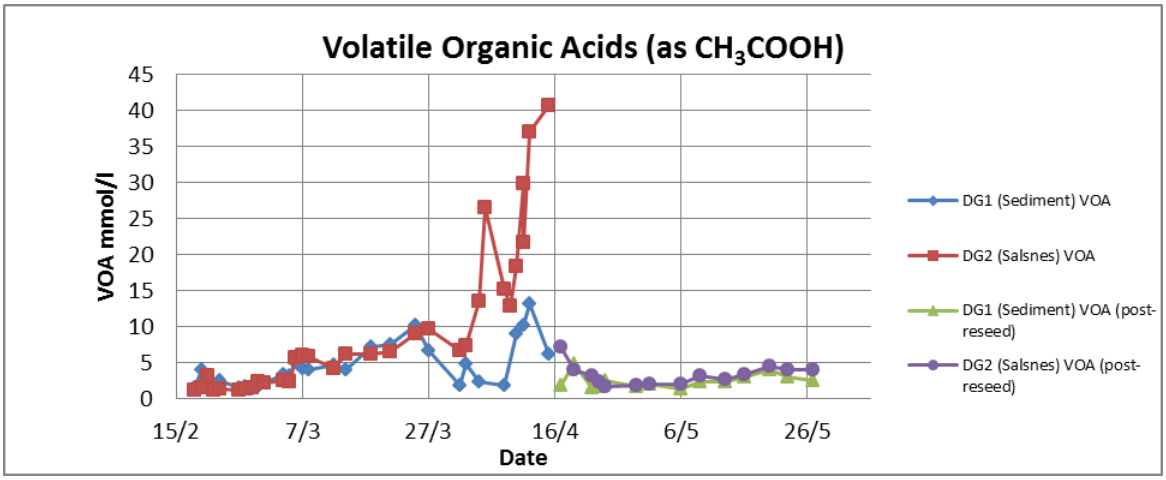


Figure 54: Volatile acid concentration (mmol/l) in the digesters for the duration of the experiment.

Volatile acid concentration is a measure of how much acetate, and to a lesser extent, butyrate, propionate, and other longer chain fatty acids are in the digester. Methanogenic bacteria feed on the acetate to produce methane, so if the concentration is very high, it signifies that either the bacteria cannot process the acids fast enough (over feeding), or because the methanogenic bacteria are being inhibited due to other environmental conditions (too low/high pH, lack of alkalinity). The acidogenic and acetogenic bacteria which convert hydrolyzed organic matter into these compounds are very hearty, whereas the methanogens are conversely very sensitive. A spike in VOA concentration should alert the operator of the digester to stop feeding so much and/or check to see if the ratio between the alkalinity and VOAs is low enough.

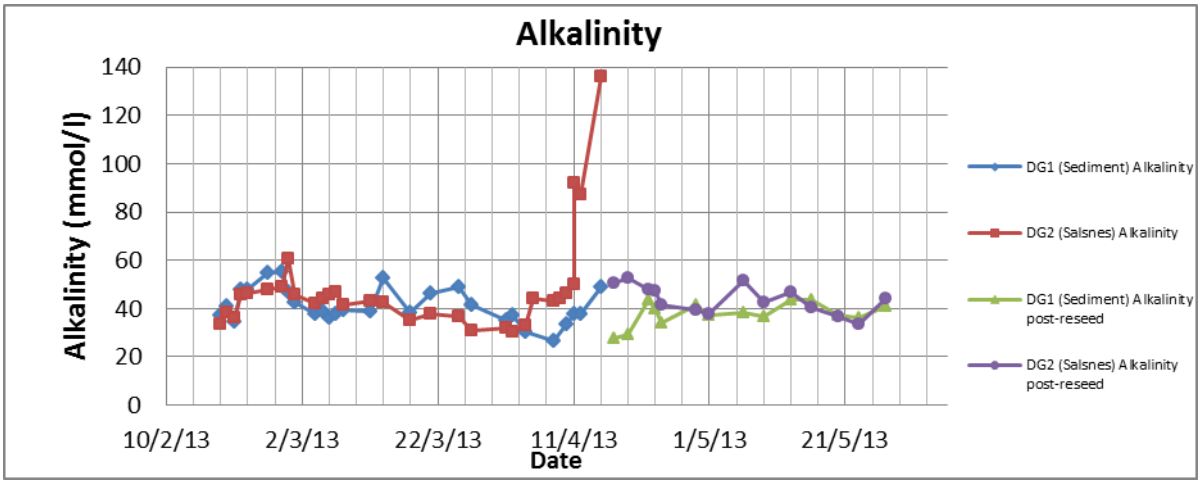


Figure 55: Alkalinity in mmol/l for the duration of the experiment.

The other important factor for digester health is the alkalinity, as it acts as a buffer for the acids, keeping the pH right around neutral, between 6.8-7.2 in a healthy digester. The formation of carbonate ions is a byproduct of methanogenesis, so if a reactor is being fed slowly enough, there is no need to artificially add alkalinity, however, if the volatile acids spike, addition of alkalinity may be necessary for buffering capacity.

The spike in alkalinity on the 11th of April was due to addition of Na_2CO_3 (baking soda) to increase alkalinity artificially, however the digester had already soured beyond repair - see below. There were several additions of alkalinity, and a spreadsheet calculation was set up to monitor this (see appendix). At the time of the souring, so much bacteria had been flushed out that the addition did not make a difference.

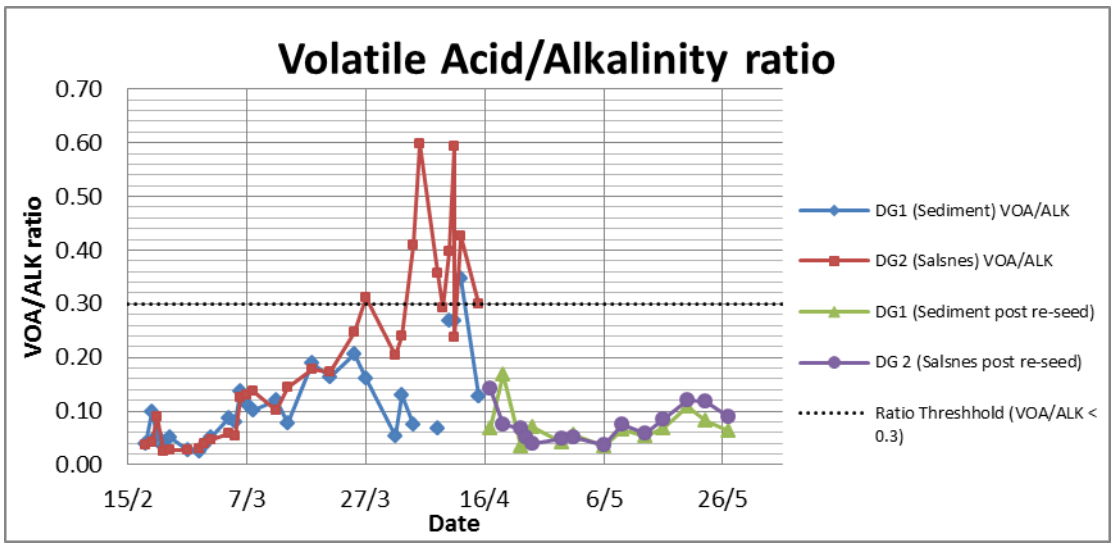


Figure 56: Volatile acid/Alkalinity ratio

With respect to alkalinity and VOA concentration, it is the ratio between the two that is of the most concern. When both units are measured in mmol/l (or meq/l), the ratio between the two should be below 0.5 or 0.3 (depending on the source) while keeping the concentration of the alkalinity above 1500-2000mg/l as $CaCO_3$ or about 3.0 mmol/l. If this is done, the pH will remain relatively constant at roughly neutral. This is also an indication, when measured often, of the Methanogenic bacteria consuming the acids to produce CO_2 and CH_4.

As can be seen in the above graph, the ratio steadily climbed until it was dangerously close to the 0.3 ratio. At this point corrective action was taken, and that can be seen in the red line by the large spikes in the ratio. Before the first experiment was abandoned, note that the ratio was below the threshold – this was due to a massive addition of Na_2CO_3, which brought the ratio down, but the rapid swing in pH due to this addition was the likely cause of completely killing off all of the gas producing bacteria simply by the shock that it caused.

After the reseed, knowledge had been gained about the operation of the digesters, and as can be seen, no problems were encountered afterward. In retrospect, as soon as the ratio began to rise in the middle of March, a reduction, and or stoppage of feeding should have occurred. It was an unfortunate and very stressful time during the course of this research, but invaluable lessons were learned from the experience.

Capillary Suction Time

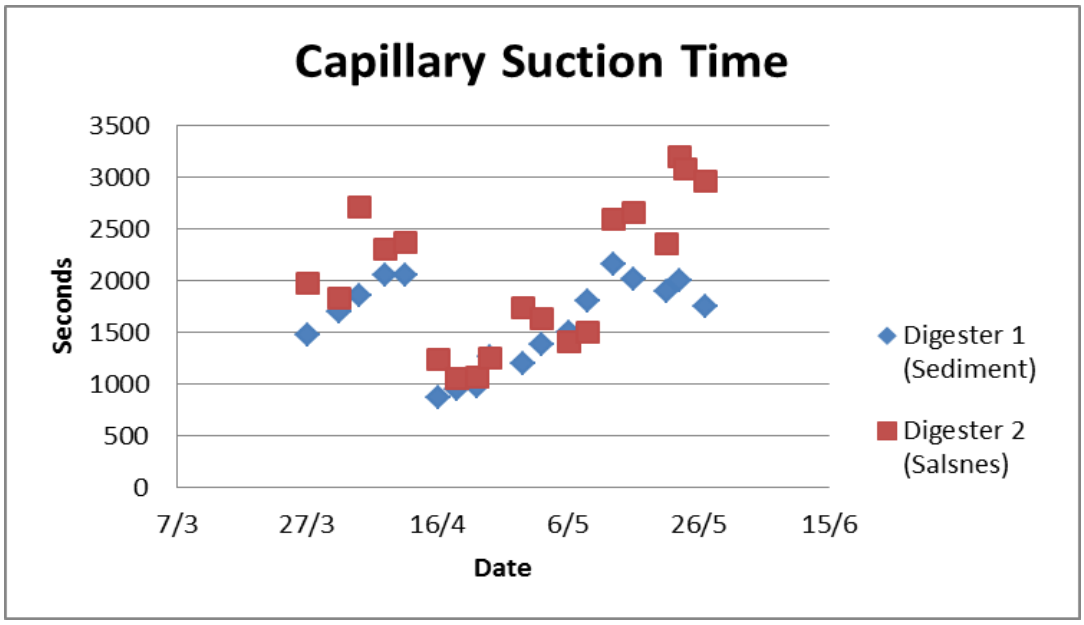


Figure 57: Capillary Suction Time

Capillary suction time is basically a measure of the filterability/dewaterability of sludge. A low time means there is good separation and the sludge can easily be dewatered, whereas a high time means that the sludge is not easily separable/filterable.

In the case of these sludge in the two digesters, the time was very high and increasing as the days past. Since the solids had been reduced so much by the bacteria, the particulate had become very small. Basically the meaning of this is that the particles in the sludge are very small, hydrolyzed, and will easily block pores in a filter – creating a sort of impermeable membrane, and making the sludge difficult to dewater by filtering. When times are high for the test, it is an indication that polymers or other flocculation chemicals must be used to increase the dewaterability by forming flocs and allowing water to escape. If the digester that was fed a much thicker sludge (5-6% TS vs. 2-3%) the expectation would actually be for the CST time to go down, as the total solids increased – thus reducing the proportion of fine particles in the digesters, at the cost of lower biogas potential (due to lower surface area reducing hydrolysis rate).

6.3 Digester Gas Production and Quality

Because of the need for re-seeding of the digesters after souring in April, there are two windows of time for which the data was adequate for reporting with respect to the gas output of the digesters. That is, it was desired to allow bacteria to acclimate and reach a pseudo steady state before comparison of the gas data was deemed due to the digester feeding itself and not due to residual solids in the seed sludge. In a continuously mixed reactor, this means about three times the HRT/SRT of the system. However, the project only was to last 4 months, and with 15-25 day retention times, this means only a small portion of the data would usable if at all. Additionally, gas sensor data was only available for a few weeks, so it is not known what the gas concentrations of the digesters were. All said, the data will be provided and every attempt will be made to present it in as fair a manner as possible.

With respect to error – there are many places error could propagate through the data. The complex nature of the project with respect to measuring sludge solids, mixing weights and volumes, bad sensors, drifting calibrations, etc., makes it impossible to analyze with any degree of certainty (or uncertainty). Therefore it is important to know that the experimentation was done as carefully as possible and with equal treatment to both feedstocks and digesters at all times.

March 6 – April 12

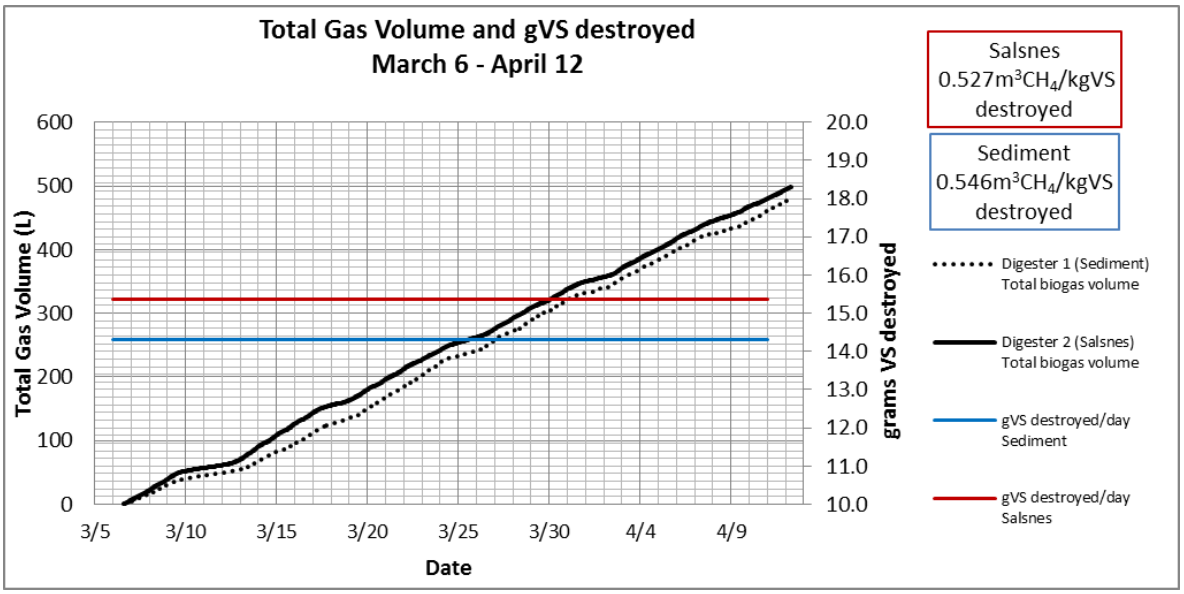


Figure 58: Total biogas volume and average destroyed VS for the period with standard volumes assuming 60% CH_4.

The first set of data chosen was the period between March 6th and April 12th, a 37 day period. Of these days, the digesters were each fed 32 of these days. March 6th was chosen for the start date since this was when methods for measuring sludge feeding became fairly reliable. Sludge from the inoculum (seed) may have some residual gas production at this point, but gas flow data suggests that this is not the case.

The specific CH_4 production per gram VS destroyed, which assumes 60% methane content is slightly lower for the Salsnes sludge in this case. With a high sieve rate (~100m^3/m^2 sieve area per hour), it is possible that filter mat was not able to capture as many fine particles and fat than with a lower sieve rate. This is also supported by the AMPTS results, which show a lower methane potential per gram VS for high sieve rate sludge than with low sieve rate sludge (~50m m^3/m^2 sieve area per hour) for the data collected in the second phase of the experiment.

Gas quality data is not available for this period, as the gas sensors were away on maintenance, so it was assumed a quality of 60% methane and 40% Carbon Dioxide for the duration. However, with the high cellulose content and stoichiometry of anaerobically digesting cellulose, it is completely possible that this assumption is wrong, and could be lower. That said, the methane content would still be in the range of 55-60% with the other material captured.

April 22 – May 29

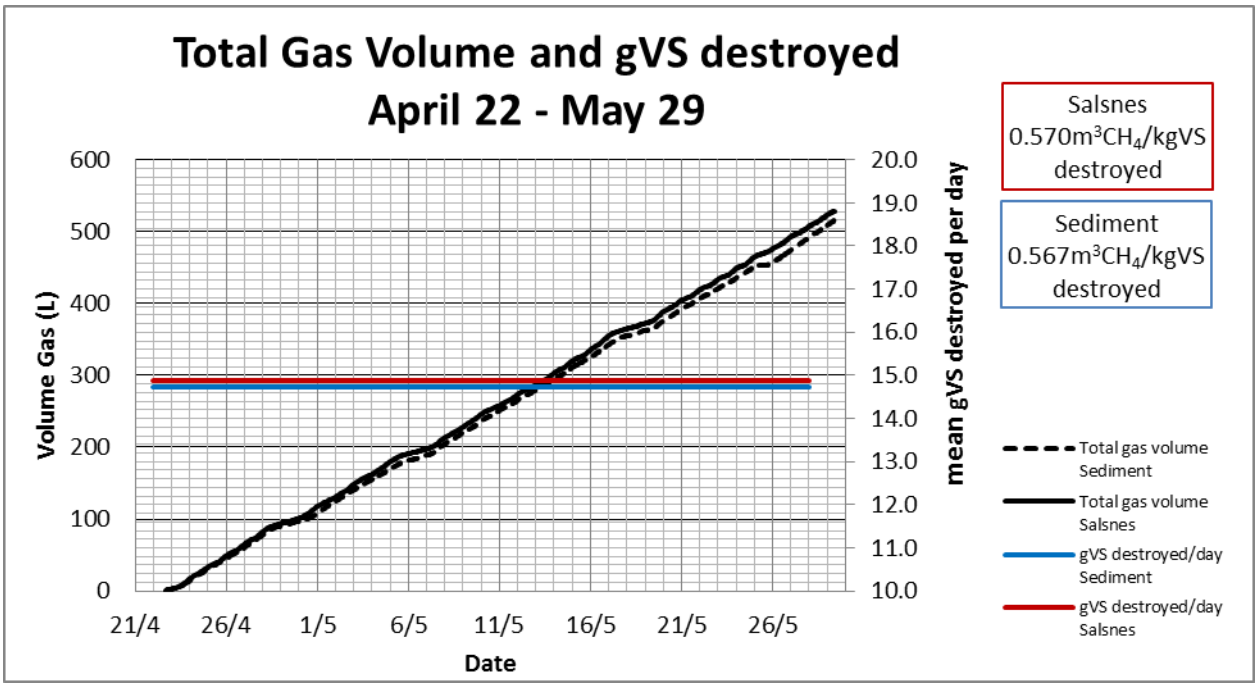


Figure 59: Total biogas volume and average destroyed VS for the period with standard volumes assuming 60% methane.

In the second phase of the experiment, the total gas volumes are similar from the first, but the difference is that the specific methane yield per gram VS is higher for the Salsnes digester. Again, the sieve rate was the only variable that was changed (that was not changed equally for both reactors). The higher fat content and filter mat development to capture more fine material in the Salsnes sludge with the lower sieve rate is the likely cause for this. The latter is also supported with the AMPTS data collected, in that the sieve sludge had higher methane potential with lower sieve rate sludge. The values in the boxes on the graphs were calculated via a mass balance over the period of the data collection and is presented in the following section.

With the lower sieve rate and the collection of fats and other fine organic material, it is evident that the sieve sludge performed better in this half of the experiment. It should be noted that there seems to be a correlation with sieve rate and methane potential, and that is also supported by data collected with the AMPTS, in section 6.4.

Calculation of Methane Yields and Mass Balance

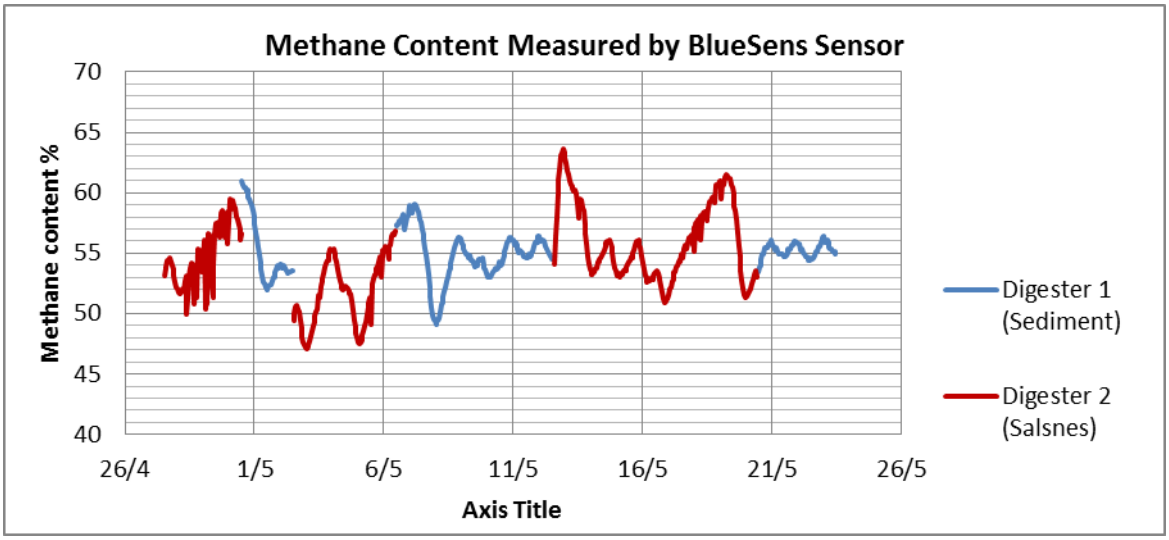


Figure 60: Percent methane content measured by sensor.

One of the big setbacks throughout this experiment was that there was only limited time that a sensor was available for gas quality measurements. April 27th, and the sensor was switched between the reactors throughout the next few weeks. There are several issues that were encountered while using these sensors, most significantly is the uncertainty in the ability to trust the data. Despite the Dolly Digester having an integrated gas condenser to remove water vapor there is a possibility that vapor may have also caused a discrepancy by generating interference. The sensors cannot be trusted for absolute accuracy, and the methane content is almost certainly higher – explanation to follow.

The sensor was hooked up, and the 'spikiness' in the line for the first data points were due to a loose screw on the sensor. Once the screw was tightened, the measured quality was tighter, but daily variations were still experienced. The drop in CH_4% would occur daily for both reactors, typically starting around 4-5 hours after feeding, which coincided with a spike in CO_2 (not reported, as 100%-CH_4% was almost exactly the measured CO_2%, and it just made reading the graphs more confusing when they were prepared). This same phenomenon of CO_2 spikes has been encountered at the University of Ås, where they noticed that after feeding the CO_2 levels would spike while using these sensors (Roald Aasen, UiÅ, personal communication).

On the second to last day of feeding, May 27, a gas bag was placed on the outlet for each digester to collect a composite sample of digester gas overnight. The gas bags were sent to Molab in Oslo for a Gas Chromatography assessment of the methane content. The results for this were 65% and 66% methane for the sediment and Salsnes reactors respectively, but came with a 10-50% margin of error (See appendix for report). It is unclear what this margin of error means, i.e. ±10% 650,000ppm when there is a detection limit of 5ppm? Since GC is an accepted measure of gas quality, it shows that the CH_4% is at least very close to these values.

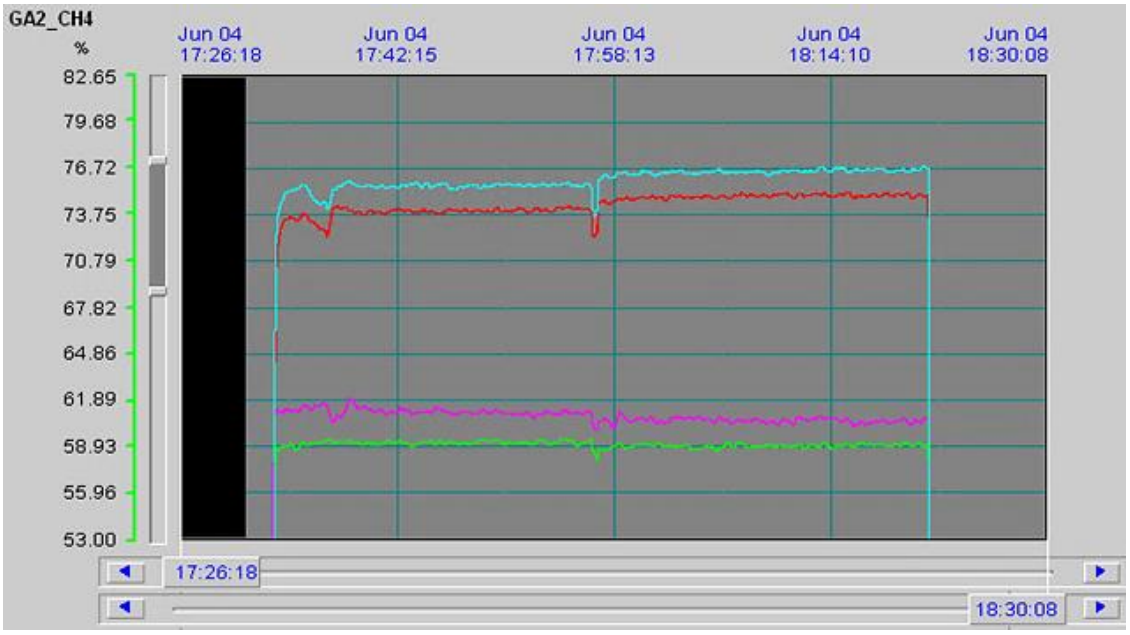


Figure 61: Gas sensor data using both BlueSens sensors, dip at 17:58 is where gas bags were changed from digester 1 to digester 2. The scale is red thusly: blue and red lines measure CO_2 (0-50% scale, divide value to left by 2) purple and green measure CH_4 (0-100%, scale to left is correct).

The second sensor was sent back on May 28th (referred to as *new* sensor). With the knowledge of the gas data from the GC, and the new sensor finally returned, one gas bag at a time was hooked up to both sensors with a splitter to see if they measured the same quality. The new sensor measured the methane content 1.5% higher than the old sensor, at 61.5% (purple line) whereas the old sensor measured 60% (green line) and was only slightly different for each gas bag (difference of ~0.25%. With both measurements showing ~60% for the methane content, and GC measurements ~65% for both with error, I have decided that for any calculations using the gas data, it would be best to use 60% of the biogas as CH_4 – which may be somewhat conservative considering the GC measurements. The differences were small between the digesters with respect to quality of a composite sample and there was so much uncertainty with the gas measurements during the experiment. With independent confirmation of at least 60% CH_4 for each digester, this seemed like a practical solution.

Table 3: Mass balance of the digesters.

	March 6-april 11		April 22-May29	
	Digester1	Digester2	Digester1	Digester2
Total Gas Produced (mL)	481593	499116	514279	522805
gVS Destroyed (gVS in - gVS out)	529	568	544	550
gCOD/gVS (avg) (calculated from COD and VS measurements)	1.28	1.42	1.45	1.58
gCOD Destroyed	677	809	789	869
Biogas mL/gCOD	711	617	651	601
mL CH_4/gCOD (assume 60%)	427	370	391	393
Biogas mL/gVS	910	878	945	950
mL CH_4 /gVS (assume 60%)	546	527	567	570

The mass balance of the digesters was completed for each digester for each phase. Destroyed VS was calculated by multiplying the feed volume by the feed VS%, similarly for the VS out of the

digester. The assumption then that the missing VS was volatilized to biogas. The gCOD/gVS was calculated by taking the COD for each feed divided by its VS%, though the values may be different than the actual (see COD/VS results). The total gas volumes were then divided by the VS destroyed and COD destroyed (gCOD/gVS • gVS-destroyed), to calculate the volume biogas per gram. Since 60% methane content was assumed in the last section, the biogas volumes were multiplied by 0.6.

The focus should be placed on the gas volumes per gram VS, as there were much more reliable measurements for VS than COD. The data shows that for the first phase the CH_4/gVS was lower for the Salsnes reactor, but recall that this sludge was captured at a 100 m^3/m^2hr sieve rate. In the second phase, the gas production per gram VS was roughly the same for both reactors, with a sieve rate of 50 m^3/m^2hr. These results agree with the AMPTS findings as well, where the sieve sludge at a high sieve rate had lower methane potential and roughly the same at the lower sieve rate.

Gas Flow

The gas flow rates of the digesters were collected continuously by the digester system, and while the flow rates are not of main concern, there were some interesting differences between the two. The sediment sludge fed reactor tended to have a more even flow rate, not much in terms of peaks after feeding. The Salsnes digester would have high peaks after feeding, and then the flow rate would tend to drop off at around 20 hours after feeding. The gas flow rates in the two digesters also tended to be out of phase with another, suggesting that substrates were hydrolyzed at different rates. The only way to describe this is through graphs.

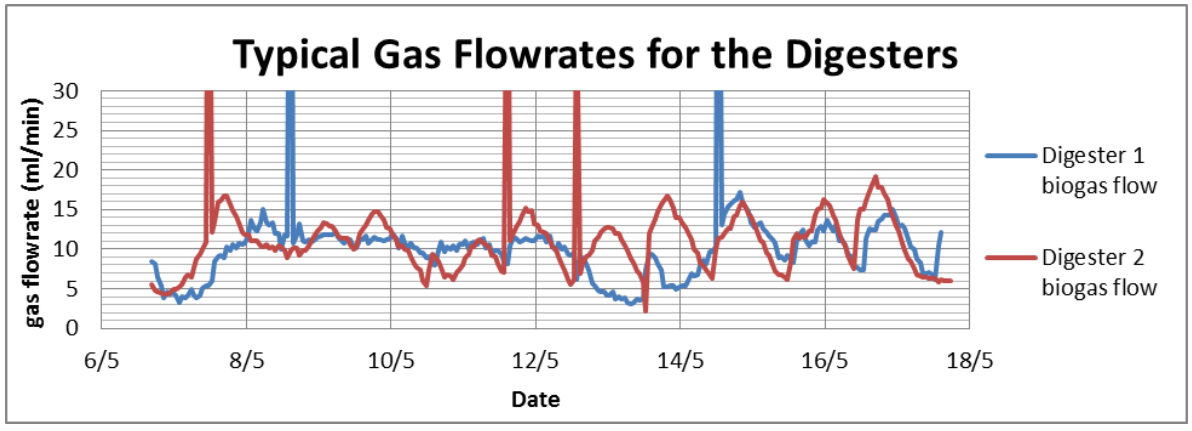


Figure 62: Typical gas flowrate profile for the digesters. The spikes are from the stirring before feeding, which caused high flowrates – data was sampled once hourly which is why this is not seen in regular intervals.

Total volumes in each digester were quite close, especially when normalized for VS loading, but the typical flowrates for each were much different from each other on a daily basis. The Salsnes sludge fed digester always tended to have a peak in gas flowrate around 5-9 hours after feeding, whereas the sediment sludge reactor would tend to have less peaks and a more sustained flow (lower peaks, higher valleys). The reasons for this could be a number of things, for example, hydrolyzation of the sieve sludge could be faster than for the sediment sludge. Another reason

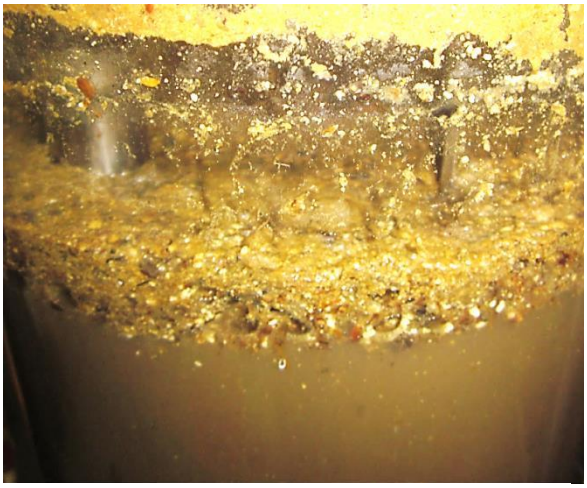


Figure 63: Scum mat on top of the Salsnes fed

could be that the fats contained in the sieve sludge would produce high amounts of gas quickly, and then slow down. One factor that could also be an issue is the scum blanket that covered the top of the reactors (possibly preventing gas from escaping), which was especially prevalent in the Salsnes reactor. This high amount of scum, and the lack of it in the Sediment reactor probably has something to do with how the solids are collected. Since the Salsnes Filter captures all particles, and not just those that settle, more material that floats would be expected in the Salsnes sludge. This scum was always destroyed before feeding, but reformed over night with a slow stirring regime. If this was blocking the gas from escaping, it could explain why there is such a difference in the period of the gas flow between the two reactors. A scum mat would develop on the sediment digester as well, but it was not nearly as pronounced as with the Salsnes. The stirring in of the fats contained in this layer before feeding could explain the large peaks in the gas flowrate immediately after.

6.4 AMPTS Results

The AMPTS was run twice during the duration of the main experiment. The first test was done with sediment sludge and sieve sludge, with the sieve sludge collected with the higher sieve rate. The second test had sieve sludge with a lower sieve rate. See appendix for data – it was found to be confusing to label each individual line (which were averages of triplicates) for this portion.

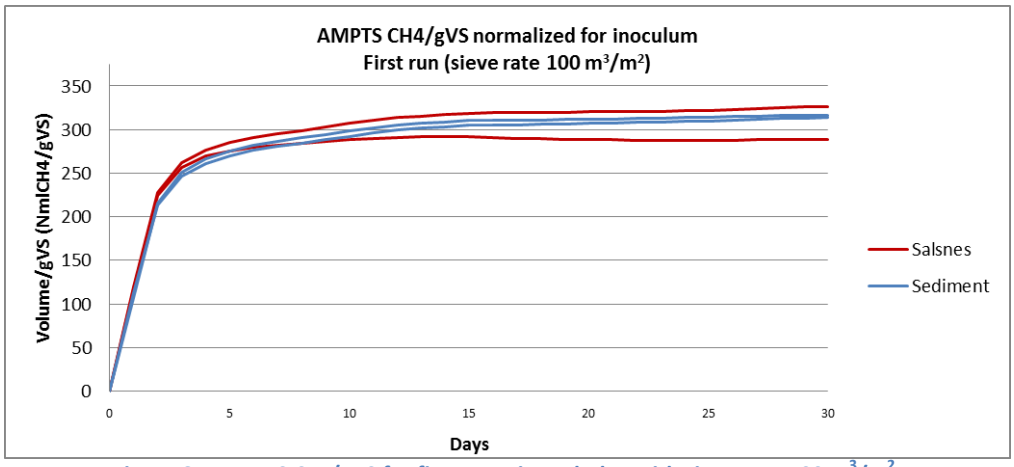


Figure 64: AMPTS CH_4/gVS for first run, sieve sludge with sieve rate 100 m^3/m^2.

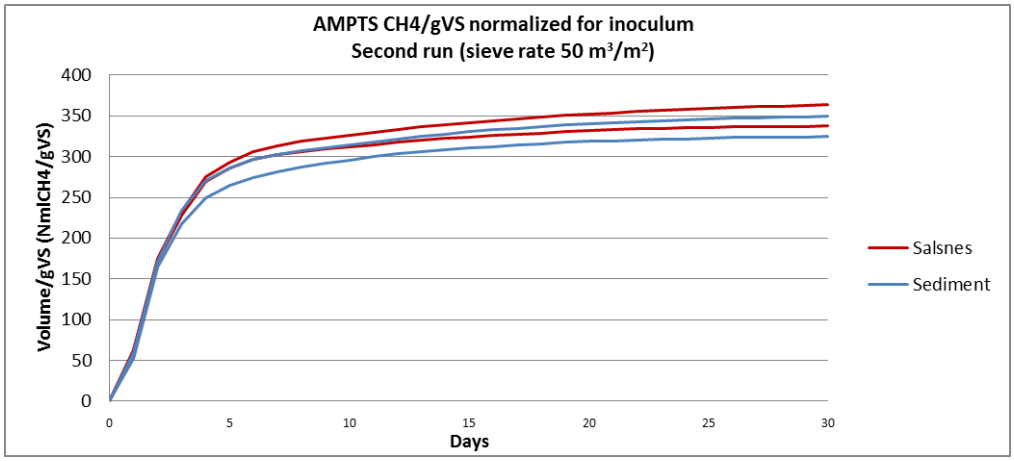


Figure 65:AMPTS CH4/gVS for second run, sieve sludge with sieve rate 50 m3/m2.

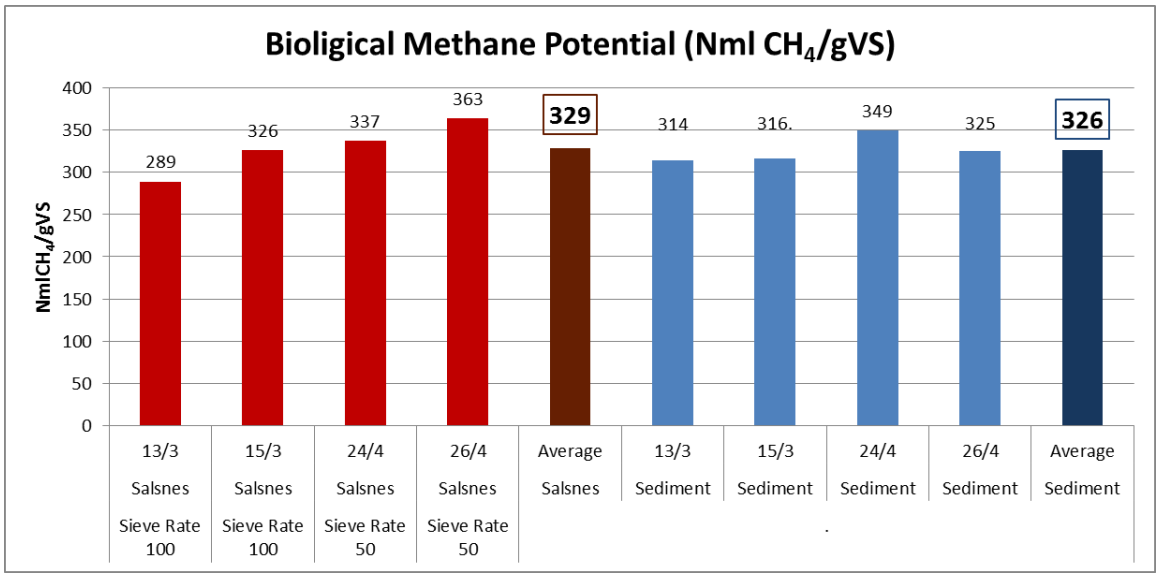


Figure 66: AMPTS BMP results. Triplicates averaged and inoculum subtracted, and volumes normalized for VS.

The AMPTS test for biomethane potential was run twice, each time with two triplicates of two different feed sludges (total of 12 AMPTS reactor vessels for each sludge type). For the first two Salsnes feedstocks tested, the sludge was collected with a sieve rate of ~100 m^3/m^2hr, whereas the second two were collected with a sieve rate of ~50 m^3/m^2hr. It has been shown the lower sieve rate was able to collect fats, and presumably smaller organic particles due to development of a larger filter mat.

The average methane potential for the sludges for all four triplicates were 329 and 326 Nml CH_4/gVS for the Salsnes and Sediment tests respectively, basically no difference. However, what is interesting is that for the second test which included the lower sieve rate sludge, i.e. the 24/4 and 26/4 sieve sludge sludge, the average was 350 NmlCH_4/gVS for sieve sludge and 337 NmlCH_4/gVS for sediment sludge. This result is interesting in that the pilot digesters support the same results – that is, higher methane potential for Salsnes sludge with a low sieve rate.

Comparing the results from phase 1 of Sludge to Energy (not to be confused with first phase of this experiment), there are some similarities and some differences. The first phase found Salsnes sludge to have a mean value of 345 Nml CH_4/gVS, and the mean for sediment sludge 287 Nml

CH_4/gVS. Those results are similar for the Salsnes sludge, especially for the sieve rate of 50 m^3/m^2hr, but the low value for the sediment sludge, 287 Nml CH_4/gVS, suggests that some sediment sludges have somehow different qualities from that collected in the current battery. However, the primary sludge tested from Nodre Follo in the first phase did show a somewhat higher result of 300 Nml CH_4/gVS.

The results from the phase 1, in which sludge was BMP tested from 4 different Salsnes plants around Norway, suggest that these plants were running at lower sieve rates of likely 50 m^3/m^2hr or lower. The significance of this is that plants already outfitted with Salsnes Filters may not have the need to run at such high capacity, suggesting that anaerobic digestion of that sludge may match or even exceed that of sediment sludge.

7. Conclusions

Despite digester failure midway through the experiment, and lack of gas sensors for nearly the entire experiment, some very valuable information was gained. The digesters were run for a significant amount of time and it was clear that the produced gas was due to the substrate and not from residual solids found in the inoculum. Although in each run neither digester made it to true steady state (which would require 3 times the HRT), the data found agreed with the data collected from the first phase of the Sludge to Energy project, and independent AMPTS tests in the current experiment.

The main conclusion that can be drawn is that sludge collected by Salsnes Filters is able to be digested just as well or slightly better than sedimentation sludge (with respect to VS reduction), however, the sieve rate in which the filters are run have a significant effect on the production. With a high sieve rate, as was tested in the first half of this experiment, the sludge produced less total gas with respect to the volatile solids destroyed – this makes sense as a thick filter mat was not able to be formed, which is in part the basis of the performance of the filters. This point is also supported by results in the AMPTS. It could be reasonably expected that if the filter sieve rate was lowered even more, more fine material and fat would be collected by the filter, and subsequently produce more methane gas. This is both good and bad for the Salsnes if methane potential would be used as a selling point, since lower sieve rate means there is a need for more and/or larger filters which increase the capital costs to municipalities. However, judging from the AMPTS data in the first phase, and from personal experience at the plants, most are running at or below this sieve rate already (producing much thicker filter mats than I have ever experienced during this experiment).

There are other benefits that the Salsnes Filters have over sedimentation basins, which may not have to do directly with gas production, but with overall energy usage in a plant. Since the filters have been shown to capture a high proportion of cellulose, it can reduce this slowly biodegradable load into an aerobic treatment regime. Also, because of the smaller footprint, the filters can save money and increase capacity of a plant by replacing existing sedimentation basins, which could feasibly be converted into extra aerobic treatment tanks. The higher VS% of TS in the Salsnes sludge means that less inorganics make it directly into anaerobic tanks, lowering the undigestable solids and potentially increasing capacity in that respect (though those solids must go somewhere). If the gas production is the same or potentially better than with sedimentation sludge, these are all winning characteristics of the filters.

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Appendix

Timeline of the experiment

This section should be read after the reader is familiar with the experiment and design. This is basically to show the rationale and explanation for the methods used and decisions that were made. It is not intended to be read scientifically, but rather as an explanation and description of what actually happened.

January 7th I arrived in Oslo, and started researching the equipment that I was to be using in the experiment. The Dolly digester had not been used for a few years and was in pieces after the last time it was shipped, so it needed a lot of work to get it running and all of the pieces put together. The BlueSens sensors were checked at this time, and were found to be registering some concentrations of gas, but no certified gasses were available to check the calibration, so it was assumed that they were working as they would register CO_2 if air was blown into them (breath).

In the beginning of February, Geir Haugen, a representative from Salsnes arrived in Oslo for installation of the filter. The filter was in the back of his van, which caused it to sit very low to the ground. It took 4 men and a forklift to move it into place (in pieces). The installation of the filter went smoothly, but it turned out that Nodre Follo had no 400V outlets, so nothing could be turned on or tested until a transformer arrived from Namsos. After this was finally taken care of, the magnetic flow meter was not working, and it took several days to find out that it was due to a loose wire inside of the unit itself.

Around February 12th, I was able to get the filter running, with the help of a 20-25kg submersible pump that had to be lifted over a railing and down into the influent water (and taken out, daily). Attached to the pump was a hose that went directly to the filter, pumping at about 12 L/s – way more than the filter could handle. I went to TESS, a plumbing store, and bought a new hose, some valves, and camlock connectors so I could easily attach the hose to the pump without all of the weight. Around the 18th of the month I was finally able to run the filter normally, but the factory settings were not what I was expecting. The filter would move entirely too quickly and prevent any filter mat from forming. Luckily, a technician was able to help me over the phone and the filter started running at what I considered normal (from my internship at Salsnes).

February 15th, I finally had all of the equipment in place, and I went to retrieve seed sludge. I filled the reactors, and started up the Dolly program. Heating had not been a problem when I had it filled with water, but I found out quickly that the temperature would drop with low stirring speed and the thick sludge – so this was adjusted. Gas was being measured for both flow and for quality, but soon it was evident that 58.5% CH_4 and 47% CO_2 was probably not correct – and this was the case for both sensors despite one never being used before.

On February 18th, I had the first feedstocks made. I had measured the solids, but the Salsnes solids were much thicker than the sediment sludge (1.68% vs. 2.91%). I fed this anyway to the digester, as I didn't know any better. As I was trying for a 15 day HRT/SRT, I fed the reactor with 1.3L of the sludge, but this was startup so it was advised to feed less than the full feed amount. A few hours later, the gas sensors showed a spike in CO_2 above measureable range, so it was decided to stop feeding for a few days (it was the sensors not the feeding that was the problem).

It became apparent that there needed to be a better way to make the solids even. I first started by diluting by pouring in raw wastewater, but this was, of course, not accurate. On the 27th of February, I started to measure the solids for VS the day before and then have a dilution factor – this worked well. At the same time it became clear that there would need to be duplicate measurements in order to be more accurate. At this time I was not using an Ultra Turrax to emulsify the sludge, as the lab I was working in at Nodre Follo was directly next to offices and the lunch room, and hot *dritt* does not smell that good. The lab at the plant was also very small, so it was hard to get good measurements and an accurate scale. By March 6th I was doing duplicate samples for all feed sludge related samples, and dilutions were calculated by VS ratio.

Each day at the plant, I would have several tasks. These included collecting a 25 L container of 1.2% solids sediment sludge, running the filter to collect sieve sludge, TS/VS of sediment and sieve sludge, COD, feeding the digesters, and then performing VOA, and Alkalinity measurements on the digested sludge as well as TS/VS. It became unbearable to do these tests at the plant because it was clear that they were not so happy with me emulsifying sludge while eating their lunch or coffee break. Also, the scales available there were manual, not digital, so weighing was very tedious.

Around the end of March, the digesters began to upset, with acid levels rising. My adviser advised to start adding baking soda to neutralize the acids, so this was done. Doing so without knowing what I was actually doing masked the problem that the digesters were beginning to sour, since the VOA/ALK ratios were below the threshold of 0.3. This continued into April, and by the middle of the month, the digesters had failed. The cause, which is supported in literature, is that I was flushing bacteria out of the reactor faster than they could grow (since the feeds were so dilute, there was not enough bacteria to keep up with the high feeding rate since methanogens grow so slowly).

On April 5 the VOA concentration spiked to about 5 times the normal amount. Baking soda was added to keep the ratio high, but this made the pH spike. At this point, I was panicking, and started adding baking soda at high enough levels that the volatilized solids from the digestate started looking like table evaporated sea salt. All of the rapid changes in pH, added to flushing of the bacteria, basically killed the reactor. The acid forming bacteria, being much hardier, were doing fine, but the methanogens had all died off, so there was nothing to keep the acids in check. By April 15, it was clear that there was no saving the reactors, so I decided to reseed.

I did not waste any time, and April 16, I got more seed sludge from Søndre Follo. This time I knew what I was doing, so I mixed the seed sludge with 20% of each of the reactor volumes and also diluted with wastewater to the VS concentration that was in the digester before they started to fail. The rationale was to keep some of the acclimated bacteria (acid formers) in the new sludge so getting to steady state would take much less time. This seemed to work very well.

Through discussion with my advisor and with people from Salsnes, I decided to make a few changes for the next part of the experiment – basically having two experiments (phases) for the duration. One major change was to reduce the feeding to 1 L/day, which meant a HRT/SRT of about 23 days (since I would take off Sundays). The other major change was to change the flowrate (sieve rate) through the Salsnes filter. I decided to slow the flow to half of what it was

running, which translates in a drop in sieve rate from about 100 to 50 m^3/m^2hr. When the sieve rate was dropped, there was noticeably more filter mat being developed, with more visible fine material and color on the filter – unfortunately this is basically impossible to take pictures of. In retrospect, I wish I had slowed down the flowrate even more, because the filter was still moving faster than I had typically experienced while in Namsos – the filter mat was never as thick as I would have liked it.

After April 16th, the digester had been running splendidly, the only problem being that it only left 6-7 weeks of experimentation time left. It was at this time the whole experiment began to make sense and come together. I started running COD and my TS/VS for feeds in triplicates instead of duplicates, and I began taking all of the sludge back to the Aquateam lab instead of the Nodre Follo lab – this drastically increased consistency of everything.

One of the gas sensors *finally* arrived on the 25th of April, after waiting '3 weeks' since the middle of February (the other sensor was still not working correctly and that didn't arrive until May 28th, the last day of feeding for the experiment *after* I got back from the plant). Finally there was some gas quality data to look at, but unfortunately it could only be hooked up to one reactor at a time. This was done, and results were interesting. After independent analysis of the gas, it was shown that the sensors were still not extremely accurate, but they were pretty close – they are better used to see daily fluctuations in gas concentrations, and should not be used for calculations (though it had been strongly requested that I do so anyway). In the future, I feel it would only be necessary to measure CH_4, since the rest is basically CO_2 and maybe some other minor concentrations of gas.

The last few weeks I decided I needed to maximize the amount of data I could collect, so I started feeding every day possible. This obviously changes the HRT from what was done before, but it seemed better than just waiting. This was a good time for the reactor to run continuously, and it is clear that they were performing well at this time through VOA/ALK and VS measurements of the digestate.

The experiment ended May 28, only because I had to take an exam in Stavanger and would be gone several days. I would have liked to run it further, but all good things must come to an end.

Feedstock Preparation and dilution calculations

	Sedimentation basin feed								Salsnes Filter feed									Salsnes Raw sludge - pre-dilution									Feedstock preparation				
date	Dish	Sample+ Dish	Dried Sample + Dish	Volatized Sample + Dish	TS	VS	VS% of TS	Average VS	Date	Dish	Sample+ Dish	Dried Sample + Dish	Volatized Sample + Dish	TS	VS	VS% of TS	Average VS	Feed date (Sed and Sals feed)	Date	Dish	Sample+ Dish	Dried Sample + Dish	Volatized Sample + Dish	TS	VS	VS% of TS	Average VS	Salsnes Dilution ratio	Volume of feed to produce (L)	Salsnes Raw Vol	Wastewater Volume	VS/VS SED/SALSNES Feed ratio
15/2/2013	1.907	46.677	2.764	2.0134	1.91%	1.68%	87.58%	1.68%	15/2/13	1.911	61.085	3.759	2.0366	3.12%	2.91%	93.20%	2.91%	#N/A	22/02/13	2.07	78.15	4.55	2.24	3.26%	3.04%	93.15%	3.04%					57.6%
18/2/2013	1.8	24.4	2.49	2.17	3.05%	1.42%	46.38%	1.42%	18/2/13	1.8	31.03	2.6	2.17	2.74%	1.47%	53.75%	1.47%	18,	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A					96.3%
19/2/2013	1.8	42.65	2.57	1.97	1.88%	1.47%	77.92%	1.47%	19/2/13	1.8	35.235	2.14	1.9	1.02%	0.72%	70.59%	0.72%	19,	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A					204.6%
22/2/2013	1.77	35.55	2.36	1.87	1.75%	1.45%	83.05%	1.45%	22/2/13	1.77	42.83	2.51	1.85	1.80%	1.61%	89.19%	1.61%	22,	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A					90.2%
25/2/2013	1.9	53.48	2.8	2.11	1.74%	1.34%	76.67%	1.34%	25/2/13	1.9	43.06	3.01	1.99	2.70%	2.48%	91.89%	2.48%	25,	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A					54.0%
26/2/2013	1.91	44.36	2.83	2.04	2.17%	1.86%	85.87%	1.86%	26/2/13	1.9	42.41	2.84	1.93	2.32%	2.25%	96.81%	2.25%	26, 27	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A					82.8%
27/2/2013	1.84	53.07	3.04	2.03	2.34%	1.97%	84.17%	1.97%	28/2/13	1.9	51.82	3.16	2.05	2.52%	2.22%	88.10%	2.22%	28, 1	27/2/2013	1.89	50.35	3.86	2.14	4.07%	3.55%	87.31%	3.55%	56%		2.78	2.22	88.7%
1/3/2013	1.87	48.24	2.82	2.14	2.05%	1.47%	71.58%	1.47%	4/3/13	1.9	59.36	2.83	1.97	1.62%	1.50%	92.47%	1.50%	4,	1/3/2013	1.87	56.38	3.72	2.01	3.39%	3.14%	92.43%	3.14%	47%		2.34	2.66	98.0%
4/3/2013	1.9	59.13	3.06	2.14	2.03%	1.61%	79.31%	1.61%	5/3/13	1.9	54.82	2.7	1.95	1.51%	1.42%	93.75%	1.42%	5,6	4/3/2013	1.9	54.88	3.88	2.02	3.74%	3.51%	93.94%	3.51%	48.8%	5.00	2.44	2.56	113.4%
4/3/2013																				1.9	54.94	3.67	2.04	3.34%	3.07%	92.09%	3.07%					
6/3/2013	1.88	61.59	3.16	2.1	2.14%	1.78%	82.81%	1.78%	7/3/13	1.9	66.77	3.25	2.03	2.08%	1.88%	90.37%	1.81%	7,8	6/3/2013	1.9	46.82	3.32	2.02	3.16%	2.89%	91.55%	2.84%	62.5%	5.00	3.12	1.88	98.0%
6/3/2013	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A				1.9	52.39	2.88	2	1.94%	1.74%	89.80%				1.9	52.46	3.47	2.06	3.11%	2.79%	89.81%					
8/3/2013	1.89	58.24	3.23	2.18	2.38%	1.86%	78.36%	1.88%	11/3/13	1.9	52.92	2.95	1.99	2.06%	1.88%	91.43%	1.92%	11,12	8/3/2013	1.9	63.63	3.81	2.05	3.09%	2.85%	92.15%	2.84%	66.0%	5.00	3.30	1.70	97.7%
8/3/2013	1.9	62.66	3.37	2.22	2.42%	1.89%	78.23%			1.9	61.45	3.19	2.02	2.17%	1.96%	90.70%				1.9	59.67	3.68	2.04	3.08%	2.84%	92.13%					
12/3/2013	1.8945	68.2128	3.646	2.185	2.64%	2.20%	83.41%	2.27%	13/3/13	1.9103	63.818	3.4865	2.004	2.55%	2.39%	94.06%	2.39%	13,14	12/3/2013	1.894	55.3645	3.6882	2.0042	3.36%	3.15%	93.86%	3.14%	72.2%	5.00	3.61	1.39	94.8%
	1.915	64.0267	3.63	2.1803	2.76%	2.33%	84.53%			1.886	62.961	3.4367	1.9776	2.54%	2.39%	94.09%				1.92	52.5534	3.5898	2.0006	3.30%	3.14%	95.17%					
14/3/13	1.9075	57.0725	3.3611	2.1416	2.64%	2.21%	83.90%	2.29%	15/3/13	1.904	62.545	3.4306	2.0105	2.52%	2.34%	93.02%	2.38%	15,16	14/3/2013	1.89	60.6096	3.9227	2.027	3.46%	3.23%	93.26%	3.24%	70.7%	5.00	3.53	1.47	96.2%
	1.904	61.735	3.5832	2.1676	2.81%	2.37%	84.30%			1.91	68.94	3.6455	2.0277	2.59%	2.41%	93.22%				1.91	64.3492	4.0857	2.057	3.48%	3.25%	93.24%					
15/3/13	1.905	67.36	3.7893	2.2253	2.88%	2.39%	83.00%	2.40%	18/3/13	1.8863	54.5584	3.3084	2.0405	2.70%	2.41%	89.16%	2.47%	18,19	15/3/2013	1.91	60.345	4.0435	2.1575	3.65%	3.23%	88.40%	3.33%	72.1%	5.00	3.61	1.39	97.2%
	1.8905	67.1975	3.8	2.224	2.92%	2.41%	82.53%			1.9106	57.8708	3.4994	2.0803	2.84%	2.54%	89.32%				1.9105	75.447	4.7523	2.2307	3.86%	3.43%	88.73%					
19/3/13	1.8743	53.7872	3.3795	2.1411	2.90%	2.39%	82.27%	2.40%	20/3/13	1.865	50.546	3.0964	1.9506	2.53%	2.35%	93.05%	2.38%	20,21	19/3/2013	1.8785	70.255	4.2287	2.0149	3.44%	3.24%	94.20%	3.28%	73.1%	5.00	3.65	1.35	100.8%
	1.9	64.2352	3.7248	2.2254	2.93%	2.41%	82.17%			1.874	48.429	3.0689	1.953	2.57%	2.40%	93.39%				1.8843	64.26	4.0835	2.0137	3.53%	3.32%	94.12%					
21/3/13	1.885	66.7724	3.5103	2.0867	2.50%	2.19%	87.59%	2.20%	22/3/13	1.9057	48.3634	2.8416	1.9683	2.01%	1.88%	93.31%	1.94%	22,23	21/3/2013	1.9043	60.572	4.0835	2.0316	3.71%	3.50%	94.16%	3.49%	63.0%	5.00	3.15	1.85	113.2%
	1.8702	57.5916	3.2742	2.0491	2.52%	2.20%	87.26%			1.9083	56.7904	3.0848	1.9875	2.14%	2.00%	93.27%				1.8855	75.3426	4.594	2.0389	3.69%	3.48%	94.34%					
22/3/13	1.9147	59.0908	3.37	2.0999	2.55%	2.22%	87.27%	2.25%	25/3/13	1.8682	61.0809	3.3258	1.956	2.46%	2.31%	93.98%	2.27%	25,26	22/3/2013	1.9019	57.7616	3.872	2.0079	3.53%	3.34%	94.62%	3.34%	67.4%	5.00	3.37	1.63	99.1%
	1.8995	61.8136	3.463	2.0999	2.61%	2.28%	87.18%			1.8753	62.3072	3.3075	1.9632	2.37%	2.22%	93.86%				1.8916	67.6602	4.218	2.024	3.54%	3.34%	94.31%					
26/3/13	1.8533	60.1707	3.1803	2.0589	2.28%	1.92%	84.51%	1.91%	27/3/13	1.8715	58.4978	3.0585	1.9483	2.10%	1.96%	93.53%	1.97%	27,28	26/3/2013	1.863	59.33	3.844	1.997	3.45%	3.21%	93.24%	3.26%	58.8%	5.00	2.94	2.06	97.1%
	1.8492	52.1523	2.9853	2.0276	2.26%	1.90%	84.30%			1.8776	64.6392	3.2078	1.964	2.12%	1.98%	93.50%				1.8645	56.1653	3.7736	1.9829	3.52%	3.30%	93.80%					
28/3/13	1.8786	55.787	3.274	2.1383	2.59%	2.11%	81.39%	2.11%	29/3/13	1.8702	58.3724	3.0718	1.962	2.13%	1.96%	92.36%	2.07%	29,30,1,2,3	28/3/2013	1.8763	61.8224	4.0477	2.0347	3.62%	3.36%	92.71%	3.45%	61.1%	8.00	4.89	3.11	101.9%
	1.8718	60.93	3.401	2.1558	2.59%	2.11%	81.43%			1.886	64.6671	3.3566	1.9919	2.34%	2.17%	92.80%				1.8824	59.118	4.0761	2.0476	3.83%	3.54%	92.47%					
3/4/13	1.9055	59.6308	3.3755	2.1709	2.55%	2.09%	81.95%	2.10%	5/4/13	1.8798	55.925	3.1468	1.9855	2.34%	2.15%	91.66%	2.25%	4,5,6	2/4/2013	1.883	63.8243	4.0207	2.0546	3.45%	3.17%	91.97%	3.14%	66.7%	7.00	4.67	2.33	93.2%
	1.9052	53.2283	3.2253	2.1458	2.57%	2.10%	81.77%			1.882	51.274	3.139	1.9803	2.54%	2.35%	92.18%				1.9124	56.3552	3.7525	2.0597	3.38%	3.11%	92.00%					
5/4/13	1.8697	60.6381	3.1276	2.0385	2.14%	1.85%	86.58%	1.87%	8/4/13	1.8821	58.8146	3.0925	1.9665	2.13%	1.98%	93.03%	1.93%	8,9	5/4/2013	1.87	59.8538	4.2903	2.0312	4.17%	3.90%	93.34%	3.76%	49.7%	6.00	2.98	3.02	96.7%
	1.8731	61.9728	3.1787	2.0466	2.17%	1.88%	86.71%			1.8765	56.2828	2.9828	1.9554	2.03%	1.89%	92.87%				1.876	58.5849	4.0796	2.0219	3.89%	3.63%	93.38%					
9/4/13	1.8692	64.493	3.5218	2.0818	2.64%	2.30%	87.14%	2.27%	10/4/13	1.876	66.0895	3.4864	1.9661	2.51%	2.37%	94.41%	2.33%	10,11	9/4/2013	1.8702	65.895	4.115	1.988	3.51%	3.32%	94.75%	3.22%	70.6%	6.00	4.23	1.77	97.6%
	1.8799	61.5642	3.4114	2.0695	2.57%	2.25%	87.62%			1.8817	64.5573	3.4033	1.967	2.43%	2.29%	94.39%				1.8799	61.5642	3.863	1.9987	3.32%	3.12%	94.01%					
11/4/13	1.8769	53.6165	3.279	2.1855	2.71%	2.11%	77.99%	2.16%	12/4/13	1.87	55.501	3.3109	2.1595	2.69%	2.15%	79.91%	2.20%	12	11/4/2013	1.864	60.1365	4.0444	2.2397	3.74%	3.10%	82.77%	3.11%	69.5%	6.00	4.17	1.83	98.2%
	1.8688	54.2996	3.3387	2.1828	2.80%	2.20%	78.64%			1.8829	59.5769	3.4943	2.1958	2.79%	2.25%	80.58%				1.8781	62.748	4.1639	2.2688	3.76%	3.11%	82.91%					
12/4/13	1.8788	54.306	3.1872	2.166	2.50%	1.95%	78.05%	1.92%	15/4/13	1.8965	53.8211	2.9636	1.9735	2.06%	1.91%	92.78%	1.92%	15,16,17,18	12/4/2013	1.8715	55.423	3.73	2.0049	3.47%	3.22%	92.82%	3.21%	59.6%	7.00	4.17	2.83	99.9%
	1.8674	51.2797	3.082	2.1516	2.46%	1.88%	76.60%			1.8636	60.3986	3.0776	1.9493	2.07%	1.93%	92.94%				1.8736	55.33	3.7067	1.9945	3.43%	3.20%	93.40%					
18/4/13	1.879	57.0382	3.6067	2.14	2.78%	2.38%	85.36%	2.48%	19/4/13	1.8786	56.8465	4.636	3.2739	5.02%	2.48%	49.40%	2.48%	19,20	18/4/2013	1.8885	63.6292	6.5959	4.3674	7.62%	3.61%	47.34%	3.58%	69.3%	5.00	3.46	1.54	100.0%
	1.858	58.9086	3.659	2.1494	3.03%	2.58%	85.26%			1.8742	53.2481	4.4241	3.1503	4.96%	2.48%	49.95%				1.8884	60.3435	6.3578	4.2844	7.65%	3.55%	46.39%					
19/4/13	1.8838	57.0052	4.357	2.7114	4.49%	2.99%	66.54%	2.97%	22/4/13	1.8572	56.4101	3.7438	2.1755	3.46%	2.87%	83.13%	2.89%	22,23	19/4/2013	1.8792	57.0713	4.4433	2.3122	4.65%	3.86%	83.11%	3.91%	76.0%	7.00	5.32	1.68	102.8%
	1.8791	53.4518	4.1739	2.6461	4.45%	2.96%	66.58%			1.8602	56.6085	3.7804	2.1854	3.51%	2.91%	83.06%				1.8745	64.311	4.8444	2.3702	4.76%	3.96%	83.31%					
23/4/13	1.8671	57.1982	3.5475	2.1127	3.04%	2.59%	85.38%	2.61%	24-Apr	1.8676	64.0391	3.6205	2.009	2.82%	2.59%	91.93%	2.60%	24,25	23/4/2013	1.8875	66.9182	4.6559	2.0801	4.26%	3.96%	93.04%	3.96%	66.0%	6.00	3.96	2.04	100.6%
	1.8642	57.6603	3.5818	2.1147	3.08%	2.63%	85.42%			1.8632	52.313	3.2888	1.9766	2.83%	2.60%	92.05%				1.8694	66.1793	4.6073	2.062	4.26%	3.96%	92.97%					
25/4/13	1.859	58.3098	3.6726	2.1174	3.21%	2.75%	85.75%	2.75%	25-Apr	1.8855	57.3789	3.4488	1.9856	2.82%	2.64%	93.60%	2.66%	26,27	25/4/2013	1.8694	54.0765	3.7999	1.9884	3.70%	3.47%	93.84%	3.51%	78.5%	6.00	4.71	1.29	103.7%
	1.8424	57.3756	3.625	2.0951	3.21%	2.75%	85.82%			1.8647	57.0972	3.4428	1.9653	2.86%	2.68%	93.63%				1.86	67.5523	4.3401	2.0104	3.78%	3.55%	93.94%					
27/4/13	1.8786	63.5934	3.6621	2.1594	2.89%	2.43%	84.26%	2.46%	29-Apr	1.897	58.66	3.467	2.0336	2.77%	2.53%	91.30%	2.54%	29,30,1	27/4/2013	1.8676	62.463	4.4256	2.112	4.22%	3.82%	90.45%	3.80%	64.7%	6.00	3.88	2.12	97.0%
	1.8908	61.4521	3.6458	2.1638	2.95%	2.49%	84.44%			1.897	62.344	3.5807	2.0398	2.79%	2.55%	91.52%				1.8653	60.595	4.3272	2.1042	4.19%	3.79%	90.30%					
30/4/13	1.8863	56.9513	3.628	2.1861	3.16%	2.62%	82.79%	2.67%	2-May	1.8964	57.9756	3.6368	2.1903	3.10%	2.58%	83.11%	2.60%	2,3,4	30/4/2013	1.893	67.8623	5.2276	2.4809	5.05%	4.16%	82.37%	4.20%	63.6%	6.00	3.81	2.19	102.6%
	1.8826	61.9808	3.8365	2.2034	3.25%	2.72%	83.58%			1.8943	56.5146	3.6109	2.1804	3.14%	2.62%	83.33%				1.8937	64.8155	5.1152	2.4542	5.12%	4.23%	82.60%					
4/5/13	1.8544	52.4885	3.342	2.0555	2.94%	2.54%	86.48%	2.58%	6-May	1.8772	62.1932	3.5439	2.0117	2.76%	2.54%	91.93%	2.58%	6,7,8	4/5/2013	1.8908	57.6846	3.7303	2.0409	3.30%	3.03%	91.84%	3.10%	0.833352369	6.00	5.00	1.00	100.1%
	1.8517	59.1526	3.5714	2.0764	3.00%	2.61%	86.93%			1.8853	61.345	3.5598	2.019	2.82%	2.59%	92.02%				1.8734	57.9892	3.7397	2.0207	3.33%	3.06%	92.11%					
	1.8524	57.2215	3.5022	2.0676	2.98%	2.59%	86.96%			1.869	59.0502	3.4853	1.9989	2.83%	2.60%	91.96%				1.8946	51.1645	3.6009	2.0255	3.46%	3.20%	92.33%					
8/5/13	1.8635	53.9503	3.3217	2.0547	2.80%	2.43%	86.89%	2.44%	9-May	1.8898	62.0636	3.3788	2.0054	2.47%	2.28%	92.24%	2.31%	9,10,11,12	8/5/2013	1.898	62.674	4.1816	2.0612	3.76%	3.49%	92.85%	3.52%	0.692947287	6.00	4.16	1.84	105.5%
	1.868	53.825	3.33	2.0751	2.81%	2.42%	85.83%			1.896	58.6026	3.333	2.0071	2.53%	2.34%	92.27%				1.8923	68.2872	4.4322	2.0751	3.83%	3.55%	92.80%					
	1.892	52.415	3.3125	2.0618	2.81%	2.48%	88.05%			1.8993	57.1171	3.291	2.009	2.52%	2.32%	92.12%				1.8703	71.304	4.5123	2.0618	3.81%	3.53%	92.75%					
11/5/13	1.8794	57.5972	3.6786	2.1619	3.23%	2.72%	84.30%	2.74%	13-May	1.9097	65.1492	3.8561	2.0659	3.08%	2.83%	91.97%	2.83%	13,14,15,16	11/5/2013	1.8874	67.2535	3.9399	2.0535	3.14%	2.89%	91.91%	2.89%	0.950151163	6.32	6.00	0.32	96.8%
	1.8666	62.7346	3.8186	2.1725	3.21%	2.70%	84.33%			1.9061	56.1741	3.5933	2.0406	3.11%	2.86%	92.03%				1.8965	67.0282	3.9537	2.0628	3.16%	2.90%	91.92%					
	1.8912	66.1034	4.0215	2.2199	3.32%	2.81%	84.57%			1.8862	64.5072	3.8041	2.0426	3.06%	2.81%	91.85%				1.864	70.2435	4.005	2.0391	3.13%	2.87%	91.82%					
15/5/13	1.8776	64.5699	3.5253	2.1512	2.63%	2.19%	83.40%	2.22%	18-May	1.8805	61.4311	3.3095	1.9896	2.40%	2.22%	92.37%	2.22%	18,19,20,21	15/5/2013	1.8865	63.7261	3.9534	2.0412	3.34%	3.09%	92.52%	3.18%	69.99%	6.00	4.20	1.80	100.0%
	1.8733	64.2256	3.5493	2.1468	2.69%	2.25%	83.68%			1.8522	55.4332	3.1368	1.9494	2.40%	2.22%	92.43%				1.8721	63.6051	3.9968	2.0304	3.44%	3.19%	92.55%					
	1.878	61.532	3.4616	2.1321	2.65%	2.23%	83.95%			1.8604	58.2679	3.2209	1.9602	2.41%	2.23%	92.66%				1.8749	56.6588	3.7962	2.0149	3.51%	3.25%	92.71%					
21/5/13	1.9015	59.7695	3.3975	2.0778	2.59%	2.28%	88.22%	2.25%	22-May	1.8658	59.4437	3.3551	2.0594	2.59%	2.25%	87.00%	2.21%	22,23,24	21/5/2013	1.8958	53.4948	3.5598	2.1047	3.22%	2.82%	87.45%	2.81%	80.16%	7.00	5.61	1.39	101.7%
	1.8982	56.4053	3.2833	2.061	2.54%	2.24%	88.25%			1.8833	55.3766	3.2244	2.06	2.51%	2.18%	86.82%				1.9047	62.8	3.8755	2.1511	3.24%	2.83%	87.50%					
	1.8968	50.0807	3.1174	2.0429	2.53%	2.23%	88.03%			1.8824	58.4064	3.3179	2.0675	2.54%	2.21%	87.11%				1.8858	50.1375	3.4173	2.0795	3.17%	2.77%	87.35%					
23/5/13	1.8997	62.378	3.8048	2.2158	3.15%	2.63%	83.41%	2.64%	25-May	1.8648	55.3836	3.4245	2.075	2.91%	2.52%	86.52%	2.55%	25,26,27,28		1.8861	55.2878	4.03881	2.166	4.03%	3.51%	87.00%	3.52%	0.75172782	6.00	4.51	1.49	103.6%
	1.879	63.4465	3.8234	2.2011	3.16%	2.63%	83.43%			1.8782	58.4616	3.5313	2.0983	2.92%	2.53%	86.69%				1.887	58.5413	4.2	2.2026	4.08%	3.53%	86.36%					
	1.8724	60.045	3.73	2.1785	3.19%	2.67%	83.52%			1.86	57.7168	3.5248	2.0745	2.98%	2.60%	87.12%				1.8976	63.3509	4.4018	2.2413	4.07%	3.52%	86.28%					

Feeding Schedule And Mass Balance

	Feeding amount		Digester 1 (Sediment)										Digester 2 (Salsnes)									
			Feed										Feed						Removed			
Date	Feed amount (L)	Removal Amount (L)	TS%	VS%	COD of feed mg/l (average)	VS Loading (mg/l*day)	VS (g/day)	COS/VS ratio	TS%	VS%	VS% Reduction	g VS removed	grams VS Destroyed (as Gas)	TS%	VS%	COD of feed mg/l (average)	VS Loading (mg/l*day)	VS (g/day)	COD/VS ratio	TS%	VS%	VS% Reduction	g VS removed	grams VS destroyed
	1.3	1.3	3.05%	1.42%	25980	14159	18.41		3.16%	#N/A		#N/A	#N/A	2.74%	1.47%	35120	14711	19.12		3.36%	#N/A			19.12
19-Feb	1.8	1	1.88%	1.47%	#N/A	14688	26.44		2.15%	1.09%		10.9	15.52	1.02%	0.72%	#N/A	7178	12.92		2.12%	1.07%		10.74948	2.17
22-Feb	0.6	0.6	1.75%	1.45%	#N/A	14506	8.70		#N/A	#N/A		#N/A	#N/A	2.70%	1.80%	#N/A	18022	10.81		#N/A	#N/A		#N/A	#N/A
25-Feb	1	1	1.74%	1.34%	#N/A	13377	13.38		#N/A	#N/A		#N/A	#N/A	2.70%	2.48%	#N/A	24781	24.78		#N/A	#N/A		#N/A	#N/A
26-Feb	1	1	2.17%	1.86%	21820	18610	18.61	1.17	2.15%	1.24%		12.4	6.26	2.32%	2.25%	29260	22464	22.46	1.30	2.12%	1.21%		12.13347	10.33
27-Feb	1.3	1.3	2.17%	1.86%	24740	18610	24.19	1.33	2.07%	1.09%		14.2	10.01	2.32%	2.25%	28620	22464	29.20	1.27	2.03%	1.10%		14.28571	14.92
28-Feb	1.3	1.3	2.34%	1.97%	24740	19715	25.63	1.25	1.94%	1.17%		15.2	10.47	2.52%	2.22%	28620	22236	28.91	1.29	2.05%	1.23%		15.95264	12.95
1-Mar	1.3	1.3	2.34%	1.97%	#N/A	19715	25.63		1.73%	1.08%		14.0	11.64	2.52%	2.22%	#N/A	22236	28.91		1.79%	1.05%		13.6744	15.23
4-Mar	1.3	1.3	2.05%	1.47%	25120	14665	19.06	1.71	1.88%	1.20%		15.6	3.51	1.62%	1.50%	19750	14967	19.46	1.32	2.08%	1.34%		17.44472	2.01
5-Mar	1.8	1.8	2.03%	1.61%	20960	16075	28.94	1.30	1.85%	1.12%		20.2	8.71	1.51%	1.42%	17100	14172	25.51	1.21	1.81%	1.11%		20.03976	5.47
6-Mar	1.8	1.8	2.03%	1.61%	20960	16075	28.94		1.88%	1.19%		21.4	7.49	1.51%	1.42%	17100	14172	25.51		1.76%	1.10%		19.74578	5.76
7-Mar	1.8	1.8	2.14%	1.78%	24815	17752	31.95	1.40	1.81%	1.16%		20.9	11.07	2.01%	1.81%	23115	18118	32.61	1.28	1.68%	1.08%		19.43987	13.17
8-Mar	1.8	1.8	2.14%	1.78%	24815	17752	31.95		1.71%	1.12%	37.14%	20.2	11.73	2.01%	1.81%	23115	18118	32.61		1.57%	1.01%	44.90%	18.11701	14.50
11-Mar	1.5	1.5	2.40%	1.88%	31065	18780	28.17	1.65	1.75%	1.05%	41.00%	15.7	12.45	2.11%	1.92%	24555	19232	28.85	1.28	1.53%	1.00%	46.80%	14.96815	13.88
12-Mar	1.5	1.5	2.40%	1.88%	31065	18780	28.17		1.76%	1.08%	41.72%	16.2	12.02	2.11%	1.92%	24555	19232	28.85		1.55%	0.97%	47.91%	14.54898	14.30
13-Mar	1.5	1.5	2.70%	2.27%	23373	22685	34.03	1.03	1.75%	1.13%	44.34%	17.0	17.06	2.54%	2.39%	29903	23919	35.88	1.25	1.39%	0.89%	52.52%	13.33064	22.55
14-Mar	1.5	1.5	2.70%	2.27%	23373	22685	34.03		1.68%	1.10%	46.09%	16.5	17.54	2.54%	2.39%	29903	23919	35.88		1.39%	0.92%	54.75%	13.74331	22.13
15-Mar	1.5	1.5	2.72%	2.29%	40730	22883	34.32	1.78	1.63%	1.05%	47.67%	15.8	18.55	2.55%	2.38%	31885	23777	35.67	1.34	1.32%	0.91%	56.17%	13.62172	22.04
16-Mar	1.5	1.5	2.72%	2.29%	40730	22883	34.32		1.70%	1.13%	48.21%	17.0	17.35	2.55%	2.38%	31885	23777	35.67		1.43%	1.01%	56.47%	15.15756	20.51
18-Mar	1.5	1.5	2.90%	2.40%	28400	24013	36.02	1.18	1.63%	1.08%	49.23%	16.3	19.77	2.77%	2.47%	24890	24715	37.07	1.01	1.26%	0.85%	57.83%	12.73556	24.34
19-Mar	1.5	1.5	2.90%	2.40%	28400	24013	36.02		1.79%	1.22%	49.29%	18.3	17.67	2.77%	2.47%	24890	24715	37.07		1.47%	1.01%	58.04%	15.22222	21.85
20-Mar	1.5	1.5	2.91%	2.40%	38400	23955	35.93	1.60	1.68%	1.09%	49.94%	16.3	19.62	2.55%	2.38%	51370	23753	35.63	2.16	1.39%	0.96%	58.28%	14.35683	21.27
21-Mar	1.5	1.5	2.91%	2.40%	38400	23955	35.93		1.58%	1.01%	50.80%	15.1	20.84	2.55%	2.38%	51370	23753	35.63		1.33%	0.93%	58.57%	13.99226	21.64
22-Mar	1.5	1.5	2.51%	2.20%	28830	21963	32.94	1.31	1.53%	0.98%	51.21%	14.7	18.19	2.08%	1.94%	36770	19396	29.09	1.90	1.34%	0.97%	57.97%	14.59388	14.50
23-Mar	1.5	1.5	2.51%	2.20%	28830	21963	32.94		1.51%	1.00%	51.50%	15.0	17.94	2.08%	1.94%	36770	19396	29.09		1.29%	0.95%	57.53%	14.27432	14.82
25-Mar	1.5	1.5	2.58%	2.25%	26020	22482	33.72	1.16	1.46%	0.97%	51.94%	14.5	19.19	2.42%	2.27%	44315	22689	34.03	1.95	1.31%	0.98%	57.51%	14.74244	19.29
26-Mar	1.5	1.5	2.58%	2.25%	26020	22482	33.72		1.54%	1.03%	52.13%	15.4	18.28	2.42%	2.27%	44315	22689	34.03		1.30%	0.96%	57.56%	14.39898	19.63
27-Mar	1.5	1.5	2.27%	1.91%	20285	19134	28.70	1.06	1.36%	0.89%	52.23%	13.4	15.35	2.11%	1.97%	23030	19712	29.57	1.17	1.16%	0.84%	57.57%	12.6264	16.94
28-Mar	1.5	1.5	2.27%	1.91%	20285	19134	28.70		1.33%	0.86%	52.40%	12.9	15.80	2.11%	1.97%	23030	19712	29.57		1.16%	0.81%	57.68%	12.09664	17.47
29-Mar	1.5	1.5	2.59%	2.11%	19890	21076	31.61	0.94	1.28%	0.83%	52.88%	12.4	19.21	2.23%	2.07%	21970	20690	31.03	1.06	1.17%	0.82%	57.85%	12.28013	18.75
30-Mar	1.5	1.5	2.59%	2.11%	19890	21076	31.61		1.30%	0.84%	53.28%	12.6	19.05	2.23%	2.07%	21970	20690	31.03		1.10%	0.75%	58.16%	11.30891	19.73
1-Apr	1.5	1.5	2.59%	2.11%	19890	21076	31.61		1.26%	0.79%	53.75%	11.9	19.73	2.23%	2.07%	21970	20690	31.03		1.16%	0.81%	58.31%	12.17483	18.86
2-Apr	1.5	1.5	2.59%	2.11%	19890	21076	31.61		1.29%	0.84%	54.07%	12.6	19.01	2.23%	2.07%	21970	20690	31.03		1.19%	0.87%	58.31%	13.1041	17.93
3-Apr	1.5	1.5	2.59%	2.11%	19890	21076	31.61		1.27%	0.81%	54.42%	12.2	19.40	2.23%	2.07%	21970	20690	31.03		1.19%	0.85%	58.36%	12.68369	18.35
4-Apr	1.5	1.5	2.56%	2.10%		20951	31.43		1.31%	0.86%	54.63%	12.9	18.54	2.44%	2.25%		22473	33.71		1.29%	0.93%	58.41%	13.89981	19.81
5-Apr	1.5	1.5	2.56%	2.10%		20951	31.43		1.34%	0.88%	54.80%	13.2	18.26	2.44%	2.25%		22473	33.71		1.27%	0.92%	58.46%	13.80071	19.91
6-Apr	1.5	1.5	2.56%	2.10%		20951	31.43		1.34%	0.88%	54.93%	13.3	18.16	2.44%	2.25%		22473	33.71		1.31%	0.84%	58.66%	12.56905	21.14
8-Apr	1.5	1.5	2.16%	1.87%	17220	18685	28.03	0.92	1.36%	0.90%	54.85%	13.5	14.56	2.08%	1.93%	35270	19331	29.00	1.82	1.29%	0.86%	58.56%	12.91187	16.08
9-Apr	1.5	1.5	2.16%	1.87%	17220	18685	28.03		1.41%	0.94%	54.70%	14.0	14.00	2.08%	1.93%	35270	19331	29.00		1.35%	0.93%	58.36%	13.92739	15.07
10-Apr	1.5	1.5	2.60%	2.27%	28915	22739	34.11	1.27	1.37%	0.91%	54.93%	13.6	20.48	2.47%	2.33%	37260	23296	34.94	1.60	1.41%	0.95%	58.41%	14.28275	20.66
11-Apr	1.5	1.5	2.60%	2.27%	28915	22739	34.11		1.35%	0.90%	55.15%	13.5	20.64	2.47%	2.33%	37260	23296	34.94		1.35%	0.91%	58.52%	13.66651	21.28
12-Apr	1.5	1.5	2.76%	2.16%	27420	21590	32.39	1.27	1.35%	0.90%	55.27%	13.5	18.84	2.74%	2.20%	24745	21988	32.98	1.13	1.78%	1.00%	58.41%	14.99047	17.99
15-Apr	0.75	0.75	2.48%	1.92%	40365	19154	14.37	2.11	1.39%	0.89%	55.24%	6.7	7.71	2.06%	1.92%	30150	19172	14.38	1.57	1.99%	0.98%	58.15%	7.351033	7.03
16-Apr	0.5	1	2.48%	1.92%	40365	19154	9.58					0.0		2.06%	1.92%	30150	19172	9.59					0	
17-Apr	0.5	0.5	2.48%	1.92%	40365	19154	9.58		1.73%	0.98%	49.07%	4.9	4.65	2.06%	1.92%	30150	19172	9.59		1.80%	1.02%	47.52%	5.077134	4.51
18-Apr	0.75	0.75	2.48%	1.92%	40365	19154	14.37		1.70%	0.96%	49.79%	7.2	7.18	2.06%	1.92%	30150	19172	14.38		1.76%	1.01%	47.70%	7.563252	6.82
19-Apr	0.8	0.8	2.91%	2.48%	43080	24790	19.83	1.74	1.71%	0.95%	53.66%	7.6	12.24	4.99%	2.48%	31360	24787	19.83	1.27	1.71%	0.97%	52.07%	7.734118	12.10
20-Apr	0.9	0.9	2.91%	2.48%	43080	24790	22.31		1.68%	0.92%	56.01%	8.3	14.01	4.99%	2.48%	31360	24787	22.31		1.76%	0.96%	54.45%	8.619579	13.69
22-Apr	1	1	4.47%	2.97%	58930	29739	29.74	1.98	1.78%	1.00%	58.35%	10.0	19.75	3.48%	2.89%	53505	28941	28.94	1.85	1.82%	0.95%	57.35%	9.506286	19.43
23-Apr	1	1	4.47%	2.97%	58930	29739	29.74		1.87%	1.04%	59.56%	10.4	19.31	3.48%	2.89%	53505	28941	28.94		1.90%	1.02%	58.75%	10.16063	18.78
24-Apr	1	1	3.06%	2.61%	24065	26113	26.11	0.92	1.83%	0.99%	60.00%	9.9	16.25	2.82%	2.60%	44950	25965	25.97	1.73	1.80%	0.96%	59.45%	9.569559	16.40
25-Apr	1	1	3.06%	2.61%	24065	26113	26.11		1.89%	1.03%	60.13%	10.3	15.84	2.82%	2.60%	44950	25965	25.97		1.86%	1.02%	59.66%	10.1901	15.78
26-Apr	1	1	3.21%	2.75%	43200	27549	27.55	1.57	1.84%	0.99%	60.62%	9.9	17.62	2.84%	2.66%	34565	26559	26.56	1.30	1.76%	0.96%	60.22%	9.560278	17.00
27-Apr	1	1	3.21%	2.75%	43200	27549	27.55		1.80%	0.98%	61.06%	9.8	17.71	2.84%	2.66%	34565	26559	26.56		1.75%	0.98%	60.54%	9.846349	16.71
29-Apr	1	1	2.92%	2.46%	22360	24616	24.62	0.91	1.73%	0.94%	61.20%	9.4	15.26	2.78%	2.54%	46145	25372	25.37	1.82	1.64%	0.90%	60.95%	9.037627	16.33
30-Apr	1	1	2.92%	2.46%	22360	24616	24.62		1.76%	0.98%	61.17%	9.8	14.81	2.78%	2.54%	46145	25372	25.37		1.64%	0.93%	61.18%	9.335312	16.04
1-May	1	1	2.92%	2.46%	22360	24616	24.62		1.73%	0.97%	61.17%	9.7	14.92	2.78%	2.54%	46145	25372	25.37		1.56%	0.91%	61.46%	9.096638	16.28
2-May	1	1	3.21%	2.67%	32580	26680	26.68	1.22	1.71%	0.94%	61.49%	9.4	17.32	3.12%	2.60%	31850	25992	25.99	1.23	1.55%	0.90%	61.79%	8.982113	17.01
3-May	1	1	3.21%	2.67%	32580	26680	26.68		1.69%	0.93%	61.79%	9.3	17.40	3.12%	2.60%	31850	25992	25.99		1.55%	0.89%	62.10%	8.905848	17.09
4-May	1	1	3.21%	2.67%	32580	26680	26.68		1.67%	0.93%	62.04%	9.3	17.40	3.12%	2.60%	31850	25992	25.99		1.59%	0.91%	62.32%	9.109239	16.88
6-May	1	1	3.26%	2.58%	49400	25803	25.80	1.91	1.65%	0.90%	62.26%	9.0	16.78	2.80%	2.58%	31543	25770	25.77	1.22	1.51%	0.87%	62.60%	8.665524	17.10
7-May	1	1	3.26%	2.58%	49400	25803	25.80		1.69%	0.97%	62.29%	9.7	16.07	2.80%	2.58%	31543	25770	25.77		1.55%	0.91%	62.74%	9.113065	16.66
8-May	1	1	3.26%	2.58%	49400	25803	25.80		1.65%	0.95%	62.36%	9.5	16.28	2.80%	2.58%	31543	25770	25.77		1.46%	0.86%	62.99%	8.574599	17.20
9-May	1	1	2.81%	2.44%	38350	24411	24.41	1.57	1.65%	0.97%	62.30%	9.7	14.73	2.51%	2.31%	40810	23141	23.14	1.76	1.51%	0.93%	62.88%	9.251788	13.89
10-May	1	1	2.81%	2.44%	38350	24411	24.41		1.58%	0.92%	62.32%	9.2	15.20	2.51%	2.31%	40810	23141	23.14		1.41%	0.85%	62.93%	8.482287	14.66
11-May	1	1	2.81%	2.44%	38350	24411	24.41		1.59%	0.94%	62.31%	9.4	14.97	2.51%	2.31%	40810	23141	23.14		1.40%	0.87%	62.95%	8.66252	14.48
12-May	1	1	2.81%	2.44%	38350	24411	24.41		1.60%	0.96%	62.26%	9.6	14.80	2.51%	2.31%	40810	23141	23.14		1.44%	0.91%	62.88%	9.100336	14.04
13-May	1	1	3.25%	2.74%	36910	27441	27.44	1.35	1.68%	0.98%	62.38%	9.8	17.65	3.08%	2.83%	42893	28350	28.35	1.51	1.54%	0.92%	63.12%	9.212556	19.14
14-May	1	1	3.25%	2.74%	36910	27441	27.44		1.66%	0.95%	62.53%	9.5	17.90	3.08%	2.83%	42893	28350	28.35		1.50%	0.91%	63.36%	9.069138	19.28
15-May	1	1	3.25%	2.74%	36910	27441	27.44		1.62%	0.94%	62.69%	9.4	18.08	3.08%	2.83%	42893	28350	28.35		1.51%	0.92%	63.56%	9.21064	19.14
16-May	1	1	3.25%	2.74%	36910	27441	27.44		1.64%	0.95%	62.81%	9.5	17.93	3.08%	2.83%	42893	28350	28.35		1.50%	0.91%	63.76%	9.107331	19.24
18-May	1	1	2.66%	2.22%	31577	22233	22.23	1.42	1.61%	0.95%	62.66%	9.5	12.74	2.40%	2.22%	44823	22225	22.23	2.02	1.42%	0.90%	63.65%	9.01458	13.21
19-May	1	1	2.66%	2.22%	31577	22233	22.23		1.65%	1.00%	62.46%	10.0	12.26	2.40%	2.22%	44823	22225	22.23		1.43%	0.90%	63.54%	9.016743	13.21
20-May	1	1	2.66%	2.22%	31577	22233	22.23		1.55%	0.91%	62.37%	9.1	13.09	2.40%	2.22%	44823	22225	22.23		1.31%	0.80%	63.57%	8.002784	14.22
21-May	1	1	2.66%	2.22%	31577	22233	22.23		1.55%	0.92%	62.29%	9.2	13.08	2.40%	2.22%	44823	22225	22.23		1.37%	0.89%	63.49%	8.887164	13.34
22-May	1	1	2.55%	2.25%	32843	22510	22.51	1.46	1.56%	0.95%	62.19%	9.5	13.05	2.54%	2.21%	41573	22131	22.13	1.88	1.36%	0.88%	63.41%	8.844572	13.29
23-May	1	1	2.55%	2.25%	32843	22510	22.51		1.56%	0.95%	62.08%	9.5	12.98	2.54%	2.21%	41573	22131	22.13		1.35%	0.88%	63.34%	8.84118	13.29
24-May	1	1	2.55%	2.25%	32843	22510	22.51		1.53%	0.89%	62.05%	8.9	13.58	2.54%	2.21%	41573	22131	22.13		1.36%	0.85%	63.31%	8.545007	13.59
25-May	1	1	3.17%	2.64%	42900	26431	26.43	1.62	1.50%	0.89%	62.20%	8.9	17.53	2.94%	2.55%	40037	25502	25.50	1.57	1.32%	0.85%	63.43%	8.456708	17.05
26-May	1	1	3.17%	2.64%	42900	26431	26.43		1.46%	0.87%	62.36%	8.7	17.73	2.94%	2.55%	40037	25502	25.50		1.33%	0.86%	63.53%	8.571769	16.93
27-May	1	1	3.17%	2.64%	42900	26431	26.43		1.51%	0.91%	62.46%	9.1	17.29	2.94%	2.55%	40037	25502	25.50		1.34%	0.87%	63.61%	8.658978	16.84
28-May	1	1	3.17%	2.64%	42900	26431	26.43		1.52%	0.93%	62.55%	9.3	17.17	2.94%	2.55%	40037	25502	25.50		1.36%	0.87%	63.69%	8.717373	16.78

Total and Volatile Solids in Digestate

TS/VS in Digestate

	Digester 1 (Sedimentation Sludge)							Solids reduction (Digester 1)		Digester 2 (Salsnes)							Solids reduction (Digester 2)	
Date	Dish (g)	Sample+ Dish (g)	Dried Sample + Dish (g)	Volatized Sample + Dish (g)	TS%	VS%	VS% of total	VS% of influent sludge	VS reduction Running average	Dish (g)	Sample+ Dish (g)	Dried Sample + Dish (g)	Volatized Sample + Dish (g)	TS%	VS%	VS% of total	VS Influent sludge (Salsnes)	VS reduction Running average
15-Feb	1.907	37.71	2.94	2.37	2.87%	1.57%	54.57%	1.68%										
18/02/13	1.8	49.59	3.31	#N/A	3.16%	#N/A	#N/A	1.42%		1.80	50.31	3.43	#N/A	3.36%	#N/A	#N/A	1.47%	
19/02/13	1.87	35.76	2.60	2.23	2.15%	1.09%	50.68%	1.47%		1.89	35.38	2.60	2.24	2.12%	1.07%	50.70%	0.72%	
26/02/13	1.9	32.66	2.56	2.18	2.15%	1.24%	57.58%	1.45%		1.90	31.57	2.53	2.17	2.12%	1.21%	57.14%	1.61%	
27/02/13	1.85	37.59	2.59	2.20	2.07%	1.09%	52.70%	1.34%		1.87	37.36	2.59	2.20	2.03%	1.10%	54.17%	2.48%	
28/02/13	1.9	35.34	2.55	2.16	1.94%	1.17%	60.00%	1.86%		1.89	48.34	2.84	2.27	2.05%	1.23%	60.00%	2.25%	
01/03/13	1.9	35.36	2.48	2.12	1.73%	1.08%	62.07%	1.97%		1.90	43.73	2.65	2.21	1.79%	1.05%	58.67%	2.22%	
04/03/13	1.9	47.02	2.75	2.21	1.88%	1.20%	63.53%	1.47%		1.90	54.81	3.00	2.29	2.08%	1.34%	64.55%	1.50%	
05/03/13	1.89	55.30	2.88	2.28	1.85%	1.12%	60.61%	1.61%		1.90	52.20	2.81	2.25	1.81%	1.11%	61.54%	1.42%	
06/03/13	1.9	51.42	2.83	2.24	1.88%	1.19%	63.44%	1.61%		1.90	59.33	2.91	2.28	1.76%	1.10%	62.38%	1.42%	
07/03/13	1.9	54.48	2.85	2.24	1.81%	1.16%	64.21%	1.78%		1.90	56.53	2.82	2.23	1.68%	1.08%	64.13%	1.81%	
08/03/13	1.9	54.42	2.80	2.21	1.71%	1.12%	65.56%	1.78%		1.90	49.59	2.65	2.17	1.57%	1.01%	64.00%	1.81%	
11/03/13	1.9	56.28	2.85	2.28	1.75%	1.05%	60.00%	1.88%		1.90	49.00	2.62	2.15	1.53%	1.00%	65.28%	1.92%	
12/03/13	1.9	50.19	2.75	2.23	1.76%	1.08%	61.18%	1.88%		1.90	53.45	2.70	2.20	1.55%	0.97%	62.50%	1.92%	
13/03/13	1.9	50.53	2.75	2.20	1.75%	1.13%	64.71%	2.27%		1.89	51.40	2.58	2.14	1.39%	0.89%	63.77%	2.39%	
14/03/13	1.905	52.85	2.76	2.20	1.68%	1.10%	65.50%	2.27%	52.12%	1.89	56.47	2.65	2.15	1.39%	0.92%	66.05%	2.39%	62.26%
15/03/13	1.8964	62.70	2.89	2.25	1.63%	1.05%	64.60%	2.29%	53.38%	1.91	64.79	2.74	2.17	1.32%	0.91%	68.75%	2.38%	62.32%
16/03/13	1.8972	53.36	2.77	2.19	1.70%	1.13%	66.74%	2.29%	52.62%	1.90	48.03	2.57	2.10	1.43%	1.01%	70.46%	2.38%	60.91%
18/03/13	1.8756	58.23	2.80	2.19	1.63%	1.08%	66.27%	2.40%	53.36%	1.88	50.00	2.49	2.08	1.26%	0.85%	67.19%	2.47%	62.27%
19/03/13	1.8898	57.66	2.89	2.21	1.79%	1.22%	68.20%	2.40%	52.60%	1.88	59.64	2.73	2.15	1.47%	1.01%	68.88%	2.47%	61.72%
20/03/13	1.8745	58.22	2.82	2.21	1.68%	1.09%	64.61%	2.40%	53.05%	1.89	68.60	2.81	2.17	1.39%	0.96%	69.04%	2.38%	61.48%
21/03/13	1.899	53.36	2.71	2.20	1.58%	1.01%	63.52%	2.40%	53.86%	1.89	56.68	2.61	2.10	1.33%	0.93%	70.22%	2.38%	61.46%
22/03/13	1.8725	55.37	2.69	2.17	1.53%	0.98%	64.19%	2.20%	54.09%	1.90	60.53	2.69	2.12	1.34%	0.97%	72.60%	1.94%	60.31%
23/03/13	1.867	52.07	2.63	2.13	1.51%	1.00%	66.04%	2.20%	54.18%	1.87	54.15	2.54	2.05	1.29%	0.95%	73.94%	1.94%	59.48%
25/03/13	1.8792	49.19	2.57	2.11	1.46%	0.97%	66.13%	2.25%	54.50%	1.88	56.83	2.60	2.06	1.31%	0.98%	75.29%	2.27%	59.26%
26/03/13	1.86	60.59	2.77	2.16	1.54%	1.03%	66.74%	2.25%	54.53%	1.90	58.77	2.64	2.10	1.30%	0.96%	73.80%	2.27%	59.17%
27/03/13	1.8712	48.36	2.50	2.09	1.36%	0.89%	65.30%	1.91%	54.48%	1.88	53.35	2.47	2.04	1.16%	0.84%	72.47%	1.97%	59.06%
28/03/13	1.8742	53.39	2.56	2.12	1.33%	0.86%	64.42%	1.91%	54.55%	1.87	54.29	2.47	2.05	1.16%	0.81%	69.69%	1.97%	59.10%
29/03/13	1.8733	56.39	2.57	2.12	1.28%	0.83%	64.40%	2.11%	55.01%	1.87	45.44	2.39	2.03	1.17%	0.82%	69.74%	2.07%	59.22%
30/03/13	1.8694	52.06	2.52	2.10	1.30%	0.84%	64.58%	2.11%	55.37%	1.88	49.97	2.41	2.04	1.10%	0.75%	68.75%	2.07%	59.52%
01/04/13	1.8704	55.46	2.55	2.12	1.26%	0.79%	62.92%	2.11%	55.82%	1.88	57.71	2.53	2.08	1.16%	0.81%	69.76%	2.07%	59.62%
02/04/13	1.8915	53.97	2.56	2.12	1.29%	0.84%	65.35%	2.11%	56.09%	1.88	49.11	2.44	2.03	1.19%	0.87%	73.64%	2.07%	59.55%
03/04/13	1.87	53.85	2.53	2.11	1.27%	0.81%	63.88%	2.11%	56.40%	1.88	45.46	2.40	2.03	1.19%	0.85%	71.19%	2.07%	59.55%
04/04/13	1.8715	53.73	2.55	2.11	1.31%	0.86%	65.38%	2.10%	56.55%	1.89	54.42	2.56	2.08	1.29%	0.93%	72.10%	2.25%	59.54%
05/04/13	1.8675	62.64	2.68	2.15	1.34%	0.88%	65.55%	2.10%	56.65%	1.86	51.45	2.50	2.04	1.27%	0.92%	72.16%	2.25%	59.54%
06/04/13	1.8724	49.29	2.51	2.09	1.34%	0.88%	65.85%	2.10%	56.73%	1.88	51.01	2.52	2.11	1.31%	0.84%	64.10%	2.25%	59.72%
08/04/13	1.8781	49.87	2.53	2.10	1.36%	0.90%	65.91%	1.87%	56.56%	1.87	55.84	2.57	2.10	1.29%	0.86%	66.70%	1.93%	59.57%
09/04/13	1.8835	56.52	2.65	2.14	1.41%	0.94%	66.38%	1.87%	56.33%	1.88	60.61	2.68	2.13	1.35%	0.93%	68.73%	1.93%	59.30%
10/04/13	1.8829	53.30	2.59	2.12	1.37%	0.91%	66.50%	2.27%	56.51%	1.87	49.56	2.54	2.09	1.41%	0.95%	67.56%	2.33%	59.31%
11/04/13	1.8897	46.71	2.49	2.09	1.35%	0.90%	66.51%	2.27%	56.70%	1.88	50.09	2.53	2.09	1.35%	0.91%	67.29%	2.33%	59.40%
12/04/13	1.8737	44.09	2.45	2.06	1.35%	0.90%	66.73%	2.16%	56.78%	1.88	48.02	2.70	2.24	1.78%	1.00%	56.25%	2.20%	59.24%
15/04/13	1.8888	50.27	2.56	2.13	1.39%	0.89%	63.82%	1.92%	56.70%	1.87	49.66	2.82	2.35	1.99%	0.98%	49.16%	1.92%	58.92%
16/04/13	1.8946	47.45	2.69	2.23	1.75%	1.01%	57.65%	1.92%	47.69%	1.89	47.68	2.74	2.26	1.86%	1.04%	56.00%	1.92%	46.03%
16/04/13	1.8691	51.61	2.74	2.25	1.76%	0.99%	56.49%	1.92%	48.13%	1.87	53.25	2.84	2.29	1.89%	1.07%	56.67%	1.92%	45.38%
17/04/13	1.868	52.28	2.74	2.24	1.73%	0.98%	57.08%	1.92%	48.44%	1.89	46.64	2.69	2.23	1.80%	1.02%	56.56%	1.92%	46.09%
18/04/13	1.8697	54.16	2.76	2.26	1.70%	0.96%	56.20%	1.92%	48.96%	1.89	49.14	2.72	2.24	1.76%	1.01%	57.45%	1.92%	46.54%
19/04/13	1.8811	44.23	2.60	2.20	1.71%	0.95%	55.63%	2.48%	52.23%	1.88	51.33	2.72	2.25	1.71%	0.97%	56.39%	2.48%	50.22%
20/04/13	1.8548	48.14	2.63	2.20	1.68%	0.92%	54.95%	2.48%	54.43%	1.85	49.03	2.68	2.23	1.76%	0.96%	54.49%	2.48%	52.53%
22/04/13	1.8592	48.16	2.68	2.22	1.78%	1.00%	56.23%	2.97%	56.83%	1.86	48.55	2.71	2.27	1.82%	0.95%	52.20%	2.89%	55.38%
23/04/13	1.8659	48.32	2.74	2.25	1.87%	1.04%	55.71%	2.97%	58.23%	1.86	47.06	2.72	2.26	1.90%	1.02%	53.58%	2.89%	56.98%
24/04/13	1.851	47.26	2.68	2.24	1.83%	0.99%	53.82%	2.61%	58.80%	1.87	49.48	2.72	2.27	1.80%	0.96%	53.21%	2.60%	57.82%
25/04/13	1.8828	51.67	2.82	2.31	1.89%	1.03%	54.35%	2.61%	59.07%	1.87	50.13	2.77	2.28	1.86%	1.02%	54.72%	2.60%	58.21%
26/04/13	1.8784	52.62	2.81	2.31	1.84%	0.99%	54.06%	2.75%	59.63%	1.90	49.01	2.73	2.28	1.76%	0.96%	54.47%	2.66%	58.86%
27/04/13	1.8501	47.93	2.68	2.23	1.80%	0.98%	54.52%	2.75%	60.12%	1.86	50.64	2.71	2.23	1.75%	0.98%	56.33%	2.66%	59.30%
29/04/13	1.8909	46.29	2.66	2.24	1.73%	0.94%	54.00%	2.46%	60.31%	1.91	49.03	2.68	2.25	1.64%	0.90%	55.08%	2.54%	59.76%
30/04/13	1.901	57.18	2.87	2.33	1.76%	0.98%	55.71%	2.46%	60.34%	1.87	47.70	2.62	2.20	1.64%	0.93%	56.81%	2.54%	60.07%
01/05/13	1.8821	45.55	2.64	2.21	1.73%	0.97%	56.04%	2.46%	60.40%	1.89	45.69	2.58	2.18	1.56%	0.91%	58.13%	2.54%	60.39%
02/05/13	1.8917	50.92	2.73	2.27	1.71%	0.94%	54.85%	2.67%	60.75%	1.90	52.68	2.69	2.24	1.55%	0.90%	57.79%	2.60%	60.77%
03/05/13	1.8727	54.00	2.75	2.27	1.69%	0.93%	55.00%	2.67%	61.08%	1.86	53.80	2.67	2.20	1.55%	0.89%	57.48%	2.60%	61.12%
04/05/13	1.8483	47.94	2.62	2.19	1.67%	0.93%	55.48%	2.67%	61.36%	1.86	50.32	2.63	2.19	1.59%	0.91%	57.29%	2.60%	61.38%
06/05/13	1.8544	59.81	2.81	2.29	1.65%	0.90%	54.57%	2.58%	61.59%	1.85	54.32	2.64	2.18	1.51%	0.87%	57.30%	2.58%	61.69%
07/05/13	1.8991	54.05	2.78	2.27	1.69%	0.97%	57.69%	2.58%	61.66%	1.89	53.18	2.69	2.22	1.55%	0.91%	58.75%	2.58%	61.87%
08/05/13	1.866	50.07	2.66	2.20	1.65%	0.95%	57.62%	2.58%	61.76%	1.89	50.28	2.60	2.18	1.46%	0.86%	58.78%	2.58%	62.15%
09/05/13	1.9062	43.62	2.59	2.19	1.65%	0.97%	58.79%	2.44%	61.72%	1.89	48.74	2.60	2.17	1.51%	0.93%	61.11%	2.33%	62.09%
10/05/13	1.8724	57.70	2.76	2.24	1.58%	0.92%	58.12%	2.44%	61.77%	1.87	54.40	2.61	2.17	1.41%	0.85%	60.12%	2.33%	62.17%
11/05/13	1.8974	56.36	2.76	2.25	1.59%	0.94%	59.29%	2.44%	61.77%	1.88	58.60	2.67	2.18	1.40%	0.87%	61.82%	2.33%	62.22%
12/05/13	1.8821	63.86	2.87	2.28	1.60%	0.96%	59.99%	2.44%	61.75%	1.87	55.78	2.65	2.16	1.44%	0.91%	63.25%	2.33%	62.19%
13/05/13	1.8819	54.32	2.76	2.25	1.68%	0.98%	58.18%	2.74%	61.88%	1.89	54.78	2.70	2.22	1.54%	0.92%	59.65%	2.83%	62.45%
14/05/13	1.912	52.79	2.75	2.27	1.66%	0.95%	57.63%	2.74%	62.04%	1.87	48.93	2.58	2.15	1.50%	0.91%	60.33%	2.83%	62.71%
15/05/13	1.8978	53.88	2.74	2.25	1.62%	0.94%	57.83%	2.74%	62.22%	1.89	59.97	2.76	2.23	1.51%	0.92%	61.06%	2.83%	62.93%
16/05/13	1.874	54.06	2.73	2.23	1.64%	0.95%	58.07%	2.74%	62.35%	1.87	51.03	2.61	2.16	1.50%	0.91%	60.75%	2.83%	63.14%
18/05/13	1.8679	49.14	2.63	2.18	1.61%	0.95%	58.96%	2.22%	62.22%	1.8688	55.88	2.64	2.15	1.42%	0.90%	63.33%	2.22%	63.05%
19/05/13	1.8722	50.33	2.67	2.19	1.65%	1.00%	60.31%	2.22%	62.03%	1.8687	51.61	2.58	2.13	1.43%	0.90%	63.04%	2.22%	62.96%
20/05/13	1.8933	50.49	2.65	2.20	1.55%	0.91%	59.08%	2.22%	61.96%	1.90	49.61	2.52	2.14	1.31%	0.80%	61.20%	2.22%	63.00%
21/05/13	1.908	48.97	2.64	2.21	1.55%	0.92%	59.20%	2.25%	61.90%	1.91	50.88	2.58	2.14	1.37%	0.89%	64.88%	2.22%	62.93%
22/05/13	1.8826	61.28	2.81	2.25	1.56%	0.95%	60.60%	2.25%	61.81%	1.86	61.68	2.67	2.14	1.36%	0.88%	65.01%	2.21%	62.87%
23/05/13	1.8977	49.47	2.64	2.19	1.56%	0.95%	60.89%	2.25%	61.71%	1.92	50.40	2.57	2.14	1.35%	0.88%	65.72%	2.21%	62.81%
24/05/13	1.876	51.32	2.63	2.19	1.53%	0.89%	58.53%	2.25%	61.69%	1.87	52.27	2.56	2.13	1.36%	0.85%	62.85%	2.21%	62.78%
25/05/13	1.8973	57.18	2.73	2.23	1.50%	0.89%	59.35%	2.64%	61.84%	1.86	63.19	2.67	2.15	1.32%	0.85%	64.08%	2.55%	62.91%
26/05/13	1.895	56.53	2.69	2.22	1.46%	0.87%	59.56%	2.64%	62.01%	1.86	57.27	2.60	2.13	1.33%	0.86%	64.37%	2.55%	63.03%
27/05/13	1.8773	55.99	2.69	2.20	1.51%	0.91%	60.67%	2.64%	62.11%	1.90	49.25	2.53	2.12	1.34%	0.87%	64.81%	2.55%	63.12%
28/05/13	1.8986	47.95	2.60	2.17	1.52%	0.93%	60.81%	2.64%	62.20%	1.90	51.34	2.57	2.14	1.36%	0.87%	64.27%	2.55%	63.21%

Chemical Oxygen Demand

Test date	Date Fed to reactors	Conventional			Salsnes		
		Reading	Actual	Average COD	Reading	Actual	Average COD
		mg/l O_1	mg/l O_2	mg/l O_3	mg/l O_4	mg/l O_5	mg/l O_6
18/2/13	18/2/13	2598	25980	25980	3512	35120	35120
18/2/13				25980			35120
19/2/13	19/2/13	3488	34880	34880	1619	16190	16190
19/2/13				34880			16190
25/2/13	25/2/13	3883	38830	38830	5157	51570	51570
25/2/13				38830			51570
26/2/13	26/2/13	2182	21820	21820	2926	29260	29260
26/2/13				21820			29260
28/2/13	27/2/13	2474	24740	24740	2862	28620	28620
28/2/13	28/2/13		24740	24740		28620	28620
4/3/13	4/3/13	2512	25120	25120	1975	19750	19750
4/3/13	4/3/13			25120			19750
5/3/13	5/3/13	2096	20960	20960	1710	17100	17100
5/3/13	6/3/13			20960			17100
7/3/13	7/3/13	2432	24320	24815	2108	21080	23115
7/3/13	8/3/13	2531	25310	24815	2515	25150	23115
12/3/13	11/3/13	2363	23630	31065	2253	22530	24555
12/3/13	12/3/13	3850	38500	31065	2658	26580	24555
14/3/13	13/3/13	2098	20980	23373	3527	35270	29903
14/3/13	13/3/13	1906	19060	23373	2330	23300	29903
18/3/13	14/3/13	2805	28050	23373	3196	31960	29903
18/3/13	14/3/13	2540	25400	23373	2908	29080	29903
18/3/13	15/3/13	4847	48470	40730	3801	38010	31885
18/3/13	16/3/13	3299	32990	40730	2576	25760	31885
19/3/13	18/3/13	2428	24280	28400	2375	23750	24890
19/3/13	19/3/13	3252	32520	28400	2603	26030	24890
21/3/13	20/3/13	4694	46940	38400	5271	52710	51370
21/3/13	21/3/13	2986	29860	38400	5003	50030	51370
22/3/13	22/3/13	3469	34690	28830	3551	35510	36770
22/3/13	23/3/13	2297	22970	28830	3803	38030	36770
25/3/13	25/3/13	3140	31400	26020	4822	48220	44315
25/3/13	26/3/13	2064	20640	26020	4041	40410	44315
27/3/13	27/3/13	1826	18260	20285	3806	38060	23030
27/3/13	28/3/13	2231	22310	20285	800	8000	23030
2/4/13	29/3/13	1864	18640	19890	2464	24640	21970
2/4/13	30/3/13	2114	21140	19890	1930	19300	21970
	1/4/13			19890			21970
	2/4/13			19890			21970
	3/4/13			19890			21970
4/4/13	4/4/13						
4/4/13	5/4/13						
	6/4/13						
8/4/13	8/4/13	1995	19950	17220	3866	38660	35270
8/4/13	9/4/13	1449	14490	17220	3188	31880	35270
10/4/13	10/4/13	2454	24540	28915	4307	43070	37260
10/4/13	11/4/13	3329	33290	28915	3145	31450	37260
12/4/13	12/4/13	3148	31480	27420	2987	29870	24745
12/4/13		2336	23360	27420	1962	19620	24745
16/4/13	15/4/13	4497	44970	40365	3046	30460	30150
16/4/13	16/4/13	3576	35760	40365	2984	29840	30150
	17/4/13			40365			30150
	18/4/13			40365			30150
19/4/13	19/4/13	4617	46170	43080	4505	45050	31360
19/4/13	20/4/13	3999	39990	43080	1767	17670	31360
22/4/13	22/4/13	5985	59850	58930	5155	51550	53505
22/4/13	23/4/13	5801	58010	58930	5546	55460	53505
24/4/13	24/4/13	1533	15330	24065	4410	44100	44950
24/4/13	25/4/13	3280	32800	24065	4580	45800	44950
26/4/13	26/4/13	4013	40130	43200	4482	44820	34565
26/4/13	27/4/13	4627	46270	43200	2431	24310	34565
29/4/13	29/4/13	2749	27490	22360	4920	49200	46145
29/4/13	30/4/13	1723	17230	22360	4309	43090	46145
	1/5/13			22360		0	46145
2/5/13	2/5/13	5684	56840	32580	2492	24920	31850
2/5/13	3/5/13	4090	40900	32580	3878	38780	31850
	4/5/13		0	32580			31850
6/5/13	6/5/13	5566	55660	49400	3093	30930	31543
6/5/13	7/5/13	4847	48470	49400	3069	30690	31543
6/5/13	8/5/13	4407	44070	49400	3301	33010	31543
9/5/13	9/5/13	3626	36260	38350	4087	40870	40810
9/5/13	10/5/13	3568	35680	38350	3916	39160	40810
9/5/13	11/5/13	4311	43110	38350	4240	42400	40810
	12/5/13			38350			40810
12/5/13	13/5/13	3892	38920	36910	4367	43670	42893
12/5/13	14/5/13	4187	41870	36910	4505	45050	42893
12/5/13	15/5/13	2994	29940	36910	3996	39960	42893
	16/5/13			36910			42893
16/5/13	18/5/13	3121	31210	31577	6473	64730	44823
16/5/13	19/5/13	3657	36570	31577	3190	31900	44823
16/5/13	20/5/13	2695	26950	31577	3784	37840	44823
	21/5/13			31577			44823
22/5/13	22/5/13	3250	32500	32843	4897	48970	41573
22/5/13	23/5/13	3082	30820	32843	3846	38460	41573
22/5/13	24/5/13	3521	35210	32843	3729	37290	41573
25/5/13	25/5/13	3896	38960	42900	4679	46790	40037
25/5/13	26/5/13	4479	44790	42900	3993	39930	40037
25/5/13	27/5/13	4495	44950	42900	3339	33390	40037
	28/5/13			42900			40037

Alkalinity

		Digester 1 (sedimentation)				Digester 2 (Salsnes)				
		Reading		Actual		Reading		Actual		
Date	Dilution	mmol/l	mg/l as CaCo3	mmol/l	mg/l as CaCo3	mmol/l	mg/l as CaCo3	mmol/l	mg/l as CaCo3	Na2CO3 Additions
18/02/13	10	3.74	224	37.40	2244	3.37	202	33.7	2022	
19/02/13	10	4.10	246	41.00	2460	3.84	230	38.4	2304	
20/02/13	10	3.48	209	34.80	2088	3.61	217	36.1	2166	10g DG1 & DG2
21/02/13	10	4.77	286	47.70	2862	4.56	274	45.6	2736	
22/02/13	10	4.81	289	48.10	2886	4.63	278	46.3	2778	
25/02/13	10	5.50	330	55.00	3300	4.80	288	48.0	2880	
27/02/13	10	5.51	331	55.10	3306	4.89	293	48.9	2934	
28/02/13	10	4.70	282	47.00	2820	6.04	362	60.4	3624	
01/03/13	10	4.25	255	42.50	2550	4.60	276	46.0	2760	
04/03/13	10	3.79	227	37.90	2274	4.21	253	42.1	2526	
05/03/13	10	3.89	233	38.90	2334	4.41	265	44.1	2646	
06/03/13	10	3.61	217	36.10	2166	4.58	275	45.8	2748	5g DG1 & DG2
07/03/13	10	3.76	226	37.60	2256	4.66	280	46.6	2796	
08/03/13	10	3.96	238	39.60	2376	4.16	250	41.6	2496	
12/03/13	10	3.87	232.20	38.70	2322	4.30	258	43.0	2580	
14/03/13	10	5.28	316.8	52.8	3168	4.28	257	42.8	2568	
18/03/13	10	3.83	229.8	38.3	2298	3.535	212	35.4	2121	10g DG2
21/03/13	10	4.61	276.6	46.1	2766	3.79	227	37.9	2274	
25/03/13	10	4.92	295.2	49.2	2952	3.66	220	36.6	2196	
27/03/13	10	4.13	247.8	41.3	2478	3.08	185	30.8	1848	20g over 3 days DG2
01/04/13	10	3.52	211.2	35.2	2112	3.21	193	32.1	1926	
02/04/13	10	3.72	223.2	37.2	2232	3.05	183	30.5	1830	20g 3/4 April DG2
04/04/13	10	3.04	182.4	30.4	1824	3.28	197	32.8	1968	
05/04/13	10	#N/A	#N/A	#N/A	#N/A	4.44	266	44.4	2664	30g DG2
08/04/13	10	2.64	158.4	26.4	1584	4.29	257	42.9	2574	
09/04/13	10	#N/A	#N/A	#N/A	#N/A	4.41	265	44.1	2646	10g DG1, 20g DG2
10/04/13	10	3.36	201.6	33.6	2016	4.62	277	46.2	2772	
11/04/13	10	3.8	228	38	2280	5.02	301	50.2	3012	90g DG2 (see new calculation of alkalinity)
11/04/13	10	#N/A	#N/A	#N/A	#N/A	9.18	551	91.8	5508	<---Sample taken after 90g addition
12/04/13	10	3.79	227.4	37.9	2274	8.7	522	87.0	5220	25g DG1, 100g DG2
15/04/13	10	4.89	293.4	48.9	2934	13.63	818	136.3	8178	
Reseed										
17/04/13	10	2.75	165	27.5	1650	5.04	302	50.4	3024	Digester 1 below 2000mg/l, add 12.5 grams to bring alk to 2100mg/l (35mmol/l)
19/04/13	10	2.91	174.6	29.1	1746	5.26	316	52.6	3156	20/4,15g to DG 1
22/04/13	10	4.38	262.8	43.8	2628	4.8	288	48.0	2880	
23/04/13	10	3.97	238.2	39.7	2382	4.71	283	47.1	2826	
24/04/13	10	3.43	205.8	34.3	2058	4.13	248	41.3	2478	15g to dg1 10g to dg2 to keep ~40mmol
29/04/13	10	4.14	248.4	41.4	2484	3.94	236	39.4	2364	
01/05/13	10	3.75	225	37.5	2250	3.78	227	37.8	2268	10g DG1 & DG2
06/05/13	10	3.85	231	38.5	2310	5.16	310	51.6	3096	
09/05/13	10	3.68	220.8	36.8	2208	4.27	256	42.7	2562	
13/05/13	10	4.39	263.4	43.9	2634	4.7	282	47.0	2820	
16/05/13	10	4.36	261.6	43.6	2616	4.03	242	40.3	2418	
20/05/13	10	3.73	223.8	37.3	2238	3.68	221	36.8	2208	
23/05/13	10	3.61	216.6	36.1	2166	3.37	202	33.7	2022	15g addition DG1 & DG2
27/05/13	10	4.12	247.2	41.2	2472	4.44	266	44.4	2664	

Volatile Organic Acids, VOA/Alkalinity Ratio and Na_2CO_3 Dosing

								Desired Ratio				
	Digester 1		Digester 2 (Salsnes)					0.20		1.66g NaCO3/mmol a		
	Reading		Reading			VOA/ALK Digester 1				VOA/ALK Digester 2		
Date	mg/l	mmol/l	mg/l	mmol/l		VOA/ALK Digester 1	mmol alkalinity deficit	NaCO3 addition (g)		VOA/ALK Digester 2	mmol alkalinity deficit	NaCO3 addition (g)
15/2/2013												
18/2/2013	87.5	1.46	72.6	1.21		0.04				0.04		
19/2/2013	241	4.02	95.5	1.59		0.10				0.04		
20/2/2013	114	1.90	196	3.27		0.05				0.09		
21/2/2013	97.5	1.63	69.3	1.16		0.03				0.03		
22/2/2013	147	2.45	78.5	1.31		0.05				0.03		
25/2/2013	90.8	1.51	75.4	1.26		0.03				0.03		
26/2/2013	96.7	1.61	81.6	1.36								
27/2/2013	85.6	1.43	89	1.48		0.03				0.03		
28/2/2013	103.5	1.73	145	2.42		0.04				0.04		
1/3/2013	129.5	2.16	127	2.12		0.05				0.05		
4/3/2013	200.5	3.34	149	2.48		0.09				0.06		
5/3/2013	188	3.13	143	2.38		0.08				0.05		
6/3/2013	299	4.98	343.5	5.73		0.14				0.13		
7/3/2013	256	4.27	364	6.07		0.11				0.13		
8/3/2013	239	3.98	344.5	5.74		0.10				0.14		
12/3/2013	277.5	4.63	261.5	4.36		0.12				0.10		
14/3/2013	244	4.07	368	6.13		0.08				0.14		
18/3/2013	435.5	7.26	375	6.25		0.19				0.18		
21/3/2013	454.5	7.58	391.5	6.53		0.16				0.17		
25/3/2013	608	10.13	543.5	9.06		0.21				0.25		
27/3/2013	400	6.67	574	9.57		0.16				0.31		
1/4/2013	106	1.77	393	6.55		0.05				0.20		
2/4/2013	291	4.85	439	7.32		0.13	0	0		0.24	0	0
4/4/2013	136	2.27	807	13.45		0.07	0	0		0.41	34	57
5/4/2013	#N/A	#N/A	1591	26.52						0.60	88	146
8/4/2013	107	1.78	916	15.27		0.07	0	0		0.36	33	55
9/4/2013	#N/A	#N/A	772	12.87						0.29	20	34
10/4/2013	543	9.05	1101	18.35		0.27	12	19		0.40	46	76
11/4/2013	612	10.20	1790	29.83		0.27	13	22		0.59	99	164
11/4/2013	#N/A	#N/A	1303	21.72						0.24	0	0
12/4/2013	788	13.13	2226	37.10		0.35	28	46		0.43	99	164
15/4/2013	374	6.23	2636	43.93		0.13				0.32	83	138
17/4/2013	113	1.88	432	7.20		0.07	8	12		0.14	0	0
19/4/2013	293	4.88	240	4.00		0.17	10	17		0.08	0	0
22/4/2013	88	1.47	195	3.25		0.03	0	0		0.07	0	0
23/4/2013	105	1.75	142	2.37		0.04	0	0		0.05	0	0
24/4/2013	147	2.45	98.8	1.65		0.07	9	15		0.04	6	10
29/4/2013	105	1.75	115	1.92		0.04	0	0		0.05	0	0
1/5/2013	125	2.08	118	1.97		0.06	6	10		0.05	6	10
6/5/2013	78.2	1.30	116	1.93		0.03	0	0		0.04	0	0
9/5/2013	142	2.37	192	3.20		0.06	0	0		0.07	0	0
13/5/2013	138	2.30	166	2.77		0.05	0	0		0.06	0	0
16/5/2013	177	2.95	205	3.42		0.07	0	0		0.08	0	0
20/5/2013	243	4.05	267	4.45		0.11	0	0		0.12	0	0
23/5/2013	179	2.98	238	3.97		0.08	0	0		0.12	0	0
27/5/2013	154	2.57	240	4.00		0.06	0	0		0.09	0	0

Capillary Suction Time

CST		
Date	Digester 1 Time (s)	Digester 2 Time (s)
27/3/13	1481	1981
1/4/13	1696	1829
4/4/13	1856	2710
8/4/13	2050	2301
11/4/13	2055	2375
16/4/13	868	1238
19/4/13	947	1057
22/4/13	978	1074
24/4/13	1266	1247
29/4/13	1194	1744
2/5/13	1379	1633
6/5/13	1500	1410
9/5/13	1802	1498
13/5/13	2162	2596
16/5/13	2021	2662
21/5/13	1898	2352
23/5/13	2005	3200
24/5/13	#N/A	3077
27/5/13	1752	2958

AMPTS Substrate and Inoculum Dosing

First Run											
Dish	Sample+ Dish	Dried Sample + Dish	Volatized Sample + Dish	TS%	VS%	VS% of total	Average VS%	Mass Substrate	Mass Inoculum	VS% Ratio	Total Mass
SALS 13/3								g	g		g
1.9005	58.3205	3.2575	1.9827	2.41%	2.26%	93.94%	2.27%	100.5	295.9	2.00	396.4
1.9043	59.7392	3.3	1.9885	2.41%	2.27%	93.97%					
1.9012	61.836	3.352	1.987	2.42%	2.28%	94.09%					
SED 13/3											
1.902	54.8977	3.3033	2.1404	2.64%	2.19%	82.99%	2.19%	104.1	295.9	2.00	400
1.9029	48.5652	3.132	2.1132	2.63%	2.18%	82.89%					
1.8902	55.7013	3.3113	2.1311	2.64%	2.19%	83.05%					
SAIS 15/3											
1.8982	55.4495	3.3072	1.9957	2.63%	2.45%	93.08%	2.48%	92.0	295.9	2.00	387.9146
1.8894	57.1313	3.358	2.0012	2.66%	2.46%	92.39%					
1.901	65.5517	3.6146	2.0051	2.69%	2.53%	93.93%					
sed 15/3											
1.8854	54.9478	3.38	2.1195	2.82%	2.38%	84.34%	2.38%	95.9	295.9	2.00	391.7374
1.8871	60.9938	3.5567	2.1485	2.82%	2.38%	84.34%					
1.8642	62.7758	3.5839	2.1346	2.82%	2.38%	84.28%					
Innoculum											
1.876	56.22	3.2977	2.4592	2.62%	1.54%	58.98%	1.54%				
1.8902	54.0752	3.2547	2.4485	2.61%	1.54%	59.08%					
1.8792	49.659	3.1227	2.3886	2.60%	1.54%	59.03%					

Second Run											
Dish	Sample+ Dish	Dried Sample + Dish	Volatized Sample + Dish	TS%	VS%	VS% of total	Average VS%	Mass Substrate	Mass Inoculum	VS% Ratio	Total Mass
SALS 24/4								g	g		g
1.8676	64.0391	3.6205	2.009	2.82%	2.59%	91.93%	2.57%	107.7	292.3	2.00	400.0004
1.8632	52.313	3.2888	1.9766	2.83%	2.60%	92.05%					
1.8611	50.3609	3.1826	1.9671	2.72%	2.51%	91.98%					
SED 24/4											
1.857	45.9102	3.1637	2.0514	2.97%	2.52%	85.12%	2.59%	106.9	292.3	2.00	399.2
1.8582	43.1969	3.1294	2.0462	3.08%	2.62%	85.21%					
1.8565	51.1796	3.378	2.0833	3.08%	2.62%	85.09%					
SALS 26/4											
1.8855	57.3789	3.4488	1.9856	2.82%	2.64%	93.60%	2.67%	103.7	292.3	2.00	396.0
1.8647	57.0972	3.4428	1.9653	2.86%	2.68%	93.63%					
1.8645	66.0443	3.7054	1.982	2.87%	2.69%	93.62%					
sed 25 26/4											
1.859	58.3098	3.6726	2.1174	3.21%	2.75%	85.75%	2.74%	101.0	292.3	2.00	393.3
1.8639	51.728	3.4319	2.0861	3.14%	2.70%	85.83%					
1.8424	57.3756	3.625	2.0951	3.21%	2.75%	85.82%					
Innoculum											
1.8647	55.5768	3.7626	2.7319	3.53%	1.92%	54.31%	1.89%				
1.8653	54.019	3.703	2.7502	3.52%	1.83%	51.85%					
1.8707	53.687	3.7194	2.7195	3.57%	1.93%	54.09%					

AMPTS Data for Run 1 and Run 2 by Day

Name	Inoculum			SALSNES 13/3			SEDIMENT 13/3			SALSNES 15/3			SEDIMENT 15/3			Inoculum			SALSNES 24/4			SEDIMENT 24/4			SALSNES 26/4			SEDIMENT 26/4		
Substrate VS/COD amount [g]	0	0	0	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	0	0	0	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76
Inoculum VS/COD amount [g]	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	5.52	5.52	5.52	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53
Type of unit [VS/COD]	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
Headspace volume [ml]	354.1	354.1	354.1	253.6	253.58	253.6	250	250	250	262.1	262.1	262.1	258.26	258.26	258.26	357.7	357.7	357.7	250	250	250	250.8	250.8	250.8	253.98	253.98	253.98	256.66	256.66	256.66
Assumed CH4 content [%]	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Flow Cell nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Day	Inoculum Volume [Nml]	Inoculum Volume [Nml]	Inoculum Volume [Nml]	SALSNES 13/3 1 Volume [Nml]	SALSNES 13/3 2 Volume [Nml]	SALNES 13/3 3 Volume [Nml]	SEDIMENT 13/3 1 Volume [Nml]	SEDIMENT 13/3 2 Volume [Nml]	SEDIMENT 13/3 3 Volume [Nml]	SALSNES 15/3 1 Volume [Nml]	SALSNES 15/3 2 Volume [Nml]	SALSNES 15/3 3 Volume [Nml]	SEDIMENT 15/3 1 Volume [Nml]	SEDIMENT 15/3 2 Volume [Nml]	SEDIMENT 15/3 3 Volume [Nml]	Inoculum Volume [Nml]	Inoculum Volume [Nml]	Inoculum Volume [Nml]	SALSNES 24-25/4 1 Volume [Nml]	SALSNES 24-25/4 2 Volume [Nml]	SALSNES 24-25/4 3 Volume [Nml]	SEDIMENT 24-25/4 1 Volume [Nml]	SEDIMENT 24-25/4 2 Volume [Nml]	SEDIMENT 24-25/4 3 Volume [Nml]	SALSNES 25-26/4 1 Volume [Nml]	SALSNES 25-26/4 2 Volume [Nml]	SALSNES 25-26/4 3 Volume [Nml]	SEDIMENT 25-26/4 1 Volume [Nml]	SEDIMENT 25-26/4 2 Volume [Nml]	SEDIMENT 25-26/4 3 Volume [Nml]
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	74.1	79.8	80.6	330	358.7	350.8	346	337.4	319.7	335.8	364.6	347.5	318.8	320.5	326.4	112.2	112.1	110.4	280.9	282.2	287.4	279.0	279.8	268.2	282.1	290.7	281.9	260.0	252.5	259.1
2	102.9	108.4	110.8	597	631.8	626.7	616.9	593.2	572.7	607.1	648	628.6	600.5	586.3	611	170.3	172.7	167.4	637.4	640.0	654.2	652.6	652.8	627.1	647.7	666.2	644.3	631.8	612.4	629.0
3	123.7	130.4	134.4	687.2	732.4	726.9	718.6	688.3	670.4	704.2	750.4	725.7	703.3	681.2	719.4	212.6	217.8	208.2	840.4	839.1	848.8	870.4	869.3	839.4	851.1	879.4	837.6	824.1	796.9	819.9
4	140	146.3	150.4	729.1	779.4	772	769	735.2	719.1	750.8	801.4	774	756.2	728.8	774.1	244.7	252.5	239.6	985.3	985.6	993.2	1003.4	995.3	974.8	1002.4	1025.7	984.3	946.1	912.4	939.3
5	153.2	160.2	163.3	753.6	809.3	800.5	803	767	751.8	782.6	835.6	807.2	790.7	759.7	809.5	272.0	282.2	266.8	1063.2	1060.2	1070.3	1076.3	1064.4	1050.0	1083.6	1104.4	1062.5	1017.1	981.4	1011.7
6	166.4	174	177.2	772.8	833.9	823.6	831.9	794.4	779.4	809.1	863.3	833.2	819.8	785.1	839.8	289.3	302.4	284.3	1109.5	1105.4	1117.6	1122.7	1107.0	1097.6	1137.8	1156.3	1113.6	1063.1	1026.0	1059.5
7	178.4	186.4	188.4	786.5	853.7	842.2	854.7	815	802	830.2	886.1	855.9	843.1	805.7	863.9	303.7	319.3	298.9	1141.8	1136.8	1150.4	1156.8	1137.2	1132.3	1176.0	1192.9	1149.5	1097.4	1058.9	1095.8
8	187.1	196	196.8	797.4	868.7	857	872.2	832.1	820.1	847.1	904.1	874.2	861.7	821.7	883.2	317.7	335.5	312.9	1165.9	1162.5	1176.4	1184.6	1162.6	1161.8	1206.5	1222.2	1177.9	1126.9	1086.6	1127.2
9	196.3	205.5	205.9	809	883.9	872	890.8	849.6	839	865	922.3	892.4	881.2	838.6	903.3	328.9	350.0	326.2	1186.7	1183.3	1198.5	1209.6	1183.7	1187.4	1231.7	1246.7	1200.4	1153.4	1112.1	1155.7
10	205.3	214.3	213.7	819.5	898.6	886.6	907.8	867.2	858.4	881.8	940.1	910.1	900.4	854.7	922.1	341.0	363.6	338.6	1206.1	1203.5	1218.4	1232.0	1204.9	1212.2	1254.1	1269.4	1221.3	1177.6	1134.4	1182.2
11	211.8	221.5	220	825.4	912.4	898.9	924.2	880.5	874	894.5	956	926	914.4	866.9	939	350.5	377.0	351.2	1223.9	1222.9	1238.1	1253.3	1224.9	1235.7	1276.1	1289.7	1241.5	1200.6	1154.8	1206.1
12	217.5	227.7	225	830.4	921.8	909	939.4	893.5	886.9	907.8	969.6	937.8	928.4	879	953.2	359.2	388.4	361.6	1240.4	1242.0	1257.1	1273.2	1243.4	1258.2	1296.9	1309.8	1260.9	1221.5	1172.8	1227.0
13	223	232.4	229.5	834.5	929.4	915.2	949.8	902.1	897.4	915.6	978.9	948.1	938	886.9	963.4	367.9	399.5	371.8	1256.4	1259.6	1273.1	1291.3	1260.6	1278.0	1316.1	1327.9	1278.5	1239.6	1187.4	1245.3
14	229	238	233.7	838.6	938.3	920.7	959.5	910.5	906.5	925.2	988.9	956.3	946.7	894.2	972.9	376.6	410.0	381.1	1271.3	1276.5	1287.8	1307.8	1277.3	1296.7	1333.3	1345.6	1295.0	1256.7	1201.3	1261.9
15	235.2	244.5	238.8	841.7	945.8	927	969.1	918.5	915.2	934.4	998.9	965.3	956	902.2	981.9	384.9	419.6	389.4	1283.7	1292.3	1301.7	1323.9	1292.5	1313.7	1349.6	1363.0	1310.7	1272.4	1213.6	1277.3
16	241.9	251.9	244.6	844.8	951.4	932.5	977.8	926.4	922.6	940.6	1007.6	973.4	964.4	909.4	990.5	391.2	428.0	396.8	1295.0	1306.3	1312.9	1335.7	1306.1	1328.1	1362.0	1377.8	1323.6	1285.7	1225.2	1290.0
17	247.7	259.5	251.3	847.4	956.5	937.6	985.8	932.5	930.3	945.6	1013.6	981.2	972	914	996.3	396.3	436.9	403.9	1304.2	1320.4	1324.0	1348.7	1318.3	1342.6	1375.8	1393.7	1337.1	1298.3	1235.6	1304.0
18	251.1	263.5	254.9	848.5	960.6	939.9	991.3	937.5	934.4	949.5	1019.5	985.4	977.3	918.4	1001.9	400.9	442.5	410.8	1311.9	1333.3	1332.8	1358.5	1328.4	1355.7	1386.7	1404.9	1346.7	1307.8	1244.5	1314.6
19	254.5	267.4	258.5	849.6	964.7	942.1	996.8	942.3	938.4	953.2	1025.6	989.8	982.3	921.3	1007.6	403.0	448.4	415.2	1319.0	1343.6	1342.2	1368.2	1337.5	1366.6	1396.8	1415.7	1356.7	1317.4	1253.6	1324.9
20	257.7	271.4	261.8	850.7	969	944.2	1002.3	947.2	942.9	956.3	1030.4	994.5	986.8	924.2	1012.9	405.1	454.6	419.5	1324.6	1351.8	1349.7	1374.2	1344.7	1375.5	1405.3	1424.0	1364.4	1325.1	1258.1	1333.4
21	260.9	275.3	265.1	851.8	973.3	946.3	1007.2	951.9	947.3	959.3	1035.1	999.4	991.6	927.3	1018.3	407.1	458.8	422.9	1329.9	1358.7	1355.4	1380.4	1351.0	1382.7	1411.8	1431.8	1370.2	1330.0	1262.3	1340.0
22	264.6	279.7	268.1	852.9	978.8	948.5	1012.2	956.5	953.9	962.4	1038.9	1005.4	997.4	931.6	1024.9	409.2	463.3	426.4	1334.9	1368.2	1362.6	1387.6	1358.8	1391.5	1419.9	1441.6	1378.7	1336.1	1268.9	1348.2
23	268.4	284	270.6	854	983.9	950.7	1018	959.7	958.5	965.5	1042.8	1009.7	1001.8	935.9	1029.3	412.1	471.0	429.8	1338.6	1377.9	1369.1	1396.3	1366.5	1400.1	1428.2	1452.1	1387.7	1343.8	1273.7	1356.3
24	271	286	273.1	855.1	987.2	953	1022.4	963	961.9	968.7	1046.2	1013.1	1005.3	938.2	1032.7	415.0	474.0	433.0	1342.0	1383.1	1373.4	1401.5	1372.5	1406.2	1434.8	1459.4	1394.0	1348.3	1277.0	1362.4
25	273	288	275.6	856.2	990.4	955.2	1025.7	966.4	965.4	972.1	1049.5	1016.6	1008.9	940.4	1036.2	417.9	477.1	436.4	1345.3	1389.4	1378.7	1407.7	1377.1	1411.7	1439.9	1465.2	1400.1	1353.5	1280.4	1367.6
26	275.1	290	278	858.9	994.4	957.8	1029	970.3	969.5	976.3	1052.8	1021.3	1013.5	942.7	1040.4	422.0	480.1	440.8	1347.5	1396.9	1385.2	1414.7	1382.2	1418.5	1445.8	1473.3	1408.3	1360.9	1284.7	1373.2
27	277.2	291.9	280.5	861.5	999.3	960.6	1033.8	974.3	973.5	980.7	1057.3	1026.1	1018.2	944.9	1044.7	426.1	483.2	444.9	1349.6	1404.1	1388.2	1421.6	1387.9	1423.3	1451.6	1478.1	1416.0	1363.9	1289.1	1378.4
28	282.4	293.7	282.9	864.1	1003.9	963.5	1039.1	980.6	976.3	986.3	1061.9	1032.4	1023.9	946.7	1050	426.2	486.4	447.8	1351.8	1407.7	1391.2	1425.6	1390.7	1427.4	1455.7	1482.4	1419.6	1366.9	1291.6	1382.3
29	286	295.4	284.8	866.3	1008.4	965.8	1046.1	984.9	978.9	989.9	1068.3	1036	1027.4	948.5	1054.3	426.2	489.7	450.7	1354.0	1411.1	1394.2	1429.7	1393.2	1431.5	1459.8	1487.5	1423.2	1370.1	1294.0	1386.2
30	287.7	297.2	286.5	868.2	1012	967.7	1049.3	987.4	981.4	991.9	1072.6	1038.4	1029.3	950.3	1056.4	426.2	493.2	453.6	1354.1	1415.3	1397.8	1434.4	1395.8	1435.7	1463.7	1492.6	1427.0	1374.7	1296.4	1391.0
31	289.4	298.9	288.1	870.2	1015.2	969.6	1051.6	990	984.2	994	1075.6	1040.9	1031.1	952.1	1058.4	426.2	496.6	456.2	1354.1	1420.2	1401.3	1439.0	1398.9	1440.0	1467.6	1497.1	1431.2	1379.4	1298.8	1395.7
32	291.2	301.1	289.8	872.1	1018.4	971.5	1054	993.2	987.8	996	1078.6	1043.3	1033	953.8	1060.5	426.2	496.6	458.8	1354.1	1424.5	1404.1	1443.6	1402.9	1444.4	1471.0	1501.3	1435.2	1383.9	1301.6	1400.2
33	292.9	306.8	291.5	873.9	1025.9	973.4	1056.3	1001.2	991.3	998	1081.1	1045.4	1034.8	955.3	1062.6	426.2	496.6	461.2	1354.1	1428.3	1406.2	1447.6	1406.5	1448.1	1473.8	1504.4	1438.9	1388.0	1304.4	1404.3
34	294.5	308.5	293.2	873.9	1029.8	974.8	1058.1	1003.3	993.6	999.8	1083.4	1047.4	1035.1	956.8	1064.4	426.2	496.6	461.2	1354.1	1431.1	1408.3	1447.6	1406.5	1448.1	1476.6	1507.5	1442.6	1388.0	1307.1	1404.3
35	296.1	308.5	294.8	873.9	1032.6	976.2	1059.9	1005.4	995.3	1001.6	1085.7	1049.5	1035.1	958.3	1066.3	426.2	496.6	461.2	1354.1	1431.1	1410.4	1447.6	1406.5	1448.1	1479.1	1509.9	1442.6	1388.0	1307.4	1404.3
36	297.6	308.5	296.5	873.9	1035.4	977.6	1061.8	1007.5	997.1	1003.4	1087.9	1051.5	1035.1	959.8	1068.1	426.2	496.6	461.2	1354.1	1431.1	1412.1	1447.6	1406.5	1448.1	1479.1	1509.9	1442.6	1388.0	1307.4	1404.3

	First Run Averages					Second Run Averages					Averages with inoculum averages subtracted									
																Sieve Rate 100	Sieve Rate 100	Sieve Rate 50	Sieve Rate 50	
	Innoculum average	SALSNES 13/3	SEDIMENT 13/3	SALSNES 15/3	SEDIMENT 15/3	Innoculum Average	SALSNES 24/4	SEDIMENT 24/4	SALSNES 26/4	SEDIMENT 26/4	Sediment 13/3	Sediment 15/3	Sediment 24/4	Sediment 26/4	Sediment **Average**	Salsnes 13/3	Salsnes 15/3	Salsnes 24/4	Salsnes 26/4	Salsnes Average
Day	Volume [Nml]	Volume [Nml] - inoculum	Volume [Nml] - inoculum	Volume [Nml] - inoculum	Volume [Nml] - inoculum	Volume [Nml]	Volume [Nml] - inoculum	Volume [Nml] - inoculum	Volume [Nml] - inoculum	Volume [Nml] - inoculum	313.8	316.5	349.4	324.8	326.1	289.0	326.2	337.5	363.6	329.1
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	
1	78.2	268.3	256.2	271.1	243.7	111.6	171.9	164.1	173.3	145.6	112.4	106.9	59.4	52.8		117.7	118.9	62.3	62.8	
2	107.4	511.1	486.9	520.5	491.9	170.2	473.7	474.0	482.5	454.2	213.6	215.7	171.7	164.6		224.2	228.3	171.6	174.8	
3	129.5	586.0	562.9	597.3	571.8	212.9	629.9	646.8	643.1	600.8	246.9	250.8	234.4	217.7		257.0	262.0	228.2	233.0	
4	145.6	614.6	595.5	629.8	607.5	245.6	742.4	745.5	758.5	687.0	261.2	266.4	270.1	248.9		269.6	276.2	269.0	274.8	
5	158.9	628.9	615.0	649.6	627.7	273.7	790.9	789.9	809.8	729.7	269.8	275.3	286.2	264.4		275.8	284.9	286.6	293.4	
6	172.5	637.6	629.4	662.7	642.4	292.0	818.9	817.1	843.9	757.5	276.0	281.7	296.1	274.5		279.6	290.6	296.7	305.8	
7	184.4	643.1	639.5	673.0	653.2	307.3	835.7	834.8	865.5	776.7	280.5	286.5	302.5	281.4		282.0	295.2	302.8	313.6	
8	193.3	647.7	648.2	681.8	662.2	322.0	846.2	847.6	880.2	791.5	284.3	290.5	307.1	286.8		284.1	299.0	306.6	318.9	
9	202.6	652.4	657.2	690.7	671.8	335.0	854.5	858.5	891.2	805.4	288.3	294.6	311.1	291.8		286.1	302.9	309.6	322.9	
10	211.1	657.1	666.7	699.6	681.3	347.7	861.6	868.6	900.6	817.0	292.4	298.8	314.7	296.0		288.2	306.8	312.2	326.3	
11	217.8	661.1	675.1	707.7	689.0	359.6	868.7	878.4	909.5	827.6	296.1	302.2	318.3	299.9		290.0	310.4	314.8	329.5	
12	223.4	663.7	683.2	715.0	696.8	369.7	876.7	888.5	919.5	837.3	299.6	305.6	321.9	303.4		291.1	313.6	317.7	333.2	
13	228.3	664.7	688.1	719.2	701.1	379.7	883.3	896.9	927.8	844.4	301.8	307.5	325.0	305.9		291.5	315.5	320.0	336.2	
14	233.6	665.6	691.9	723.2	704.4	389.2	889.3	904.7	935.4	850.7	303.5	308.9	327.8	308.2		291.9	317.2	322.2	338.9	
15	239.5	665.3	694.8	726.7	707.2	398.0	894.6	912.0	943.1	856.4	304.7	310.2	330.5	310.3		291.8	318.7	324.1	341.7	
16	246.1	663.4	696.1	727.7	708.6	405.4	899.4	917.9	949.1	861.6	305.3	310.8	332.6	312.2		291.0	319.2	325.9	343.9	
17	252.8	661.0	696.7	727.3	707.9	412.4	903.8	924.2	956.5	867.0	305.6	310.5	334.8	314.1		289.9	319.0	327.5	346.6	
18	256.5	659.8	697.9	728.3	709.4	418.1	908.0	929.5	961.4	870.9	306.1	311.1	336.8	315.5		289.4	319.4	329.0	348.3	
19	260.1	658.7	699.0	729.4	710.3	422.2	912.7	935.2	967.5	876.4	306.6	311.5	338.8	317.5		288.9	319.9	330.7	350.6	
20	263.6	657.7	700.5	730.1	711.0	426.4	915.7	938.5	971.5	879.2	307.2	311.8	340.0	318.5		288.5	320.2	331.8	352.0	
21	267.1	656.7	701.7	730.8	712.0	429.6	918.4	941.7	975.0	881.2	307.8	312.3	341.2	319.3		288.0	320.5	332.7	353.3	
22	270.8	655.9	703.4	731.4	713.8	433.0	922.3	946.3	980.4	884.7	308.5	313.1	342.9	320.6		287.7	320.8	334.2	355.2	
23	274.3	655.2	704.4	731.7	714.7	437.6	924.2	950.0	985.0	886.9	308.9	313.5	344.2	321.4		287.4	320.9	334.9	356.9	
24	276.7	655.1	705.7	732.6	715.4	440.7	925.5	952.7	988.7	888.6	309.5	313.8	345.2	321.9		287.3	321.3	335.3	358.2	
25	278.9	655.1	707.0	733.9	716.3	443.8	927.3	955.1	991.3	890.0	310.1	314.2	346.0	322.5		287.3	321.9	336.0	359.2	
26	281.0	656.0	708.6	735.8	717.8	447.6	928.9	957.5	994.8	892.0	310.8	314.8	346.9	323.2		287.7	322.7	336.5	360.4	
27	283.2	657.3	710.7	738.2	719.4	451.4	929.2	959.5	997.2	892.4	311.7	315.5	347.6	323.3		288.3	323.8	336.7	361.3	
28	286.3	657.5	712.3	740.5	720.5	453.5	930.1	961.1	999.1	893.5	312.4	316.0	348.2	323.7		288.4	324.8	337.0	362.0	
29	288.7	658.1	714.6	742.7	721.3	455.5	930.9	962.6	1001.3	894.6	313.4	316.4	348.8	324.1		288.6	325.7	337.3	362.8	
30	290.5	658.8	715.6	743.8	721.5	457.6	931.4	964.3	1003.5	896.4	313.8	316.5	349.4	324.8		289.0	326.2	337.5	363.6	

Molab Gas Chromatograph Results

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Besøksadr. Porsgrunn: Herøya Forskningspark B92
Organisasjonsnr.: NO 953 018 144 MVA

Kunde:
AQUATEAM AS
Att: Anders Gåre Søraunet
POSTBOKS 6875 RODELØKKA

0504 OSLO

RAPPORT

Bestemmelse av metan

Ordre nr.:	Antall sider + bilag:
50759	1
Rapport referanse:	**Dato:**
KR-17143	04.06.2013

Rev. nr.	Kundens bestillingsnr./ ref.:	Utført:	Ansvarlig signatur:
0	Metan	Lilian Karlsen	Lilian Karlsen

Prøver mottatt dato: 30.05.2013

RESULTATER

Prøve merket:			DG1	DG2
Parameter	Enhet	Analyse dato	KA-079130	KA-079131
Metan (CH_4)	%	03.06.13	65	66

ANALYSEINFORMASJON

Parameter	Analyseteknikk	Relativ usikkerhet (%)	Deteksjons-grense	Enhet
Metan (CH_4)	GC-FID	10-50[a]	5	ppm

a: Det vil være høyest usikkerhet knyttet til lave konsentrasjonene.