Estimation of Methane Levels in Sewer Systems

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Picture on front page: Manhole cover on Sölvegatan. Photo by Johan Cavefors

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Preface

This bachelor thesis is executed at Water and Environmental Engineering at the Department of Chemical Engineering. It is a step in our education to become civil engineers. The thesis is made in collaboration with NSVA and VA SYD. To make this thesis, a lot of help from different contacts has been necessary. We would like to thank the following persons for their big contribution to our thesis:

First we would like to thank our supervisors Jes la Cour Jansen and Karin Jönsson. Jes, for being a fantastic help in many of those speculations and questions we have had during the whole process and also for all the help of finding great contacts and information. Karin for giving us the idea and subject for the thesis and also for the contact to Jes.

Secondly we would like to thank Malin Isgren and Patrick Mårtensson for their great contribution of data but also for explaining and answering all of our questions regarding the chemistry and calculations of methane.

Next, we would thank NSVA for their participation and collaboration, especially Jan Nilsson, Marinette Hagman, Bo Petersson, Kenneth Welander, Rolf Olofsson and Avdula Aljija. Jan, for spending countless hours to supply us with all the possible sampling sites, necessary information and answering all of our questions about the sewer system in Helsingborg. Marinette, Bo and Rolf for giving us further contacts and help which enabled us to quickly proceed with our work. Kenneth, for the great mail conversations about pump stations and for providing us with data. Avdula, for spending two whole mornings helping us taking the samples around Helsingborg.

We would also like to thank David Gustavsson (VA SYD) who has been of great help when sampling at Sjölunda WWTP and providing us with necessary data.

Last but not least, we would like to thank Gertrud Persson for teaching us how to use the laboratory, providing us with sampling equipment and for all the valuable tips received throughout the work.

Sammanfattning

Det finns väldigt lite forskning på metanformation i avloppssystem och bara ett fåtal studier har gjorts. Det har påvisats att en liten mängd metan finns vid inloppet på Sjölunda reningsverk men detta var vid låga vattentemperaturer. För att vidare utforska detta togs nu provtagningar vid högre vattentemperaturer för att undersöka temperaturens påverkan på metannivåer. Sjölunda reningsverk är ett av Sveriges största och tar således emot mycket spillvatten. Det är därför ett bra val av reningsverk att analysera.

Provtagningar gjordes vid inloppet på Sjölunda reningsverk genom att använda en metod utvecklad av Isgren & Mårtensson (2013). Denna metod modifierades något för att minska felkällorna och få ut mer exakta resultat. Proven analyserades via en gaskromatograf och jämfördes därefter mot tidigare resultat från lägre vattentemperaturer.

Resultaten visar att en betydligt större koncentration av metan produceras när temperaturen blir högre. Med en temperaturskillnad på bara 5 ºC steg metannivån från 1,8 kg/h till 3,7 kg/h. Inom dessa små temperaturintervall kan en linjär funktion antas. Genom att använda denna funktion estimeras metanproduktionen på sommaren till ungefär 8 kg/h. Detta bidrag till den globala uppvärmningen motsvarar ungefär 12 bilar som kör 100 km/h.

Det här kandidatarbetet analyserar också Helsinborgs avloppssystem. Metan kan endast produceras i anaeroba miljöer, såsom i trycksatta ledningar. En nyligen gjord studie påvisar att knappt någon metan produceras i gravitationsledningar. På grund av detta har fokusen i det här arbetet legat på de trycksatta ledningarna. Eftersom Helsingborgs avloppsystem består av många trycksatta ledningar har detta varit en bra plats att ta prover från. Provtagningar från utvalda brunnar har tagits genom att använda ungefär samma metod som på Sjölunda reningsverk. Tyvärr var nedstigning i brunnarna ej möjligt vilket gjorde att en modifikation på provtagningsmetoden behövde göras. En specialgjord provtagningsenhet tillverkades och provtagningarna kunde sedan göras med denna. Senare analyserades proverna via en gaskromatograf.

Resultaten från Helsingborgs avloppssystem visar att det sker en produktion av metan i de trycksatta ledningarna. Både hydraulisk uppehållstid och rörledningens material verkar ha stor inverkan på metanproduktionen. Inget samband mellan metanproduktion och area/volym ration kunde ses utifrån resultaten från det här arbetet. Genom att använda den totala längden av trycksatta ledningar uppskattades metanproduktionen från Helsingborgs ledningssystem grovt till 25 kg/dag. Det motsvarar en CO_2 ekvivalens på 1,5 bilar som kör 100 km/h. Detta är ett väldigt litet värde och påverkar således inte miljön i någon större utsträckning.

Summary

The research of methane formation in sewer systems is very limited and only a few studies have been made. It has been shown that a small amount of methane occurs at the inlet of Sjölunda WWTP but this was at a low wastewater temperature. To further investigate this, new samples were taken at higher wastewater temperatures to analyze the difference in methane levels. Sjölunda WWTP is one of Sweden's biggest WWTP and hence receives a lot of wastewater; it is therefore a good choice of WWTP to analyze.

Field samples were collected at the inlet of Sjölunda WWTP, using a sampling method developed by Isgren & Mårtensson (2013). This method was slightly modified to minimize the error sources and receive even more accurate results. The samples were then analyzed using a GC-machine and compared to earlier results from lower wastewater temperatures.

The results show that a significantly higher amount of methane is produced when the temperature is higher. With a temperature difference of only 5 ºC, the methane levels rose from 1.8 kg/h to 3.7 kg/h. Within these small temperature differences, a linear estimation can be made. Using this estimation, the methane production during summer will be about 8 kg/h. This contribution to the global warming equals about 12 cars driving 100 km/h.

This thesis also analyzes Helsingborg sewer system. Methane can only be produced in anaerobic environments, such as rising mains. Recent studies have shown that almost no methane is produced in gravity mains and therefore, the focus in this thesis has only been on rising mains. Since Helsingborg sewer system consists of many rising mains, this has been a good sampling site. Samples from singled out manholes were taken, using approximately the same sampling technique as on Sjölunda WWTP. However, descent of the manholes in Helsingborg sewer system was not possible and thus, a modification to the sampling method had to be made. A customized sampling device was created with success and the samples could hence be taken. Afterwards, they were then analyzed using a GC-machine.

The results from Helsingborg sewer system shows that methane is being produced in rising mains. Both the hydraulic retention time and the material of the pipe seem to have a big impact on the methane production. No connection between methane production and area/volume ratio can however be seen in the results from this thesis. Using the total length of rising mains, the rough estimation of methane being produced from Helsingborg sewer system is 25 kg/day. It equals a CO_2 equivalent of about 1.5 cars, driving 100 km/h. This is a very small value and is thus not of a big concern to the environment.

To further investigate this, an equation can be made to predict the methane production in rising mains. This can be achieved by using HRT, material, A/V-ratio and temperature as the depending factors. However, this thesis contains too few values to get a good estimation and thus, much more sampling needs to be made.

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1 Introduction

1.1 Background

The content of this bachelor thesis continues on the master thesis of Isgren & Mårtensson (2013) and focuses on methane production in sewer systems and wastewater treatment plants (WWTP). In the thesis, a method was developed for measuring methane in WWTP's and rising mains. The master thesis also consists of field data from samples of methane levels from the inlet at Sjölunda WWTP. However, these samples were obtained during wintertime and the prevalent temperature was thus very low (<15 °C). These results needed to be complemented with further data obtained during a warmer period of the year, i.e. summer time or early autumn. This would help to more accurately describe a proper presentation of the methane level since the variation of methane production depends on water temperature (El-Fadel & Massoud, 2001).

The amount of methane produced in sewer systems has not received a lot of attention and only a few studies have been made on this subject (Guisasola *et al.,* 2008; Guisasola *et al.,* 2009; Gutierrez *et al.,* 2009; El-Fadel & Massoud, 2001). Guisasola (*et al.,* 2008) proved that a considerable amount of methane was being produced in the sewer systems of the Gold coast area in Australia under certain times of the day. In Sweden, the only estimation of methane produced in rising mains is made by Isgren & Mårtensson (2013). No studies, however, have estimated the total methane production of a full sewer system.

1.2 Aim

The first aim with this report is to obtain proper data of the methane levels at the inlet of Sjölunda WWTP when the wastewater is warmer, and thus complement the samples taken during wintertime. These data will then be used to try and evaluate a connection between methane production and temperature. During this process, a secondary aim will be to further develop the method used for taking samples of methane.

The next aim is to make an estimation of how much methane that is produced in the rising mains at the sewer system of Helsingborg and to evaluate the potential impact on global warming from the sewer network in Helsingborg, Sweden. Field samples from a variation of rising mains will be taken during different time of the day to obtain a more correct estimation of methane levels. Thenceforth, an estimate will be made of the methane produced in the whole system.

2 Participating Organizations

2.1 VA SYD

VA SYD is a municipally joint water and wastewater organization, working in Skåne, Sweden. The collaborative municipalities are Lund, Burlöv, Eslöv and Malmö. VA SYD has three main tasks; provide fresh drinking water, manage wastewater and dispose of household waste (VA SYD, 2013a). The vision of VA SYD is to be a leading actor in the sustainable society, both to the customer and to the environment. VA SYD is a non-profit organization, which means they are not allowed to make a profit. Because of this, no extra costs will be charged upon the customers (VA SYD, 2013b).

Sjölunda WWTP is one of Sweden's biggest waste water treatment plants and manages wastewater from about 300 000 people. It was put in operation 1963. The main part of the wastewater comes from Malmö city but a little bit also come from Burlöv, Lomma, Staffanstorp and Svedala municipalities (VA SYD, 2013c). Sjölunda WWTP receive about 1000 liter per second of wastewater (Gustavsson, 2013).

2.2 NSVA

NSVA is a municipal organization that administers the water and wastewater treatment in six municipalities; Bjuv, Båstad, Helsingborg, Landskrona, Avalöv and Åstorp (in Skåne) (NSVA, 2013a). These municipalities are also the joint owners of NSVA and all have an equal influence in the organization (NSVA, 2013b). NSVA makes sure the municipalities are supplied with fresh water and transporting and managing the wastewater in wastewater treatment plants (NSVA, 2013a).

The sewer consists of about 1380 kilometers pipeline, whereas 150 kilometers is combined stormwater and wastewater pipes (including all the municipalities). However, the combined stormwater and wastewater pipes are gradually rebuilt into separated pipes to prevent submersion and stress on the system (NSVA, 2013a).

NSVA's environmental policy, concerning water-related issues, is to strive for a sustainable and problem-free development and always to have the hydrologic cycle in mind. However, this has to be feasible in an economical and technical aspect (NSVA, 2013c). NSVA purify their wastewater with high standard following the established environmental requirements. New requirements for diminished discharge of chemicals are developed all the time and hence, NSVA is putting a lot of effort into new research to reach the requirements of the future (NSVA, 2013d).

3 Methane Formation in Sewers and Global Impact of Methane

3.1 Sewer Systems

The municipal sewer system in Sweden has a total length of 102 000 km (Lidström, 2012) which mainly is made of concrete pipes. Though today, the most common material of newly produced pipes is plastic.

A sewer system is made of gravity mains, rising mains, service lines, manholes, pump stations etc. The main part of the system, however, consists of gravity mains. The rising mains are often rather short, mostly because of the difficulty of maintenance on pressurized systems. The purpose of the rising main is to elevate the water from a lower situated gravity main to a higher situated gravity main. This is done by pressurizing the wastewater through a pump into a rising main and thus, transferring the wastewater in a vertical direction. When the wastewater reaches the top, it is released into the gravity main and atmospheric pressure occurs again. Pressurizing the wastewater into rising mains creates an anaerobic environment in the pipe as a result of the pipe being filled up with water and as oxygen consuming processes takes place in the sewers. The gravity main, on the other hand, is only partly filled with water and therefore aeration of the sewage is easily obtained (Lidström, 2012).

The ventilation of the sewer system via manholes could be of interest if the pressure in the pipe is higher than the surrounding pressure. In that case, a flow of air could appear and gas (e.g. methane) could leave the sewer system. This is often not taken into consideration when measuring gas in sewer systems (Edwini-Bonsu, 2006).

The sewage is often divided into two categories based on the source of the water; municipal and industrial wastewater.

Municipal wastewater mainly consists of water from the households and sometimes stormwater. The content of the wastewater is of big importance when deciding the effects on the recipient where the wastewater finally ends up. All unfamiliar substance combined as a group is called pollution. Different pollution can have different outcomes in a recipient depending on the recipient's origin state.

Industrial wastewater could contain damaging substances that might harm the sewage system. It could also affect the purification at the WWTP and the recipient. Therefore it is important to investigate how to take care of the industrial wastewater (Chalmers, 1993).

Manholes main purpose is to enable inspection or different investigation of the sewer systems. They also provide the system with cleansing possibilities when needed. Manholes are supposed to be located within a distance of 80 to 100 meters or, if the sewer system can be presumed self-cleansing, a maximum distance of 200 meters (Chalmers, 1993).

Earlier the manholes were exclusively built in a way that allowed persons to descend the manholes, but as the technics of repairing and investigation has evolved a lot of the manholes are built with smaller dimensions (Chalmers, 1993).

3.2 Methane

Methane is a colourless and odorless gas that burns with a blue flame. It has an explosion limit of 5-15 vol. % in air at 20°C, which indicates that methane is very flammable and explosive already at small concentrations when mixed with air (Nyns, 2000). Methane is a tetrahedron with a carbon atom in the center of mass (Nationalencyklopedin, 2013a). The chemical formula is CH_4 (See Figure 1). Naturally occurring methane is essentially of biological origin (Nyns, 2000).

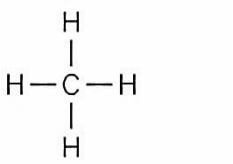

Figure 1: Chemical formula of methane.

3.2.1 Biological Methanogenesis

Methanogenesis is a biochemical process that generally occurs in anaerobic conditions. The procedure consists of two steps. In the first step the organic substance is converted into less complex polymers and is thereafter hydrolyzed to yield amino acids, sugars and high molecular fatty acids (HMFA). The amino acids and sugars are then either converted into by-products or fermented into acetic acids. The second step consists of two important chemical reactions; the methanogens (methanogenic achaeas) decompose the acetate (through acetate cleavage) into methane and inorganic carbon (Nyns *et al.*, 2012):

$$CH_3OOO^- + H_2O \leftrightarrow CH_4 + HCO_3^-$$

This reaction is known to be the predominant mechanism for methanogens (Guisasola *et al.*, 2009).

The methanogens also reduce the inorganic carbon with hydrogen which generates more methane:

$$4H_2 + HCO_3^- + H^+ \leftrightarrow CH_4 + 3H_2O$$

However, the latter reaction can only take place if the partial pressure of hydrogen is very low (Nyns *et al.*, 2012).

The production of methane mainly depends on the quantity of organic matter in the water (provided that the environment is anaerobic). Measurement of the organic material is thus an important factor to determine the potential of methane production in wastewater. By determining the Biochemical Oxygen Demand (BOD) or the Chemical Oxygen Demand (COD), the amount of degradable organic material can be measured (Casey, 1997; Droste, 1997; DeHollander, 1998).

3.3 Global Warming

Global warming implicates the amplification of the greenhouse effect (Brandt & Gröndahl, 2000). The greenhouse effect is natural and a condition for life on earth.

When the sunbeams hit the earth, most of it will pass through the atmosphere to become absorbed by the surface of the planet. The heat radiation will however not stay absorbed in the surface, but will later emit back out again. Gases that contribute to the greenhouse effect are called greenhouse

gases (GHG). These gases are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O) and Freons (CFC). GHGs absorb the heat radiation emitted from the planet's surface and thus diffuse the heat onto planet earth (Brandt & Gröndahl, 2000).

An increased level of GHG's contributes to an amplified greenhouse effect and an overall warmer climate on earth (SMHI, 2012). An increased temperature could lead to extreme draught and even new deserts in some places. It could also produce an increased movement in the atmosphere, which leads to more storms and cataclysms. Furthermore, a higher temperature also entails more pest and diseases. The sea level would also rise; due to the meltdown of the Antarctic ice (Brandt & Gröndahl, 2000).

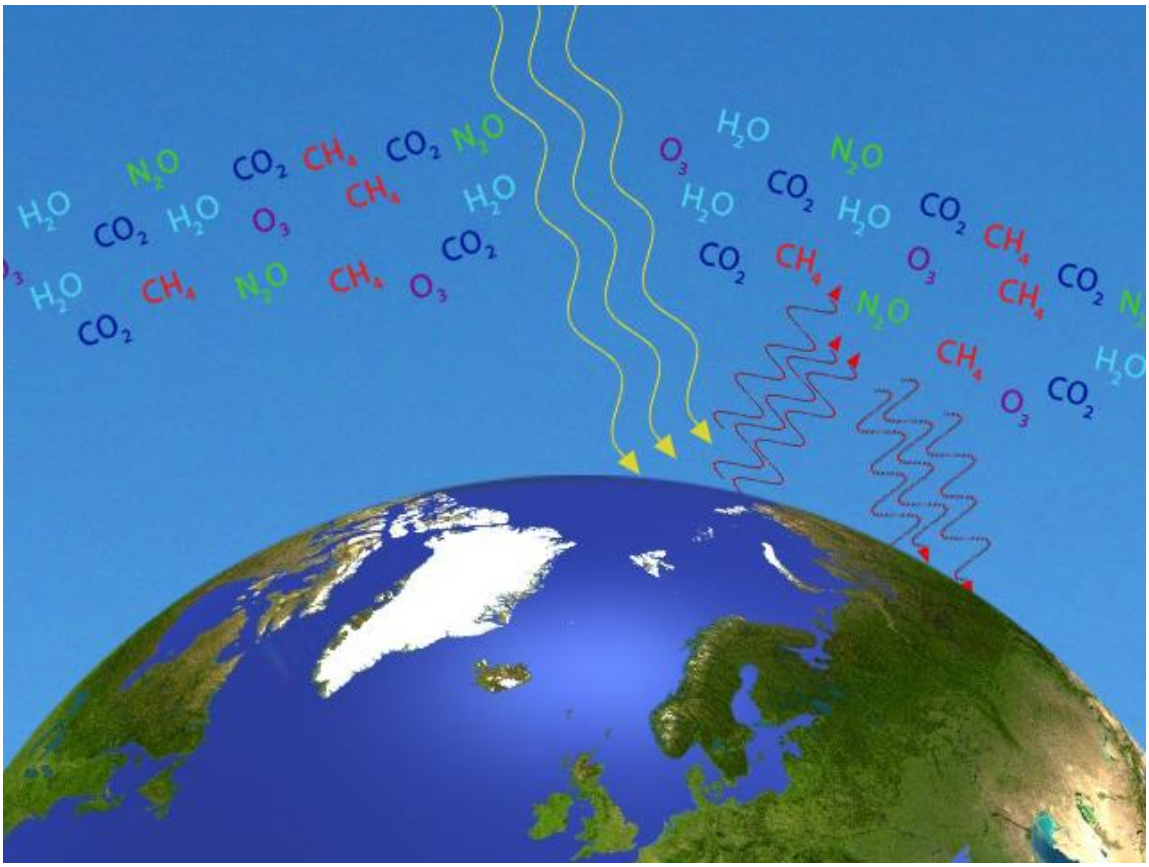

Figure 2: Illustration of sun rays absorbed by the Earth. The absorbed energy is hence emitted from the surface, absorbed by the GHG's and diffused back onto the Earth.

3.3.1 Methane's Contribution to Global Warming

The atmospheric concentration of methane has increased with 145 % since 1800. Methane concentration in particular has more than doubled since the pre-industrial age. It has increased from about 0.7 ppmv (parts per million by volume) to about 1.7 ppmv. This big increase has gained people's attention and thus, more research on the subject have been made (El-Fadel & Massoud, 2001).

Methane is the second biggest contributor to global warming and is considered as the most important GHG emitted from wastewater management (El-Fadel & Massoud, 2001). This is due to two reasons; its high potency of capturing infrared radiation (methane has a greenhouse gas potential 25 times that of carbon dioxide) (Daelman *et al.*, 2013) and its relatively high persistence in the atmosphere with a lifespan of about 12 years (Guisasola *et al.*, 2008).

In developing countries, only a small fraction of the industrial wastewater is treated whereas in the industrialized countries, almost all of the industrial wastewater is treated. This means a significant difference in the contribution to global warming. The main contributors to the organic load in from which the methane is produced, is pulp and paper, agriculture, cattle, meat, poultry and organic chemical industries (El-Fadel & Massoud, 2001; EPA, 2010).

4 Formation of Biofilms in Sewer Systems

A biofilm is a stratum of microorganisms, coating a surface in contact with water. It is held together by secreted polymeric compounds, called extracellular polymeric substance (EPS) (Kokare *et al.*, 2009).The biofilm contains of organisms combined with complex carbon hydrates, which mainly is produced by the organisms themselves. The biofilms inside rising mains contributes to a cleansing effect on the water but also creates unwanted matters (Nationalencyklopedin, 2013b). One of the substances that biofilms can produce in anaerobic environments is hydrogen sulfide (Gutierrez *et al.*, 2009). A coexistence of methane organic compounds and hydrogen sulfides has been proved by (Guisasola *et al.*, 2008) which implies that the biofilms also produces methane under the same conditions as the hydrogen sulfide.

4.1 Biofilm Formation in Rising Mains

The formation of biofilms on inner walls of sewer pipelines is well known and exists in almost all of them. The formation is similar to the development of a multicellular organism (Harrison *et al.*, 2005). The biofilm starts to form when a free planktonic bacteria adsorbs to the surface of the wall inside the pipeline. It attaches on the surface, making the adsorption irreversible. This initial adsorption triggers more planktonic bacteria to form on top of the first one and the bacteria's aggregate. When the bacteria colony grows bigger, the microbes produce an extracellular polymeric substance containing polysaccharides, DNA and proteins. This encasing is usually referred to as "slime" and can be seen on slippery rocks, lake bottoms, etc. The planktonic cells produced in the colony may leave to establish new colony structures, resulting in a new biofilm formation (Harrison *et al.*, 2005).

The growth rate of a biofilm is highly dependent of the surface material on which it is growing. Due to the larger surface area on rougher surfaces (e.g the surface of concrete) a greater amount of microbial can colonize and thus, the biofilm can grow bigger. The extent of microbial colonization has also shown to be greater on hydrophilic surfaces, such as glass and stainless steel. Hydrophobic surfaces, such as Teflon and fluorinated hydrocarbon, have shown a smaller amount of bacterial attachment (Kokare *et al.*, 2009).

When the growth rate of the biofilm is restricted, all the energy will be used to produce EPS and thus give protection to the bacterial community. The EPS works as a diffusion barrier, influencing the rate of transport of the molecules to the biofilm's interior and also influencing the reaction of antimicrobial agents with the material. When the biofilm is covered with the EPS it inhibits further growth and it is therefore the last step in the biofilm formation (Kokare *et al.*, 2009).

Models of predicting hydrogen sulfide or methane production assume that the biofilm is homogenous along the pipe. This does often not conform to reality, but the biofilm seems to vary. It has been shown that sulfide production could deplete if the sewer is long or/and has a long HRT. This is because of the limitation of sulfate reducing bacterias (SRB) which generates hydrogen sulfide. This could verify that there is a variation of the biofilm along the pipe; the SRB gets more limited downstream the pipe, hence less production of hydrogen sulfide can occur (Mohanakrishnan *et al.*, 2009). Though, this has not been proved to also apply to methane production and according to Guisasola *et al. (*2008) the methanogens did not seemed to be limited with an increased HRT. However, a fully executed study, of the variation of biofilms could affect and deplete methane formation along the pipe, has not been done.

4.2 Competition of Hydrogen Sulfide and Methane Producing Bacteria in Biofilms

Electron donors, such as hydrogen and acetate, are needed both for the methanogenic archaea (MA) generation of methane and the sulfate reducing bacteria (SRB) generation of sulfide hydrogen. The MA and the SRB are therefore competing for electron donors. Studies have shown that MA seems to be more competitive for hydrogen and acetate than SRB. However SRB can use other substances as electron donors and could therefore, depending on the substance in the wastewater, have an advantage (Guisasola *et al.*, 2009). It is also shown that if the ratio COD/SO_4^{2-} decreases below a certain value SRB is dominating. However, if the ratio increases above this value methane production is dominating (Euiso Choi *et al.*, 1991).

Nitrate dosage is commonly used as a method to control hydrogen sulfide production and has also shown to have a great inhibitory effect on methane. However, the degree of inhibition and the recovery period for methanogenic archaea (MA) seems to differ from the Sulfate reducing bacteria (SRB). It is therefore suggested that SRB can coexist with MA but in different depth of the biofilm. It seem like MA persist in the deeper layers of the biofilm. This is due to the limited penetration depth of nitrate and sulfate in comparison with the full penetration depth of sCOD (which is basically the only compound needed for methanogenisis in anaerobic environments) (Jiang *et al.*, 2013). This process is illustrated in Figure 3.

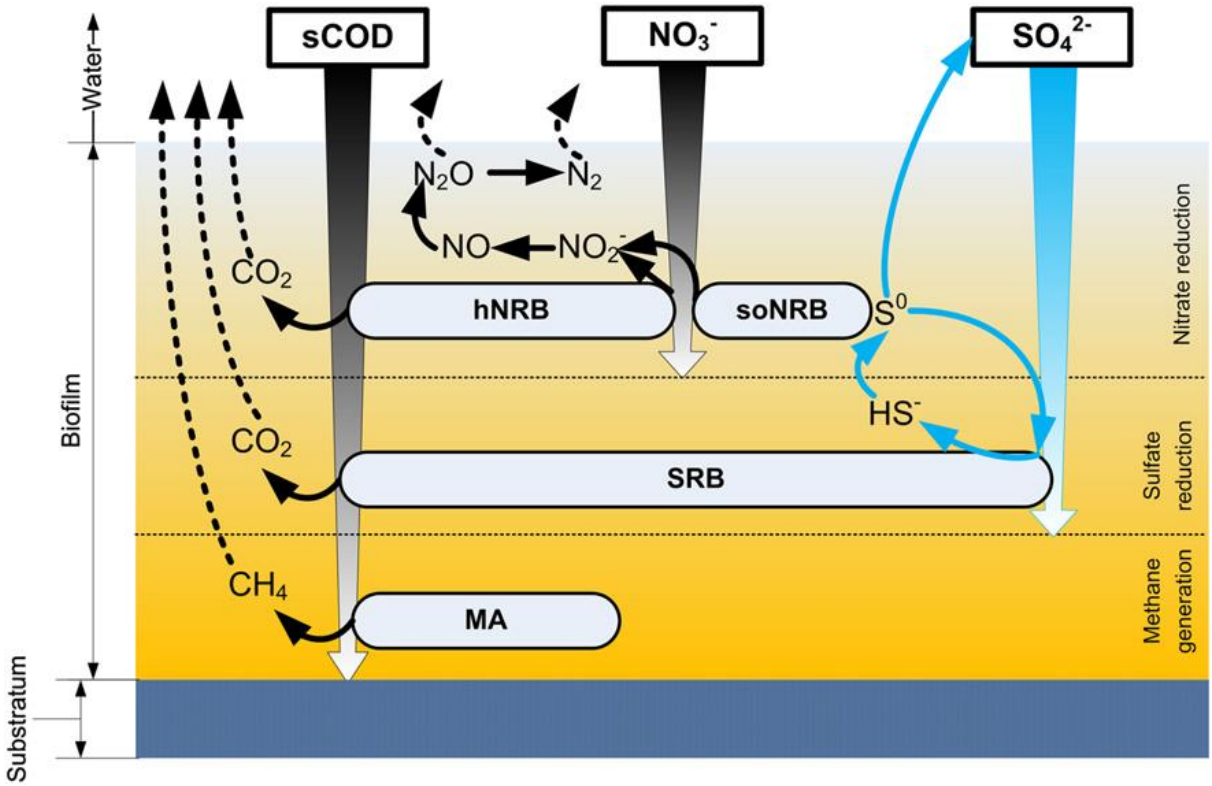

Figure 3: SRB and MB in different depth of the biofilm (Jiang et al., 2013). Reproduced with permission.

5 Formation of Methane in Sewer Systems

The formation of hydrogen sulphide in sewer systems is a well-known problem and a lot of studies have been made in this subject. However, the production of methane has received less attention and only a few studies have been made (Guisasola *et al.*, 2008; El-Fadel & Massoud, 2001; Daelman *et al.,* 2013). The environment in a rising main is ideal for methanogenesis and the report from Guisasola *et al. (*2008) showed that a considerable amount of methane actually is produced and needs further investigations.

5.1 Formation of Methane within Rising Mains

The biofilm inside the pipelines decomposes the organic material and hence produces methane (See chapter 1.6.1). The factors that favour the methanogenesis within the pipelines are explained below:

The amount of methane produced is highly dependent on organic matter and thus the COD (Considering the anaerobic environment). A high COD fuels the methanogenesis, which yields more methane.

The pH level in the biofilm regulates the production of methane. To reach optimal production, a nearly neutral pH level should be strived after. A pH level lower than six and higher than nine can inhibit the acetonic stage of the methanogenesis. A higher pH level also affects the undissociated fraction of ammoniac and volatile fatty acids (VFA), which inhibits the methanogenesis (César *et al.*, 2013).

Methane production has also shown to be dependent of temperature. The higher the temperature, the more methane is produced (El-Fadel & Massoud, 2000). The optimal temperature for methane production is around 37ºC (Jerman, *et al*,. 2009). Some studies has shown that methane production is minimal to none under 15ºC (IPCC, 2006) but Metje & Frenzel (2007) shows that a significant amount of methane is produced from CH_3COO^- at already 4ºC (see Figure 4).

The pressure inside the rising mains is also of big concern. A higher pressure stimulates the activity of hydrogen and thus the level of methanogenesis (Sharma *et al.,* 2009). A higher pressure also increases the saturation level of methane within the pipeline; hence more methane can be produced (Guisasola *et al.,* 2008, Metje & Frenzel 2007).

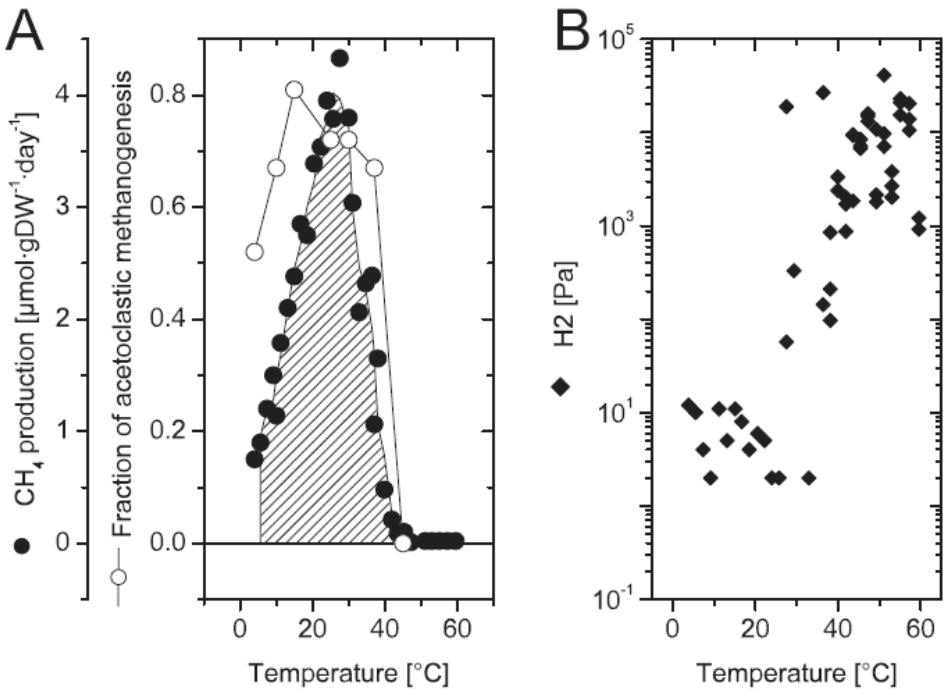

Figure 4: A. CH_4 production rate (filled symbols) and fraction of CH_4 produced from CH_3COO^- (Open symbols). B. H_2 partial pressures (Metje & Frenzel, 2007). Reproduced with permission.

The hydraulic retention time (HRT) also has an impact on the amount of methane. The longer the wastewater is exposed to the biofilm, the more methane will be produced (Liu *et al.*, 2008). The HRT is also a parameter coupled with the pH level in the biofilm. A short HRT could lead to a low pH level. As described above, a low pH level in the biofilm could hence decrease the methane production (Liu *et al.*, 2008).

Another important factor which highly regulates the level of methanogenesis is the area/volume (A/V) ratio inside the pipeline. A larger A/V ratio grants a bigger amount of wastewater to stay in contact with the biofilm and hence, more methane can be produced (Guisasola *et al.*, 2009)

5.2 Inhibition of Methane in Sewer Systems

The most effective method for inhibition of MA and SRB is, in the current situation, nitrate dosing. Control of MA and SRB is dependent on the nitrate's penetration depth in the biofilm along with the amount and the time presence of nitrate (Jiang *et al.*, 2010*;* Jiang *et al.*, 2013).

MA is more vulnerable to nitrate comparing to SRB. Studies has shown that methane production in biofilm could be suppressed within two days using a very small amount of nitrate, while the amount needed to suppress SRB is larger and takes longer time (Jiang *et al.*, 2010*).* Constant dosing of 30 mg-N/L nitrate could completely suppress MA and have a suppressing effect on SRB of 75 %. The time of recovery after a nitrate dosage also seems to differ between MA and SRB, the recovery time for SRB is about three weeks without nitrate dosing, and at least three month for MA. However, the recovery time does not seem to have a correlation with the concentration of the nitrate dosage. The biofilm's thickness also affects the suppressing degree on MA and SRB; if the biofilm is thin the nitrate could easier penetrate the biofilm and vice versa (Jiang *et al., 2010*).

6 Selection of Sampling Sites for Methane Measurments

6.1 Motivation of Selected WWTP

Sjölunda WWTP was selected for sampling of wastewater in a WWTP. This mainly to enable comparison between the results from Sjölunda WWTP received in the rapport of Isgren & Mårtensson (2013). The inlet of the wastewater is also convenient for sampling.

6.2 Motivation of Selected Rising Mains in Helsingborg

Helsingborg was chosen as a suitable municipality because of its many rising mains; hence a big variation of rising mains was available and a big amount of methane might be produced. The rising mains were selected by an aspect of the main factors for methane production in sewer systems:

- The A/V-ratio of the pipe
- HRT
- Material

The selected rising mains should therefore include a variation of diameter, length and material and also have to be convenient for sampling (a manhole in the middle of a highway is for example inconvenient). To help the analysis of the samples, it would be helpful to only vary one factor at a time. However, finding rising mains that enabled sampling possibilities with this in mind was very difficult. Data of the sewer system was received from Nilsson (2013).

Motivation for each selected rising main is described below:

1. *Hasslarp- Folkparksgatan*
   Hasslarp is a small village outside Helsingborg. The main reason for selecting this rising main is because of its long length and its relatively small diameter. If there is a big amount of methane produced, it would seem like the length has a big impact on the methane production. The pipe is made of PVC, which could also be of interest.

2. *Hasslarp- Kontorsgatan*
   This rising main was chosen because the wastewater origin from the same category as "Hasslarp- Folkparksgatan" but varies in other aspects, such as length (shorter), diameter (larger) and most importantly, the material of the pipe. The pipe is made of concrete which could be of big interest, especially in comparison with the PVC pipes.

3. *Marknadsvägen*
   Marknadsvägen is situated in Helsingborg nearby the shopping center "Väla centrum". The diameter of the pipe is small and its length relatively short. This rising main could therefore give an indication of which of these factors that have the largest impact on the production rate of methane. PVC is the most common material of pressurized pipes (Sörensen, 2013). An assumption was therefore made that the pipe was made of PVC.

4. *Mörsaregatan*
   Mörsaregatan is situated relatively near Marknadsvägen but is located in an industrial area which could be of interest. This rising main is rather short, has a big diameter and is assumed being made of PVC. These factors indicate that a small amount of methane should be produced. It can also easily be compared with the rising main on Marknadsvägen because they have similar length, are made of the same material, but have a larger diameter (i.e a smaller A/V-ratio) and thus, the production rate of methane should be lower. Since it has about the same length as the rising main at Kontorsgatan but is made of a different material, a comparison between these two could also give an indication about how the material affects the production rate of methane

Table 1: Information and data of the selected rising main.

Location	Diameter (mm)	Length (m)	Material
1(Folkparksgatan)	225	4538	PVC
2(Kontorsgatan)	300	770	CONCRETE
3(Marknadsvägen)	200	1025	PVC
4(Mörsaregatan)	400	832	PVC

Another location, Hittarp Kruareliden, was also used for sampling. However, when opening the lid of the manhole, the main appeared to be a gravity main and the results are hence not presented with the results of the other locations.

7 Materials and Methods

7.1 Overview of Measuring Methods

In Corrie (n.d.) a procedure for sampling collection of hydrogen sulfide in the field is described. This can be applied to the sampling of methane as they are depending on the same factors.

When sampling methane, it is of significance that the samples, as far as possible, avoid being exposed to oxidation after the sampling and during storage. This is often practically difficult to achieve and can therefore affect the reliability of the analysis. Interference of other compounds, such as precipitation of iron compounds, in the wastewater when analyzing the samples should also be considered (Corrie, n.d.). Therefore it is of big importance to handle the samples in a way that minimize oxidation. When transferring the wastewater to the container; pour the sample in a way that prevents it from oxidation. This procedure can be done with a sterile syringe drawing the sample from below the surface and thereafter invert and tap the syringe to get rid of potential air bubbles. Discharge the sample into a container slowly and when possible (when the level of sample has increased) below the surface of the sample. When filtering, the samples the procedure is done by the same principle (Corrie, n.d).

To avoid further production of methane after sampling the samples ought to be placed in a cooling box filled with ice. However, the samples and the ice must not be in direct contact or else the melted ice could contaminate the samples. The analysis then ought to take place within 24 hours (Corrie, n.d).

7.2 Background Methane in Vacuum Tubes

The vacuum tubes used during the sampling originally contain a small amount of methane (Isgren & Mårtensson, 2013). To receive a more precise value of the amount of methane from the sampling areas, this small amount have to be subtracted. The vacuum tubes used during the sampling from Sjölunda WWTP were the same tubes as were analyzed of background methane by Isgren & Mårtensson (2013). Hence, their calculated value could be used. However, when taking samples from the sewer system of Helsingborg, another vacuum tube was used. This vacuum tube needed to be analyzed of background methane in order to receive a more precise value from the sampling area.

One 12 ml vacuum tube was filled with 6 ml of distilled water through a filter (same volume as used during sample analysis). It was shaken for 30 seconds. The 12 ml vacuum tube was then placed in the fridge (4ºC) for 60 minutes, allowing equilibrium, along with an empty 12 ml vacuum tube. Both vacuum tubes were analyzed in the GC and the amount of background methane could hence be calculated, using the same calculations as for the other samples.

7.3 Measuring Method at Sjölunda WWTP

The method used for taking samples at Sjölunda WWTP is based on the method developed by Isgren & Mårtensson (2013) but with a few modifications (to only see the modifications, go to chapter 7.5). For a list of the equipment used, see appendix.

7.3.1 Sampling at Sjölunda WWTP

A cooling box was filled with ice and then a small blanket was put on top of the ice (to avoid direct contact between ice and glass bottles). The 100 ml bottles were all marked with a number.

The samples were taken from a platform right above the main inlet to the WWTP. The sampling device was submerged into the wastewater right next to the inlet. The device was lowered into the water and with an effort to try and keep it as central as possible in the stream. A marking was made on the rope holding the device to enable the same submerging level on all tests. When the sampling device was filled with water, it was raised to the platform. A pipet was used to transfer the water from the sampling device to a 100 ml bottle. The sample from the device was taken from the bottom to avoid the top water which might be exposed to oxidation. When filling the 100 ml bottle, the tip of the syringe was put against the bottom of the bottle and then emptied slowly to avoid slipping of methane. The 100 ml bottle was filled until surface tension occurred to minimize the amount of air inside when closed (however, a small air gap is impossible to avoid). The 100 ml bottle was then put inside the cooling box for storage. The procedure was repeated every 30 minutes for seven hours, receiving a total amount of 15 sample bottles.

7.3.2 Analysis of Samples from Sjölunda WWTP

To make more accurate calculations, the precise volume of the 7 ml vacuum tube needed to be determined. This was made by weighting the 7 ml vacuum tube, filling it up with distilled water and then weight it again. The volume water (i.e. volume of the vacuum tube) could thus be measured. The next preparation was to rinse the 0.22 µm filter with wastewater to avoid a mixture of other matters from the filter. This was done by drawing wastewater, with a 5 ml syringe, from one of the samples. Thereafter, attach the filter on top and then eject the wastewater through the filter.

The first 100 ml sample was taken out of the cooling box. A 5 ml syringe was used to draw the wastewater from the bottle. The wastewater was taken from the middle of the bottle to avoid ooze in the bottom and the more oxidized wastewater at the top. The 5ml syringe was then inverted to dispose of the air by tapping on the side. The 0.22 µm filter was then mounted on the 5ml syringe and a needle was attached. Each wastewater sample was ejected into two 7ml vacuum tubes (two tests per sample). The wastewater was drawn into the vacuum tubes due to the vacuum and almost no extra force was needed. The 7 ml vacuum tubes were filled to a water/air ratio of 50 %. To reach atmospheric pressure in the vacuum tubes (making calculations possible), they were punctured with a needle and thus, the vacuum was released. The vacuum tubes were then shaken for 30 seconds, put on the vacuum tube rack and placed in the fridge (4ºC) in 60 minutes, this to allow equilibrium of the methane to occur.

Thenceforth, the volume of methane in the samples was measured, using the Gas Chromatograph (GC). By using a Hamilton syringe, gas from the 7 ml vacuum tube (two for each sample) was transferred to the GC. The samples were analyzed in the GC. The mean value of the two vacuum tubes from each sample was calculated to receive a more precise GC-area from the sample. From these results, a concentration of methane could be calculated.

7.4 Measuring Method of Helsingborg's Sewer System

The method of taking samples in sewer system is also based on the method developed by Isgren & Mårtensson (2013). However, the samples was not collected by descending the manholes, but were instead collected by using different apparatuses. For a list of the equipment used, see appendix.

7.4.1 Sampling in Helsingborg's Sewer System

The preparation phase was done in similar manners as preparation for sampling of Sjölunda WWTP with some minor differences; a cooling box was filled with ice and then a small blanket was put on top of the ice, then both the vacuum tubes and the 100 ml glass bottles were numbered.

Figure 5: Cooling box filled with ice and a blanket put on top of the ice. 100 ml bottles marked with a number.

The customized sampling device was then prepared;

A needle was mounted on the edge of a stick while making sure that air could flow through the needle. A tube holder was customized and taped on a stick with a cup placed on the end. Thereafter a funnel was placed right above the tube holder (with enough room to place a vacuum tube in the tube holder); this to easier be able to penetrate the vacuum tubes membrane with the needle.

Figure 6: Left. Customized sampling device. Right. Close up on tube holder with the needle stick placed above.

When arriving to specific manhole, its lid was removed. Since descending the manhole was not possible, the stick with the cup was submerged into the stream of the rising mains outlet. When the cup was filled, it was emerged to the platform and hence the wastewater was transferred into to the 100 ml glass bottles by the same method as for Sjölunda WWTP (see chapter 3.2.2 “sampling”). The samples were then placed in the cooling box for cooling.

Figure 7: Pipet with pipet bulb, used for transferring water to 100 ml bottles.

When sampling gas, a vacuum tube was placed in the tube holder on the device. The device was then submerged into the manhole and the stick with the needle was used to penetrate the membrane on the vacuum tube allowing gas to enter the tube. The samples were then placed in the cooling box for cooling.

7.4.2 Analysis of Samples from Helsingborg's Sewer System

The same analysis method was used for the samples from Helsingborg as for the samples from Sjölunda WWTP. Beyond this, an analysis for the samples with gas only was made. The 12 ml vacuum tubes with gas only were placed in the fridge to reach the same temperature as the other 12 ml vacuum tubes with wastewater (4ºC). The gas samples were then analyzed in the GC in the same way as the wastewater samples and a volume of methane could hence be calculated from the received GC area.

7.5 Modifications of Measuring Methods

The method used for measuring by Isgren & Mårtensson (2013) was used with some minor modifications. Following modifications for measuring methods of Sjölunda WWTP were made:

- A small blanket was put inside the cooling box between the ice and the samples. This to avoid the samples from being contaminated from melted ice during transport.
- A pipet with a pipet bulb was used for transferring the wastewater from the sampling device to the 100 ml glass bottles at Sjölunda WWTP. This to avoid unnecessary contact with air, which would increase slipping of methane from the samples.
- The 7 ml vacuum tube's volume was measured to make a more precise water/air ratio.
- The water/air ratio in the 7 ml vacuum tubes was 50 % which makes it easier to calculate the methane concentration.
- Two vacuum tubes were used for each sample instead of one. The mean value could hence be calculated and the content of methane could thus become more precise.

The modifications mentioned in the chapter above (3.4.1) are also applied in the sampling procedure of Helsingborg's rising mains. Following modification was also made:

- Customized sampling devices were created and used to allow taking samples without descending the manholes.

8 Calculations of Methane Production in Sewage Water

8.1 Computation of Sjölunda WWTP

The Areas were received from the GC ($A_{CH_4Sample}$) and hence, the concentrations from the samples could be calculated, using equations 1, 2 3 and 4. To see the results in a more usable unit, equation 5 is used.

$$C_{CH_4,water} = \frac{n_{CH_4gas} + n_{CH_4liquid}}{V_{liquid}} \quad (1)$$

$C_{CH_4,water} = Concentration\ of\ methane\ in\ wastewater$ (moles/m^3)
$n_{CH_4gas} = Moles\ of\ methane\ in\ gas$ (moles)
$n_{CH_4liquid} = Moles\ of\ methane\ in\ liquid$ (moles)
$V_{liquid} = Total\ volume\ of\ liquid$ (m^3)

$$n_{CH_4gas} = \frac{P_{tot} \cdot X_{CH_4} \cdot V_{gas}}{R \cdot T} \quad (2)$$

$P_{tot} = Atmospheric\ pressure$ (kPa)
$X_{CH_4} = Partial\ pressure\ of\ methane$ (%)
$V_{gas} = Volume\ of\ gas$ (m^3)
$R = Gas\ constant$ (mol$^{-1} \cdot$ K^{-1})
$T = Temperature$ (K)

$$n_{CH_4liquid} = \frac{P_{tot} \cdot X_{CH_4} \cdot V_{liquid}}{k_{H,CH_4}} \quad (3)$$

$k_{H,CH_4} = Henry's\ constant\ for\ CH_4\ at$ 298K (Pa $\cdot$ m$^3 \cdot$ mol^{-1})

k_H is extracted from table (J. Villadsen *et. al.* 2011).

$$X_{CH_4} = \frac{A_{CH_4Sample}}{A_{CH_4Pure}} \quad (4)$$

$A_{CH_4Sample} = Area\ of\ sample\ from\ GC$ (m^2)
$A_{CH_4Pure} = Area\ of\ pure\ methane = 1$ m^2

$$Q_{m,CH_4} = \frac{Q_{water} \cdot C_{CH_4,water} \cdot R \cdot T \cdot \rho_{metan}}{P} \cdot 3{,}6 \quad (5)$$

$\rho_{metan} = Density\ of\ methane$ (kg/m^3)
$Q_{m,CH_4} = Amount\ of\ methane\ produced\ through\ pipeline$ (kg/h)

8.2 Computation of Methane in Helsingborg Sewer System

To calculate the amount of methane produced in the rising mains in Helsingborg sewer system, the same method as for Sjölunda WWTP was used. I.e. the equations 1, 2, 3, 4 and 5 were used.

To further investigate the methane production, the flow in the rising mains needed to be estimated. This estimation was done by using a pump graph for each pump at respectively pipe, see appendix 5. A presumption was made that the pump operates at the plotted efficiency by the square on the graph. To confirm this, an estimation of the hydraulic characteristics for each pump was made through equation 6 and 7. The height difference data was received from Nilsson (2013). The estimation confirmed that the pumps operate at the plotted efficiency by the square on the graph (Appendix 5) and thus, these flow values could be used. Data for the average pumping time per day for each pump at the sampling sites from Welander (2013) was also received. There are two (sometimes three) pumps at each sampling location. These are standardized pumps and thus operate alternately (Welander, 2013); the total pumping time is therefore calculated by adding the two average pumping times. The total daily flow for each pipe could then be calculated through equation 8. Equation 9 could then be used to calculate the HRT for each pipe.

$\Delta h = z + \frac{Q_{water}^2 \cdot L_{pipe}}{Constant^2}$ (Sörensen, 2013) (6)

$Q_{water} = water\ flow\ through\ pipeline$ (m^3/s)
$L_{pipe} =$ Length of pipe (m)
$Constant = constant\ for\ each\ pipe\ (calculated\ below)$
$z = height\ difference\ from\ start\ to\ end\ of\ pipe\ (m)$

$Constant = \frac{1}{n} \cdot (\frac{d_{pipe}}{4})^{2/3} \cdot \frac{\pi}{4} \cdot {d_{pipe}}^2$ (Sörensen, 2013) (7)

$n = Manning's\ roughness\ coefficient$ ($Wong\ \&\ Lim,$ 2006; $Kammand,$ 1988)
$d_{pipe} = diameter\ for\ pipe\ (m)$

$Q_{day} = Q_{pump} \cdot t_{pump}$ (8)

$Q_{pump} = Flow\ generated\ by\ pump\ (m^3/h)$
$t_{pump} = Average\ pumping\ time\ per\ day\ (h/d)$

$HRT = \frac{L_{pipe}}{Q_{day}/A_{pipe}} \cdot 24$ (Guisasola *et al., 2009*) (9)

$HRT = Hydraulic\ retention\ time\ (h)$
$L_{pipe} = Length\ of\ pipe\ (m)$
$Q_{day} = Average\ daily\ flow\ through\ pipe\ (m^3/d)$
$A_{pipe} = Cross\ sectional\ area\ of\ pipe\ (m^2)$

To calculate the concentration of methane in the air of sewer systems, equation 10 was used. A rough estimation of the total amount of methane in the sewer system of Helsingborg was calculated using equations 11, 12, 13 and 14. The total length of the rising mains in Helsingborg sewer system was extracted from Svenskt Vatten VASS (2013).

$$C_{CH_4.air} = \frac{P_{tot} \cdot X_{CH_4}}{k_{H,CH_4}} \quad (10)$$

$C_{CH_4.air} = Concentration\ of\ methane\ in\ air$ (moles/m^3)

$$CH_{4,tot} = CH_{4,avrg} \cdot L_{tot} \quad (11)$$

$CH_{4,tot} = Total\ amount\ of\ methane\ in\ sewer\ system\ (kg/d)$
$CH_{4,avrg} = Average\ amount\ of\ methane\ per\ meter\ and\ day\ (kg/(m \cdot d))$
$L_{tot} = Total\ length\ of\ rising\ mains\ in\ sewer\ system\ (m)$

$$CH_{4,avrg} = \frac{\left(\sum_{i=1}^{n} CH_{4,pipe,i}\right)}{n} \quad (12)$$

$CH_{4\ ,pipe} = Average\ amount\ of\ methane\ in\ each\ pipe\ per\ meter\ and\ day\ (kg/(m \cdot d))$

$n = number\ of\ pipes$

$$CH_{4,pipe} = \frac{\left(\sum_{i=1}^{n} CH_{4,sample,i}\right)}{n} \quad (13)$$

$CH_{4\ ,sample} = Amount\ of\ methane\ in\ each\ sample\ per\ meter\ and\ day\ (kg/(m \cdot d))$
$n = number\ of\ samples\ per\ pipe$

$$CH_{4\ ,sample} = \frac{\left(Q_{day} \cdot C_{CH_4,water}\right)}{10^6} \quad (14)$$

9 Results

This Chapter contains the results from chapter 5 "Measuring methods", chapter 6 "Background methane in vacuum tubes" and chapter 7 "Calculations". All calculations were made in MATLAB and the code is attached in appendix.

9.1 Results of Background Methane in Vacuum Tubes

The amount of methane found in the 12 ml vacuum tubes was minimal and essentially smaller than the amount of methane found in the 7 ml vacuum tubes. The concentration of methane found in the 12 ml vacuum tube filled with 6 ml distilled water was $5.83*10^{-4}$ moles/m^3 and with gas only, the concentration was $2.02*10^{-4}$ moles/m^3. Compared to the amounts of methane in the samples from Sjölunda WWTP and Helsingborg's sewer system, this background methane could almost be excluded. However, to make the calculations for Sjölunda WWTP and Helsingborg's sewer system more accurate, the background methane is subtracted anyway.

9.2 Results from Sjölunda WWTP

A higher amount of methane has been observed in Sjölunda WWTP from the sampling data, compared to the methane levels received by Malin & Mårtensson (2013). The average temperature of the wastewater was 19.2ºC compared to Malin & Mårtensson (2013) whereas the temperature was 14.2ºC. The result from the samples taken 2 of October, 2013 is compared below, to the results from Malin & Mårtensson (2013).

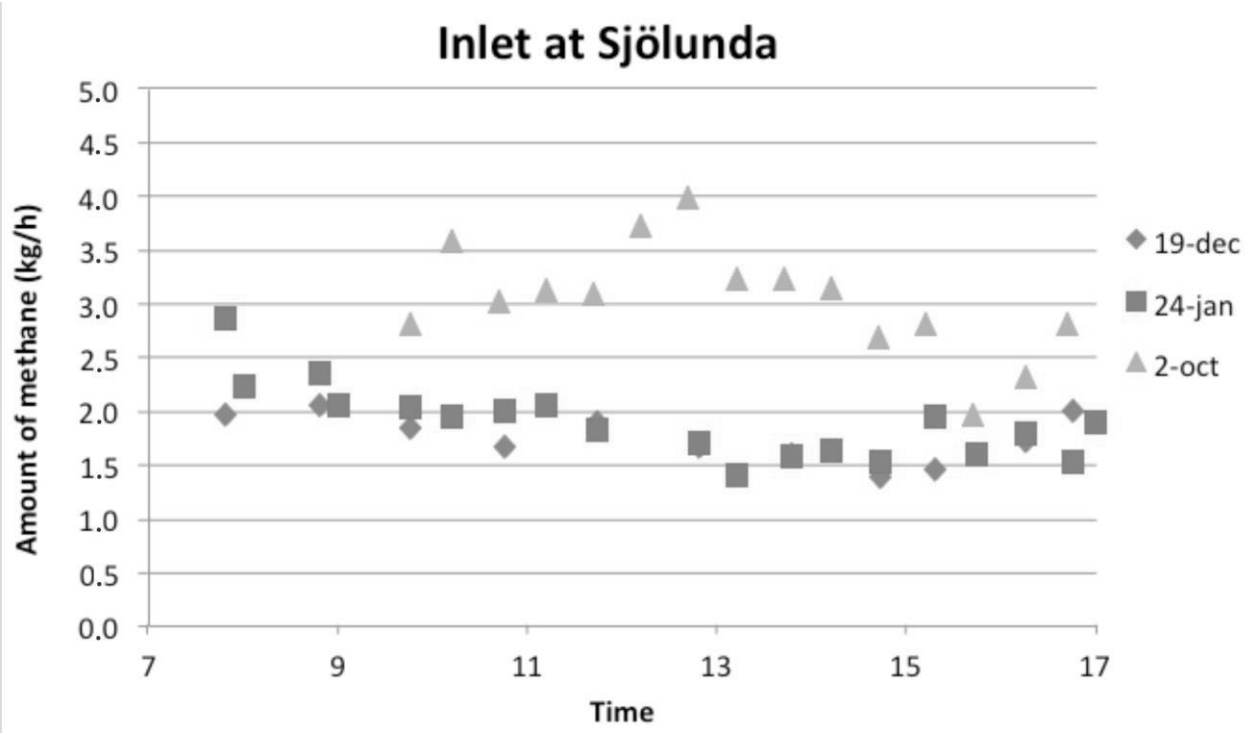

Figure 8: Methane flow at the inlet of Sjölunda WWTP.

This shows that the methanogenesis within pressurized pipes is highly dependent of temperature and methane levels in the summer could hence be even higher. The average methane flow from the

samples taken 2nd of October is 3.66 kg/h and the production of methane is relatively equal throughout the day. The highest amounts of methane from the day seem to be when the flow is at its maximum. The lowest values seem to be in the afternoon. However, the highest concentration seems to be around 10:00 (see appendix).

9.3 Results from Helsingborg Sewer System

The results of the samples from Helsingborg sewer system for different sampling times are presented in Table 2, the methane concentration in the wastewater is also presented in figure 9.

Table 2: Results of the samples in Helsingborg sewer system.

Rising main (RM)	Time	Temperature (ºC)	Concentration in wastewater (mg/L)	Concentration in gas (mg/L)
1 (Folkparksgatan)	08:15**	9.3	1.43	0.15
	09:00*	7.7	1.37	0.81
	09:25**	9.3	2.15	0.05
2 (Kontorsgatan)	08:25**	10.4	0.87	0.09
	09:40*	7.7	0.93	0.06
	09:40**	10.4	1.20	0.03
3 (Marknadsvägen)	08:40**	12.4	0.21	0.11
	09:50**	12.4	0.25	0.02
	10:20*	11.2	0.25	0.87
4 (Mörsaregatan)	08:55**	10.0	0.17	0
	10:10**	10.0	0.30	0.20
	10:50*	7.9	0.14	0.02

*First sampling occasion (2013-11-15)
**Second sampling occasion (2013-11-20)

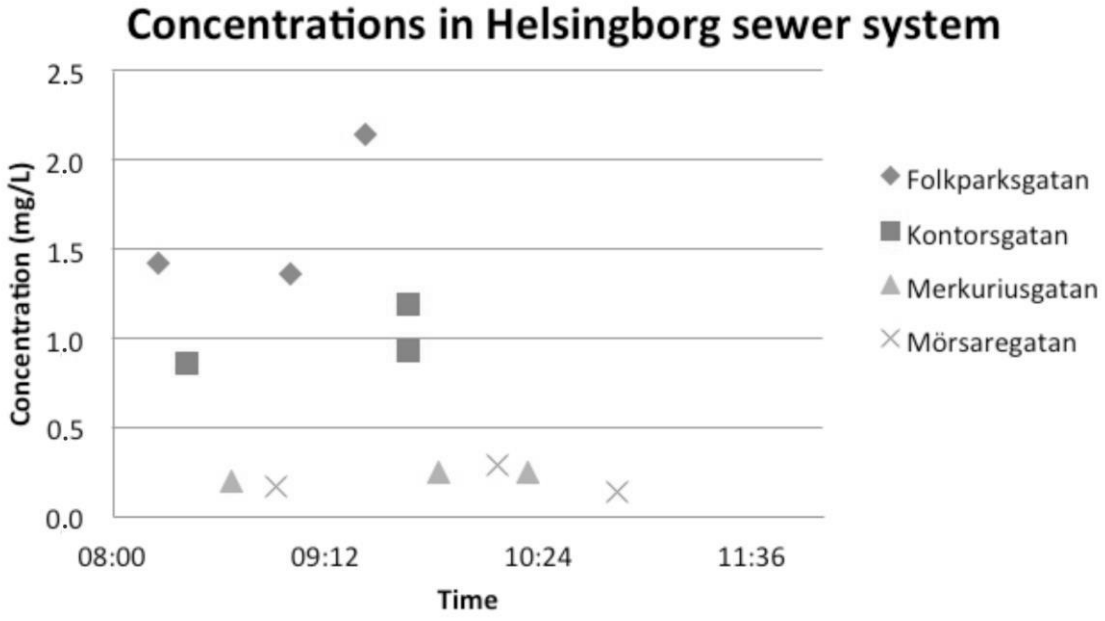

Figure 9: Concentrations of methane from Helsingborg sewer system.

The results show a small variation in concentration depending on time. The concentration of methane seems peak around 9:30-10:00. However, the concentration differences within each pipe are overall very small, this also between the different sampling dates. A relation between the temperatures and the concentrations is hard to prove. The results also show that methane is present in the air in the manholes. However, the values vary a lot. The methane levels in the air in the manholes were higher at the first sampling occasion.

The results of the average values for each rising main are presented in Table 3.

Table 3: Average values from rising mains in Helsingborg sewer system.

Rising main (RM)	AV-ratio (m^{-1})	HRT (h)	Material	Temperature (ºC)	Concentration (mg/L)
1(Folkparksgatan)	17.8	5.7	PVC	9.3	1.65
2(Kontorsgatan)	13.3	1.7	CONCRETE	10.4	1.0
3(Marknadsvägen)	20.0	1.0	PVC	12.4	0.24
4(Mörsaregatan)	10.0	0.7	PVC	10	0.20

RM 1 compared to RM 3 and 4 shows that the HRT seems to have a significant impact on the amount methane produced; a longer HRT seems to enhance the methane production. Also, the material of the pipe seems to have a significant effect on the methane product. RM 2 compared to RM 3 shows that the wastewater from a concrete pipe has a higher amount of methane in comparison with a PVC pipe with an equal HRT. The surface of the two materials differs; concrete has a rougher surface and is probably also more hydrophilic than PVC. These assumptions are however uncertain since it is based on very few measurements.

The estimation of the total methane production from Helsingborg sewer system is about 25 kg/day.

The gravity main tested show a low value of methane, the concentration was 0.075 mg/L.

10 Discussion

The results from Sjölunda WWTP have shown that the temperature of the wastewater has a big impact on the production rate of methane. The temperature difference between the samples from 2nd of October, 2013 and 24 of January, 2013 respectively 19 of December, 2012 is 5ºC. This rather low temperature difference generates an increase of the methane production by a bit more than 100%. Assuming that the graph of methane production depending on temperature (figure 4) applies, it seems as the methane production varies non-linear with the temperature. Though, within the current range of temperature in the wastewater (between wintertime and summertime, 14-22ºC) the methane production could be assumed almost linear. The gradient of the graph is large around these temperatures and therefore, the methane production will continue to rise rapidly even with low temperature differences. The methane production during summertime, at 21.8ºC, will be approximately 8 kg/h.

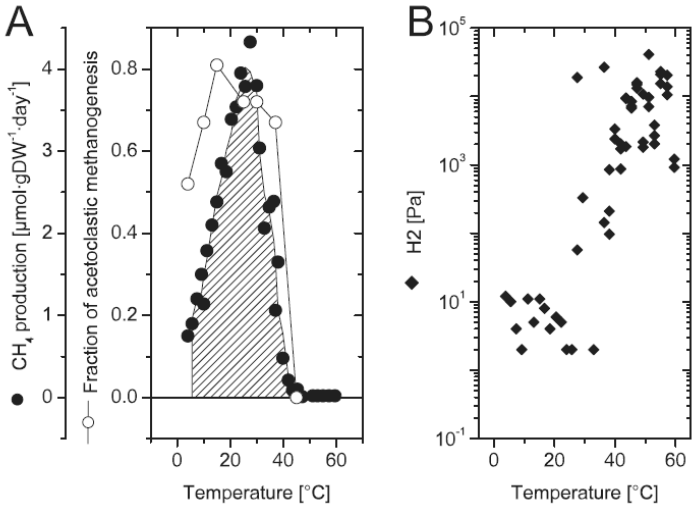

Figure 10: A. CH_4 production rate (filled symbols) and fraction of CH_4 produced from CH_3COO^- (Open symbols). B. H_2 partial pressures (Metje & Frenzel, 2007). Reproduced with permission.

Methane has a CO_2 equivalent of 25 (IPCC, 2006). A European car emits approximately 165 g CO_2/km. Provided that a car is traveling in 100 km/h; it emits 16.5 kg CO_2/h. In the summertime, Sjölunda WWTP's emits CH_4 equivalent to the emission of CO_2 from 12 cars driving in 100 km/h. Compared to wintertime (Isgren & Mårtensson, 2013), this estimation tells us that the emission of CO_2 equivalents is four times higher in summertime. Hence, the emission in the summer seems to be significantly higher than in the winter but is still very low and thus, not contributing very much to the environmental issues (i.e. the greenhouse effect). The amount of cars corresponding to the results of Sjölunda WWTP from this thesis is about six. This value is slightly smaller than the estimated summertime value, this due to a lower temperature than the maximum summertime temperature.

The methane levels in the samples from Helsingborg sewer system seems to vary a lot for the different rising mains. However, the samples collected at different times from a specific rising main seem to have a similar concentration of methane. Even though the temperature of the wastewater is low, methane is produced in a noticeable amount. IPCC (2006) claims that methanogenesis is not present within temperatures underneath 15ºC. The results from this test prove the contrary and seem to be more accommodated to the studies from Metje & Frenzel (2007) where methanogenesis is

present even in lower temperatures. As long as the wastewater is exposed to the biofilm for a long time, i.e. if the HRT is long enough, methane is likely to be produced. The gravity main tested showed a very low methane concentration that confirms that not a lot of methane is produced in aerobic environments.

The material of the pipes seems to be of surprisingly high significance. Recent studies have shown that the A/V-ratio, the HRT and the temperature have a big impact on the methane production REF. It is difficult to prove a connection between the A/V-ratio and the methane concentration from the results of this thesis. Pipes with different A/V-ratios, but with other factors rather constant are not compared; if the A/V-ratio differs the material or/and the length also differs, which makes it difficult to see a connection (see table 2). To further investigate this, more tests are necessary where the A/V-ratio differs and the other influential factors (such as temperature, HRT and material) are constant for the different sampling sites. The material of the pipe has not gotten as much attention as the other influencing factors. Proceeding from the results of this thesis, pipes made of concrete seems to produce much more methane than a pipe made of PVC. This could be due to the hydrophilic properties of concrete. The biofilm easier attaches to the surface of the concrete than to the surface of the PVC. When predicting methane levels, it therefore seems important to take the material of the pipe into account.

The methane level in the samples from Sjölunda WWTP seems to be relatively equal throughout the day (with a few exceptions). The maximum value of methane turns out to be when the flow rate peaks. This contradicts the theory that a longer HRT generates more methane. A lower flow rate gives a higher HRT that should foster the amount of methane. The reason for this could be that the pressurized inlet pipe to Sjölunda WWTP is too short to produce any substantial amount of methane and hence, the methane in the wastewater origins from upstream pipes. This could be other rising mains in the sewer system.

At 10:00, the highest concentration is observed. A connection can be seen with Helsingborg sewer system whereas its highest concentration also peaked around 10:00. Why this is the case is uncertain. However, it could be because of the pumps activity. When a larger flow occurs in the early morning (due to people waking up and using water), the pumps activate. The amount of methane might then be very high because of the stagnant wastewater in the rising mains when the pumps are not active as often during nighttime. Because of the pumps being activated more often, the stagnancy of the wastewater decreases and hence a lower amount of methane could be produced. Around 10:00, when people go to work, the pump activity decreases and thus, the stagnancy of the wastewater increases. When this occurs, more methane could be produced once again, probably not as much as the early peak but noticeable in the results. To validate these theories, more sampling needs to be made earlier in the morning and also throughout the day.

The time interval in this thesis for the sampling in Helsingborg is very short. Therefore, the variation of methane depending on time is very difficult to predict, only using these values. To receive a better understanding of how the methane production varies along the day, a sampling with larger time interval needs to be made.

The results from the methane in the air of the manhole vary a lot. The manhole on Folkparksgatan and Marknadsvägen showed a higher amount of methane, when opened in the first sampling occasion (2013-11-15). These two manholes were the ones that did not seem to have been opened for a long time. One (Folkparksgatan) was tightly wedged and took a lot of effort to open. The other one (Marknadsvägen) had a lawn planted on top of it and had to be dug out. Since they had not been open for a long time, methane could probably have stacked up inside the two manholes and thus,

given a higher methane level. In the second sampling occasion, the results from the two manholes showed the same low amount of methane as the rest of the results. This could be due to that they were opened just a few days ago.

Another reason why the first two manholes had a larger amount of methane in the air could be due to the slipping of methane. Since these two manholes probably were tightly sealed, no methane could slip out from them. In the other ones that were less sealed, methane might slip out through tiny interstices. In the sampling occasion, when the two manholes already had been opened a few days ago, methane could slip out just as in the other manholes and thus, the methane levels were equally low.

The result from the calculation of the total amount of methane produced in Helsingborg sewer system is very uncertain. The estimation presupposes that the pipes measured in this thesis are the average in pipe length, materials and A/V ratio of Helsingborg sewer system. This is most likely not the case. However, this rough estimation still says something about the amount of methane being produced. The estimated emitted amount is only about 28 % of the measured amount from Sjölunda WWTP. It corresponds to about 1.5 cars driving in 100 km/h. This is not an amount that is of big concern to the environmental issues. The amount of methane might be slightly higher during summertime but it still should not be an issue to the environment. Though, measurement of methane production in very long pressurized pipes could still be of interest, this because the length of the pipe seems to have a big impact on the methane production.

The method for sampling has been developed from Isgren & Mårtensson's (2013) sampling method. The modifications used allow sampling very near the pressure release of a rising main, which could decrease the slipping of methane. By transferring the wastewater via a pipette, the slipping of methane could be avoided even more. The modification should, theoretically, improve the results. However, it is very difficult to prove this without further investigation. Also, if air accidently enters the pipet it creates bubbles which could enhance the oxidation even more than transferring the wastewater just by carefully pouring it.

The pumps in the pressurized pipes were assumed to work at the efficiency marked on the graph. These efficiencies were only validated on two of the graphs since not enough data was available. The flow rates used might therefore not be entirely correct but is likely a good estimation.

The 7 ml vacuum tubes used during analysis of the samples from Sjölunda WWTP were the same kind as used by Isgren & Mårtensson (2013). These vacuum tubes have proven to contain a significantly higher amount of background methane, compared to the 12 ml vacuum tube used for the analysis of samples from Helsingborg. However, to better be able to compare the results from Sjölunda WWTP with the results from Isgren & Mårtensson (2013), the same 7 ml vacuum tubes were used. This gives the opportunity to use the same background methane values and thereby make the comparison of the values more accurate. When analyzing the samples from Helsingborg, no comparison with Isgren & Mårtensson (2013) was required and therefore the 12 ml vacuum tubes were used. These tubes had a smaller amount of background methane (almost none) and hence, the area received in the GC was very small. Since this GC area is very small, the variation of the tests of background methane has a smaller impact on the final result compared to the vacuum tubes with a bigger GC area. The error is thus lower.

11 Conclusion

When sampling wastewater at a WWTP, an already developed method was used with some minor modifications. These modifications should decrease the slipping of methane when in contact with air. A successful method of sampling wastewater close to a pressure release of a rising main was also developed. By using a customized sampling device, this was done without descending the manholes. This method enables sampling very close to the pressure release.

When analyzing the samples from Sjölunda WWTP, the 7 ml vacuum tubes were used since they had a low amount of background methane. When analyzing the samples from Helsingborg sewer system, the 12 ml vacuum tubes were used instead. These showed an even smaller concentration of background methane than the 7 ml vacuum tubes. However the 12 ml tubes had not yet arrived when analyzing the wastewater from Sjölunda WWTP.

The temperature has proven to have a big impact on the methane production rate. Is seems to be about twice as much methane produced with a 5°C raise of the temperature. However, the amount of methane is still not high enough to have any significant impact on the environment. The estimation of methane emitted in the summer approximately corresponds to an emission of CO_2 from 12 cars driving in 100 km/h in one hour. However, this is still not an amount that significantly contributes to any environmental issues.

The results from Helsingborg sewer system shows that the HRT is of importance when estimating the concentration of wastewater in sewer systems. The material, more surprisingly, also seems to have a big impact on the methane being produced. This could be due to the hydrophilic qualities of concrete which ease the attachment of the biofilm. The A/V-ratio's impact is very difficult to note from the elaborated results. The temperature varies slightly from pipe to pipe. However, this small temperature difference does not seem to have any substantial effect on the amount of methane being produced.

12 Future Work

The presence of methane in sewage, due to this thesis, does not seem have any substantial effect on the environment. Though, it is still a quite unexplored field and hence a lot more research needs to be done to really exclude this. In order to make a better prediction of the methane emission from rising mains, a lot more sampling from various mains is necessary. These sampling mains should vary in A/V-ratio, HRT and material. Only one property at a time should preferably vary while the others stay the same. This is to more accurately be able to say how much each property affects the methane production. Since rising mains are not very common, a large area probably needs to be investigated which would aggravate the sampling. To ease this investigation of methane production, a laboratory research might be to prefer where pressurized pipes are made artificially, with various properties similar to Guisasola, *et al.,* (2009). However, laboratory research needs to be confirmed with reality and thus, more sampling in rising mains is inevitable.

This thesis showed a very high value of methane in a concrete main. To confirm that concrete effects methane production in such a high rate, more sampling on this specific material of rising mains is necessary.

According to the results from Sjölunda WWTP, temperature seems to be of big importance. The results from the sewage in Helsingborg showed a low temperature and thus, sampling in the summer needs to be made as well to investigate how much the methane level might increase.

To ease the future estimation of methane an equation could be compiled using the Matlab. The idea is to be able to estimate the concentration of methane in a specific pipe by inserting the diameter, length, flow and temperature into an equation. Since it is difficult to include the influence of the different materials in the same equation, an equation for each material is to prefer. However, to do this a lot more sampling is necessary. In this thesis, only four samplings were made and an accurate equation could hence not be made.

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Appendix

Table Of Contents

1 Equipment used when measuring and analyzing

Equipment for Sjölunda WWTP

The equipment used for taking samples:

- 100ml glass bottles with plastic screw caps.
- 100ml pipet with pipet bulb.
- Cooling box filled with ice and a small blanket.
- Customized sampling device.

The equipment used for analysis of the samples:

- 5ml syringe.
- Hamilton syringe.
- Needles.
- 0.22µm filter.
- 7ml vacuum tubes.
- Vacuum tube rack.
- Gas Chromatograph Agilent 6850, equipped with a FID detector and a HP-1 column (19091Z-413E) 30m + 0.32 mm + 0.25 µm.
- Scale

Equipment for Helsingborg sewer system

The equipment used for taking samples in sewer systems in Helsingborg:

- 100ml glass bottles with plastic screw caps.
- 100ml pipet with pipet bulb
- Cooling box filled with ice and a small blanket.
- 12ml vacuum tubes
- Vacuum tube rack
- Customized sampling devices

The equipment used for analysis of the samples:

- 5ml syringe.
- Hamilton syringe.
- Needles.
- 0.22µm filter.
- 7ml vacuum tubes.
- Vacuum tube rack.
- Gas Chromatograph Agilent 6850, equipped with a FID detector and a HP-1 column (19091Z-413E) 30m + 0.32 mm + 0.25 µm.
- Scale

2 Background methane in vacuum tube

A. 1: Sample data from background methane in 12ml vacuum tubes.

Type of sample	GC area ($m^2 \cdot 10^{-5}$)	Concentration ($moles/m^3$)	Moles
6ml water	1.1	5.8e-004	3.4e-009
Only gas	0.5	2.0e-004	2.4e-009

3 Results from Sjölunda WWTP

A. 2: Sample data from wastewater in Sjölunda WWTP, 2013-10-02.

Sample	Time	Temperature (K)	Flow (m^3/s)	GC area ($m^2 \cdot 10^{-5}$)	Concentration ($moles/m^3$)	Amount of methane (kg/h)
1	09:40	292.25	0.83	183	0.07	3.3
2	10:10	295.35	0.89	210	0.08	4.2
3	10:40	295.35	0.90	182	0.07	3.6
4	11:10	295.35	0.91	186	0.07	3.7
5	11:40	295.45	0.89	187	0.07	3.7
6	12:10	295.45	1.11	182	0.07	4.4
7	12:40	295.45	1.11	193	0.07	4.7
8	13:10	295.45	1.08	167	0.06	3.9
9	13:40	295.45	1.06	169	0.06	3.9
10	14:10	295.45	1.10	163	0.06	3.8
11	14:40	295.45	1.07	148	0.05	3.3
12	15:10	295.45	1.03	157	0.06	3.4
13	15:40	295.45	0.99	127	0.04	2.5
14	16:10	295.45	1.00	141	0.05	2.9
15	16:40	295.45	1.00	162	0.06	3.4

4 Results from Helsingborg sewer system

A. 3: Sample data from wastewater in Helsingborg sewer system, 2013-11-15.

Location	Sample	Time	Temperature (K)	Flow (m^3/s)	GC area ($m^2 \cdot 10^{-5}$)	Concentration ($moles/m^3$)	Amount of methane (kg/h)
Folkparksgatan	1	09:00	280.85	30.2	190	0.09	1.0
Kontorsgatan	2	09:40	280.85	36.0	130	0.06	0.7
Marknadsvägen	3	10:20	284.35	38.0	36	0.02	0.2
Mörsaregatan	4	10:50	281.05	78.0	21	0.01	0.5

A. 4: Sample data from gas in manholes of Helsingborg sewer system, 2013-11-15.

Location	Sample	Time	GC area ($m^2 \cdot 10^{-5}$)	Concentration ($moles/m^3$)
Folkparksgatan	1	09:00	116	0.05
Kontorsgatan	2	09:40	9	0.00
Marknadsvägen	3	10:20	125	0.05
Mörsaregatan	4	10:50	3	0.00

A. 5: Sample data from wastewater in Helsingborg sewer system, 2013-11-20

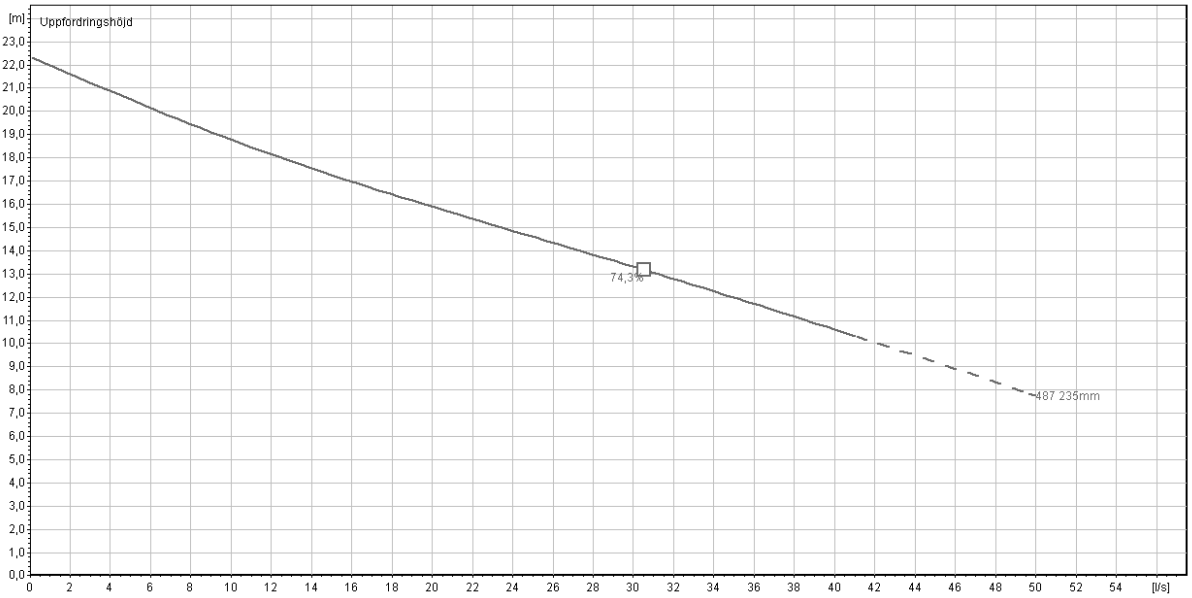
Location	Sample	Time	Temperature (K)	Flow (m^3/h)	GC area ($m^2 \cdot 10^{-5}$)	Concentration ($moles/m^3$)	Amount of methane (kg/d)
Folkparksgatan	1a	08:15	282.45	30.2	199	0.09	1.1
	1b	09:25	282.45	30.2	299	0.13	1.6
Kontorsgatan	2a	08:25	283.55	36.0	121	0.05	0.7
	2b	09:40	283.55	36.0	167	0.08	1.0
Marknadsvägen	3a	8:40	285.55	38.0	30	0.01	0.2
	3b	9:50	285.55	38.0	36	0.02	0.2
Mörsaregatan	4a	8:55	283.15	78.0	25	0.01	0.7
	4b	10:10	283.15	78.0	42	0.02	1.1

A. 6: Sample data from gas in manholes of Helsingborg sewer system, 2013-11-20

Location	Sample	Time	GC area ($m^2 \cdot 10^{-5}$)	Concentration ($moles/m^3$)
Folkparksgatan	1a	08:15	22	0.01
	1b	09:25	8	0.00
Kontorsgatan	2a	08:25	14	0.01
	2b	09:40	5	0.00
Marknadsvägen	3a	8:40	16	0.01
	3b	9:50	3	0.00
Mörsaregatan	4a	8:55	0.84*	0.00*
	4b	10:10	25	0.01

*Uncertain value

5 Pump graphs and pumping times (NSVA, 2013d)



A. 7: Pump graph for Folkparksgatan.

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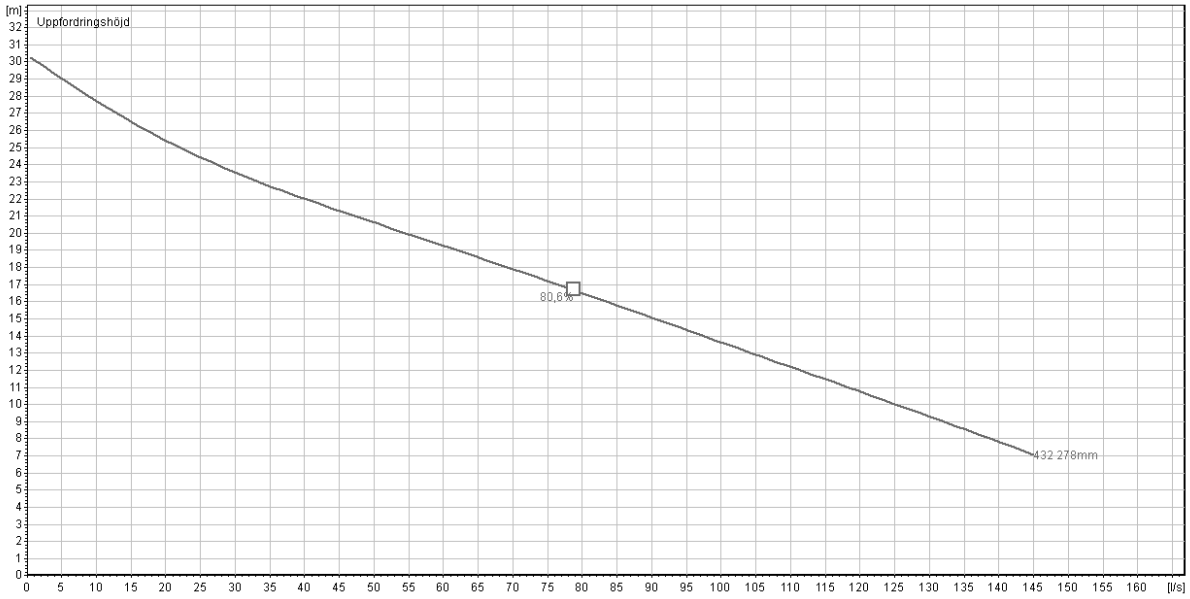
A. 8: Pump graph for Kontorsgatan.

A. 9: Pump graph for Marknadsvägen.



A. 10: Pump graph for Mörsaregatan.

A. 11: Total average pumping time for pump stations.

Location	Average pumping time (h)
1 (Folkparksgatan)	7.0
2 (Kontorsgatan)	6.1
3 (Marknadsvägen)	5.8
4 (Kontorsgatan)	13.8

6 Pressurized sewer systems in Sweden (Svenskt Vatten VASS, 2013)

A. 12: Pressurized sewer systems in Sweden (Svenskt Vatten VASS, 2013)

				Administrativa- och tekniska basdata		
				Bd315	Bd316	Bd317
				Ledningslängd för "konventionell" tryckavloppsledning	Ledningslängd för LTA-ledningar	Ledningslängd för vacuumled-ningar
Kommun						
Nr	Namn	År	Personer	km	km	km
114	Upplands-Väsby	2012	40589	27	0	0
127	Botkyrka	2012	86062	54,071	0	0
180	Stockholm inkl. Huddinge	2012	890663	92	10	0
181	Södertälje	2012	89178		69	
182	Nacka	2012	92736	43	62	0
183	Sundbyberg	2012	40621	4		
191	Sigtuna	2012	42174	28,6	0	0
562	Finspång	2012	20818	33		
580	Linköping	2012	148374	90,784	5,198	0
581	Norrköping	2012	131917	0	0	0
583	Motala	2012	41825	27	2,7	0
584	Vadstena	2012	7335	1	0	0
617	Gnosjö	2012	9358	6,4		
765	Älmhult	2012	15725	29,89		
780	Växjö	2012	84618	83,6	0	0
1080	Karlskrona	2012	63805	195	50	0,9
1214	Svalöv	2012	13266	12	0	0
1231	Burlöv	2012	17006	2	0	0
1260	Bjuv	2012	14883	8	0,4	0
1261	Kävlinge	2012	29439	42,5	95,5	0
1263	Svedala	2012	19928	18,1	31,7	0
1272	Bromölla	2012	12275	13,1	20,3	0
1277	Åstorp	2012	14788	13		
1278	Båstad	2012	14283	16		
1280	Malmö	2012	307207	49	7	0
1281	Lund	2012	112962	22	4	

1282	Landskrona	2012	42497	42	35	0
1283	Helsingborg	2012	131782	52	7	0
1285	Eslöv	2012	31740	29	0,5	2,5
1287	Trelleborg	2012	42516	34	63	12
1290	Kristianstad	2012	80395	74,5	19,3	0,17
1382	Falkenberg	2012	41424	56	0	0
1383	Varberg	2012	59099	84	0	0
1401	Härryda	2012	35167	21,2	2,5	0
1415	Stenungsund	2012	24816			
1419	Tjörn	2012	14974			
1447	Gullspång	2012	5223	6,8		
1463	Mark	2012	33758	30	0	0
1473	Töreboda	2012	9018	5,376		
1485	Uddevalla	2012	52496	59,5	0	0
1487	Vänersborg	2012	36949	49,2	0,05	0
1488	Trollhättan	2012	55659	43,9	1	0
1489	Alingsås	2012	38298	41,4	0,6	0,5
1490	Borås	2012	104650	76	2,2	0
1493	Mariestad	2012	23697	29,8	1	0
1494	Lidköping	2012	38233	86		
1496	Skövde	2012	52170	57,84	0	0
1499	Falköping	2012	31624	46,6	0	0
1780	Karlstad	2012	86949	58	2	0
1783	Hagfors	2012	12196	18	0	0
1784	Arvika	2012	25796	4,8	0,48	0
1880	Örebro	2012	138748	87,96	0	0
1980	Västerås	2012	140392	129	21,6	0
2021	Vansbro	2012	6792			
2132	Nordanstig	2012	9523		0,5	0
2262	Timrå	2012	18000	9,9	5,77	0
2281	Sundsvall	2012	96622	27	11,5	0
2282	Kramfors	2012	18516	24	2	0
2480	Umeå	2012	117176	81,25	5,8	0
2514	Kalix	2012	16518		0	0

7 MATLAB code, used for calculation of background methane

BACKGROUND METHANE LIQUID

```
%Variables
Vtot=12*10.^-6 %Volume total m3
Vl=6*10.^-6 %Volume liquid m3
Agas=1.29/100000 %Area of sample m2

%Constants
T=278 %Temperature
R=8.3145 %Gas constant
Vg=Vtot-Vl %Volume gas phase m3
He=75538 %Henrys constant in pascal m3/mol
Ptot=101325 %Pascal
Cren=Ptot/(R*T) %Concentration of pure methane
Aren=1 %Area of pure methane
Xch4=Agas/Aren %Procent of pure methane

%Calculations
ngas=(Cren*Xch4)*Vg %Amount of molar in the gas face
nl=(Ptot*Xch4/He)*Vl %Amount of molar in the liquid face

%Methane concentration
Ch4tot=(ngas+nl)/Vg %Total concentration of methane mol/m3
Ch4totmg=Ch4tot*16 %Total concentration mg/dm3

molmetan=ngas
```

BACKGROUND METHANE GAS ONLY

```
%Variables
Vtot=12*10.^-6 %Volume total m3
Vl=0 %Volume liquid m3
Agas=0.461/100000 %Area of sample m2

%Constants
T=278 %Temperature
R=8.3145 %Gas constant
Vg=Vtot-Vl %Volume gas phase m3
He=75538 %Henrys constant in pascal m3/mol
Ptot=101325 %Pascal
Cren=Ptot/(R*T) %Concentration of pure methane
Aren=1 %Area of pure methane
Xch4=Agas/Aren %Procent of pure methane

%Calculations
ngas=(Cren*Xch4)*Vg %Amount of molar in the gas face
nl=(Ptot*Xch4/He)*Vl %Amount of molar in the liquid face

%Methane concentration
Ch4tot=(ngas+nl)/Vg %Total concentration of methane mol/m3
Ch4totmg=Ch4tot*16 %Total concentration mg/dm3

molmetangas=ngas
```

8 MATLAB code, used for Sjölunda WWTP

```
He=75538

% methane concentration

%Changeable variables
Vtot=0.000012 % Volume total m3
Vl=0.000006 %Volume liquid m3
Agas=[183.04 210.122 182.426 185.607 187.132 182.435 192.809 167.963 169.494
162.692 148.450 156.905 126.784 141.093 161.512]/100000 %Area of sample m2
nch4back=7.9*10^-8 %Background methane in vacuum tubes moles

%Constants
T=278 %Temperature kelvin
R=8.3145 %Gas constant
Vg=Vtot-Vl %Volume gas phase m3

Ptot=101325 %Pascal
Cren=Ptot/(R*T) %mol/m3
Aren=1 %Area of pure methane
Xch4=Agas/Aren %part of methane in gas phase

%Calculations
ngas=(Cren*Xch4)*Vg-(nch4back) %Total amount mole of ch4 in liquid
nl=(Ptot*Xch4/He)*Vl %Total amount mole of ch4 in liquid

%Methane content
ntot=ngas+nl %Total amount of mole
Ch4tot=(ngas+nl)/Vl %Total concentration, presuming that everything will leave
gas phase in sewer moles/m3
Ch4totmg=(Ch4tot*16) %Total concentration in mg/dm3

flode= [0.8344 0.8909 0.9043 0.9121 0.8909 1.111 1.1057 1.0795 1.0647 1.1002
1.0673 1.0343 0.9903 0.9959 0.9952]; %Flow every hour dm3/s
amountch4=(Ch4totmg*1000/10^6).*flode*3600 %Amount of methane produced kg/h
amountch4.*25 %CO2 equivalent of the methane produced kg/h
```

9 MATLAB code, used for Helsingborg sewer system

METHANE CONCENTRATION IN FIRST OBSERVATION

```
function Helsingborg
He=75538

% Methane concentration in first observation

%Changeable variables
Vtot=0.000012 %Volume total m3
Vl=0.000006 %Volume liquid m3
Agas=[190.023 130.128 35.646 20.633]/100000 %Area of sample
nch4back=3.3929e-009 %Background methane moles

%Constants
T=278 %Temperature kelvin
R=8.3145 %Gast constant
Vg=Vtot-Vl %Volume gas phase m3

Ptot=101325 %Pascal
Cren=Ptot/(R*T) %mol/m3
Aren=1 %Area of pure methane
Xch4=Agas/Aren %Part of methane in gas phase

%Calculations
ngas=(Cren*Xch4)*Vg-nch4back %Total amount mole of ch4 in gas
nl=(Ptot*Xch4/He)*Vl %Total amount mole of ch4 in liquid

%Methane content
ntot=ngas+nl %Total amount of moles
Ch4tot=(ngas+nl)/Vl %Total concentration moles/m3
Ch4totmg1=(Ch4tot*16)*1000 %Total concentration mg/m3
Ch4totmg1dm3=Ch4totmg1/1000 %Total concentration mg/dm3

%METHANE CONCENTRATION IN SEWER GAS

Vgas=Vtot %Volume gas m3
Agas=[115.899 8.583 124.614 3.168]/100000 %Area of gas m2
Xch4=Agas/Aren %Part of methane in gas phase
Ch4totgas=((Cren*Xch4)*Vgas-nch4back)/Vgas %Total concentration in gas moles/m3
Ch4totmggas1=Ch4totgas*16 %Total concentration in gas mg/dm3
```

METHANE CONCENTRATION IN SECOND OBSERVATION

```
%Changeable variables
Vtot=0.000012 %Volume total m3
Vl=0.000006 %Volume liquid m3
Agas=[199.079 121.214 29.661 24.536 298.522 167.197 36.001 42.321]/100000 %Area
of sample m2
nch4back=3.3929e-009 %Background methane moles

Vg=Vtot-Vl %Volume gas phase m3

%Constants
Ptot=101325 %Pascal
Cren=Ptot/(R*T) %mol/m3
Aren=1 %Area of pure methane
Xch4=Agas/Aren %Part of methane in gas phase
```

```
%Calculations
ngas=(Cren*Xch4)*Vg-nch4back %Total amount mole of ch4 in gas
nl=(Ptot*Xch4/He)*Vl %Total amount mole of ch4 in liquid

%Methane content
ntot=ngas+nl %Total amount of moles
Ch4tot=(ngas+nl)/Vl %Total concentration, presuming that everything will leave
gas phase in
%sewer (moles/m3)
Ch4totmg2=(Ch4tot*16).*1000 %Total concentration moles/m3
Ch4totmg2dm3=Ch4totmg2/1000 %Total concentration mg/dm3

%METHANE CONCENTRATION IN SEWER GAS

Agas=[22.243 14.027 15.966 0.84 7.71 4.683 3.198 29.587]/100000 %Area of sample
m2
Xch4=Agas/Aren %Part of methane in gas phase
Vgas=Vtot
Ch4totgas=((Cren*Xch4)*Vgas-nch4back)/Vgas %Concentration of methane in gas
moles/m3
Ch4totmggas2=Ch4totgas*16 %Concentration of methane in gas mg/dm3
```

ESTIMATION OF TOTAL METHANE PRODUCTION

```
%1=folkparksgatan
%2=kontorsgatan
%3=merkuriusgatan
%4=mörsaregatan
Q=[30.2 36 38 78]./1000*3600 %Flow in m3/h
Pumptime=[7.0 6.1 5.8 13.8] %Average pumping time h/d
dailyflow=Q.*Pumptime %Daily flow m3/d
length=[4538 770 1025 832] %Pipe length m
diameter=[0.225 0.300 0.200 0.400] %Pipe diameter m
crossarea=(diameter./2).^2.*pi %Cross sectional area of pipe m2
avrgHRT=length./(dailyflow./crossarea)*24 %Average HRT h

pipeprod2=([dailyflow dailyflow].*Ch4totmg2)./10^6 %Total amount of methane in
second observation kg/d
pipeprod1=([dailyflow].*Ch4totmg1)./10^6 %Total amount of methane in first ob-
servation kg/d
avrgprod=(sum(pipeprod2)+sum(pipeprod1))/(sum(length)*3) %Average produced me-
thane per meter kg/(d*m)
totallength=(52+7)*1000; %Total length of pressurized pipes in Helsingborg m
totalprod=avrgprod*totallength %Total methane produced per day in Helsingborg
kg/d

Co2kgram=totalprod*25 %kg/dygn
```

CALCULATIONS FOR DIFFERENT KIND OF PIPES

```
lengtharea=diameter.*pi.*length
volume=crossarea.*length
ratio=lengtharea./volume
for k=1:n
ch4(k)=(Ch4totmg1(k)+Ch4totmg2(k)+Ch4totmg2(k+4))./3 %Average ch4 mg/m3 (for
each pipe)
end
x= %n number of ones
y= %A/V-ratio m^-1
z= %HRT h
```

```
u= %Temperature K
A=[x y z u]
[b,bi,r]=regress(ch4,A) %for mor info, write "help regress"
```