Evaluation of Odomin and potential factors reducing the hydrogen sulphide levels in sewage systems

Karin Wannerberg

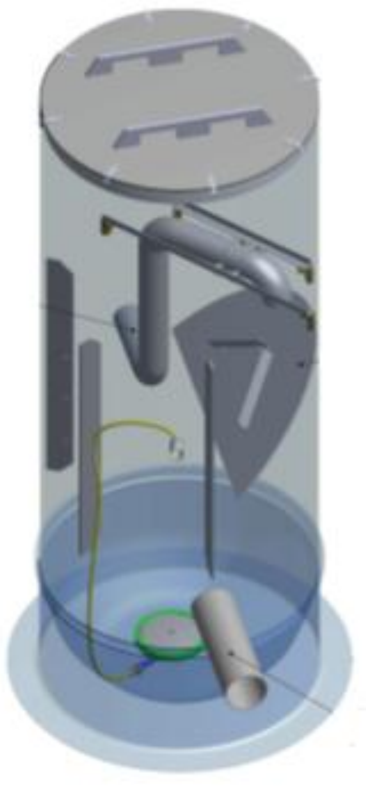
KTH Industrial Engineering and Management

Master of Science Thesis
Stockholm, Sweden 2014

Evaluation of Odomin and potential factors reducing the hydrogen sulphide levels in sewage systems

A study made by

Karin Wannerberg



Master of Science Thesis MMK 2014:95 MKN 126
KTH Industrial Engineering and Management
Machine Design
SE-100 44 STOCKHOLM

Master of Science Thesis MMK 2014:95 MKN 126

Evaluation of Odomin and potential factors reducing the hydrogen sulphide levels in sewage systems

KTH Industrial Engineering and Management

Karin Wannerberg

Approved	Examiner	Supervisor
2014-12-09	Ulf Sellgren	Ulf Olofsson
	Commissioner Xylem Inc.	Contact person Tore Strandberg

Abstract

Xylem Inc. develops pumps and integrated solutions for sewages systems. A new concept has been designed to reduce the levels of hydrogen sulphide, H_2S, in wastewater. H_2S is a toxic, stinking gas that smells at levels above 0.002-0.2 ppm. Recommended exposure level is 15 ppm for 15 minutes. The gas is soluble in water and arises with both increasing temperatures and long retention times. Levels of H_2S normally differ between 0-1000 ppm, depending on the time of year.

The new concept, a pre-chamber installed upstream a pump station, is called Odomin. Inside Odomin H_2S is oxidized to sulphuric acid, H_2SO_4, on moist surfaces. A plate is used to splash the wastewater onto the moist surfaces surrounding the plate.

This master thesis aims to find the reduction rate, in terms of H_2S, between Odomin 65 and the pump sump and to evaluate three factors that have possibility to improve the performance of Odomin 65. The investigated factors are 1) a sacrificial anode made from carbon steel 2) a reduced area of the inlet which increases the splash effect and 3) an increased inner area to increase the moist surfaces inside Odomin. The evaluation is made with 2^3 factorial design

The analysis indicates that no factor affect the daily mean value with a significance at 5%. The sacrificial anode is the one factor showing a reduction by the levels of H_2S in the pump sump for both mean and extreme values. The general reduction rate is 5.33 and this can be increased with 55% by using the splash.

The tests were affected by several influences that impact the trustworthiness of the results. Therefore this analysis needs additional investigations in order to be verified.

Keywords: Hydrogen sulphide, sewage systems, odour, oxidation, reduction

KTH Industriell teknik och management	**Examensarbete MMK 2014:12 MKN 126** **Utvärdering av Odomin och troliga faktorer som reducerar svavelvätenivåerna i avloppssystem** Karin Wannerberg

Godkänt	Examinator	Handledare
2014-12-09	Ulf Sellgren	Ulf Olofsson
	Uppdragsgivare Xylem Inc.	Kontaktperson Tore Strandberg

Sammanfattning

Xylem Inc. utvecklar pumpar och lösningar för avloppssystem. De har utvecklat ett nytt koncept för att reducera halten av svavelväte, H_2S, i avloppsvattnet. H_2S är en giftig, illaluktande gas med kännbar lukt vid 0.002-0.2 ppm. Rekommenderat är att utsättas för högst 15 ppm under 15 minuter. Gasen är löslig i vatten och nivåerna ökar med både höga temperaturer och långa uppehållstider i ledningarna. Normalt sätt kan nivåerna av H_2S variera mellan 0-1000 ppm, beroende på årstid.

Det nya konceptet som kallas Odomin är en för-kammare som installeras uppströms till en pumpstation. I Odomin oxideras H_2S till svavelsyra, H_2SO_4, på våta ytor. Genom att avloppsvattnet kaskaderar på en platta kan gasen komma i kontakt med våta ytor kring plattan.

Examensarbetet syftar till att hitta reduktionstalet mellan Odomin 65 och pumpsumpen samt utvärdera 3 faktorer som kan förbättra effekten av Odomin. De undersökta faktorerna är 1) en offeranod av kolstål 2) en minskad inloppsarea för att öka kaskadet och 3) en ökad inre area, för att öka andelen våta ytor, i Odomin. De 3 faktorerna utvärderas med faktorförsök (factorial design).

Utvärderingen ger indikationen att ingen av de tre faktorerna påverkar det dagliga medelvärdet på en 5 % signifikansnivå. Offeranoden är den faktor som tenderar minska både medelvärdet och extremvärdet i pump sumpen. Reduktionen av H_2S mellan Odomin 65 och pump sumpen är 5.33 och analysen visar att en ökad kaskadeffekt kan öka reduktionen med 55 %.

Testerna influeras av flera yttre faktorer vilket påverkar resultatens trovärdighet. Denna analys bör därför repeteras för att resultaten ska kunna verifieras.

Nyckelord: svavelväte, avloppsystem, odör, oxidation, reduktion

Nomenclature

H_2S	Hydrogen sulphide
H_2SO_4	Sulphuric acid
H^+	Hydrogen ion
PSS	Pressurized Sewage System

TABLE OF CONTENTS

1. INTRODUCTION

1.1. Background

Hydrogen sulphide, H_2S, is a bad smelling, toxic gas that can occur in wastewater and sewage systems. The gas is highly corrosive, which affects the wastewater pipes negative, and arises in anaerobic environment. An anaerobic, *no oxygen*, environment can be caused by low flows and high retention times in the pipes. Due to the foul and unwanted properties of H_2S it is desired to reduce the levels of the gas as much as possible. At places where H_2S is a problem levels up to 1000 ppm can normally occur, depending on the time of year.

There are different methods for reducing the level of H_2S in wastewater. One approach is to add chemical compounds in the sewage system that affects the oxygen/nitrate level or pH level or by adding ions that affects the chemical reaction producing or oxidizing H_2S. To reduce the bad smell ozone or ventilation can be used.

Xylem Inc. is an international company that develops water and wastewater solutions. Flygt is a Xylem brand and they provide wastewater pumps and pump stations. Since H_2S causes large problem in pump stations it was desired to find a solution.

Odomin is their new product that reduces the level of H_2S in the wastewater by oxidizing it to sulphuric acid, H_2SO_4. Odomin is a pre-chamber installed upstream a pump station, but can also be installed in the discharge point between a pressurized pipe and a gravity force main. Previous investigations have shown a reduction of H_2S levels above 10 times between Odomin and the pump station.

Odomin is developed in 2 sizes: Odomin 65, with a diameter of 1 m and Odomin 150 L, with a diameter of 1.8 m. In this master thesis Odomin 65 will be tested and analysed in order to identify the reduction rate between the pre-chamber and the pump station and to increase the knowledge of influencing factors for oxidizing H_2S. Odomin 150 L will not be analysed since none is yet installed.

1.2. Purpose

This master thesis aims to give Xylem Inc. a greater knowledge of their hydrogen sulphide-reducing product Odomin 65 and how effective it is. It is of special interest to identify the reduction rate between Odomin and the pump sump and to find improvements for the design.

An evaluation and a testing series of Odomin 65 will be made in order to explain if any factors can affect the reduction of H_2S. The results from the evaluation will aim to improve Odomin making it more effective in reducing H_2S. The tests will also give information of which design parameters or changes that are of interest. These modifications shall lower the levels of H_2S in the pump station and reduce the maintenance of Odomin.

1.3. Goal

- Evaluate how to decrease the level of H_2S in the pump station
- Decrease the maintenance needed by reducing the volume of organic material that easily get stuck onto the plate under the inlet.
- Find the relationship, in terms of H_2S reduction, between Odomin 65 and the downstream pump station
- Evaluate the reduction rate and possible influencing factors with a statistical method

1.4. Method

In the early stage of this project the goals, delimitations and purpose for the project were defined. The methods to be used were decided upon and an overall time plan was put up for the process. A planning seminar was held to present the outline of the project, where a risk analysis and time plan was presented. This was to get an opportunity to discuss the project and its setup with others.

The approach of this master thesis is a statistical evaluation of the product Odomin. Factorial design, one kind of Design of Experiments (DoE), is a way to plan experiments and is used as the method for the assessment. This was chosen since it enables to find which factors those are of importance for the reduction of H_2S.

An information gathering was made to increase the knowledge in the field of interest. Decisions for the following approach could be made with this gained information. It was analysed which factors that affects the chemical oxidation of H_2S, how Odomin operates and which circumstances the current pump station had.

When the tests were defined the testing series could start. A full scale testing series was made on an installed Odomin 65 in Uppsala.

The test series took a long time and required visits at the pumping stations. Therefore it was of importance that the different factors were easy to remove and install inside Odomin. The data from the testing series was analysed in Matlab.

1.5. Delimitations

In this master thesis it was investigated how efficient Odomin is compared to previous studies and how the performance is affected by the chosen factors evaluated with factorial design.

In order to make the testing viable only three different factors was analysed. The factors were chosen in terms of viability and the chemical effect of the reduction. Due to time limitations there were no replications of the tests made.

In this study a 2^3 factorial design was performed and therefore only this approach is described.

Only Odomin 65 was investigated in this study, not the greater size of Odomin: Odomin 150 L with a diameter of 1.8 m. The main reason for this is that there is no installed Odomin 150L today.

In the analysis the results of the daily mean values, the reduction rates and the extreme values are evaluated.

2. FRAME OF REFERENCE

This chapter will give the reader a greater knowledge in fields that are of importance for understanding the problem with hydrogen sulphide, H_2S, in sewage systems.

2.1. Hydrogen Sulphide, H_2S

In wastewater and sewage system there is a risk for hydrogen sulphide to be produced, due to the properties of the system: high retention times and low flows in combination with high temperatures.

In gaseous form hydrogen sulphide H_2S is colourless and toxic with a bad smell. The smell is often compared with rotten eggs. The gas has a density, 1.36 kg/m³, slightly heavier than air and is soluble in water. The gas can be noticed due to its bad smell even at a very low level. The threshold for smelling the odour is about 0.002-0.2 ppm. (Hedmark P., Strandberg T.; 2013) A person that continuously is exposed for low levels of H_2S, or a person that is exposed for higher levels, can lose the ability to smell the gas. That loss of senses can be very dangerous for people working in environments with H_2S or being exposed for the gas. (OSAH, 2005)

In Table 1 the effects from H_2S at different content levels can be seen.

Table 1. The different levels of hydrogen sulphide. (Hedmark P., Strandberg T.; 2013)

Content of H_2S in air [ppm]	**Human reactions**
0.002-0.2	Smell threshold
1	Faint but noticeable smell
3-5	Distinct smell
10	Acceptable sanitary level for 1-day exposure
10-50	Irritation to eye
30	Unpleasant odour
50-100	Eye- and respiratory difficulties after 1-hour exposure
100-200	Coughing and eye irritation (the odour disappears after 1-15 minutes. Dizziness occurs after 10-20 minutes)
150-300	Paralysis of the sense of smell
500-1000	Paralysis of the breathing system and unconsciousness

The Swedish working environment institute, Arbetsmiljöverket, recommend levels for exposure of H_2S on two levels: NGV (Nivågränsvärde) and TGV (takgränsvärde). The NGV corresponds to 1-day exposure (8 hours) and the TGV is the recommendation for a maximum exposure on 15 minutes, see Table 2.

Table 2. Recommended levels of H_2S for exposure, NGV for 8-hours and TKV for 15 minutes. (Arbetsmiljöverket, 2011)

NGV [ppm]	TKV [ppm]
10	15

Hydrogen sulphide can naturally be found in hot springs, natural gas, crude petroleum and is a product of the degradation of organic material, which is the process that takes place in wastewater and sewage system. H_2S can also be produced in industrial activities such as coke ovens, tanneries, kraft paper mills and drilling for natural gas or petroleum. (OSAH, 2005)

The gas has a condensation point at -62 °C and a density slightly heavier than air. The gas is relatively soluble in water and the level of dissolved H_2S depends on the temperature: a lower temperature enables more gas to dissolve in the water. At a temperature on 20 °C about 2.7 litres of H_2S can dissolve per litre of water or 3 850 mg H_2S/l water. (Richard D., 1976, 2nd edition)

2.2. Hydrogen Sulphide in wastewater

Sulphur naturally occurs in wastewater: organic material contains sulphides and if industries are connected to the mains they increase the levels.

The build-up of H_2S in wastewater mainly depends on:

- Flow of sewage in pipes [l/s]
- Temperature of sewage [°C]
- BOD, Biochemical Oxygen Demand [mg/l]
- Presence of sulphates [mg/l]
- Slope of the pipe [m/100m]
- Ratio of wetted pipe wall and the width of the sewage in pipe

(Richard D., 1976, 2nd edition, p. 9-10)

The temperature in the air also has influences on the levels of H_2S. In wastewater and sewage system, hydrogen sulphide is often a problem where low flow and high retention times appears. The gas is noticed by the bad smell, but also since it is highly corrosive. The gas corrodes different kinds of metals and concrete, which causes problems since the materials slowly break down.

When hydrogen sulphide is dissolved in water it is ionized according to the following equilibrium:

$$H_2S \leftrightarrow HS^- + H^+ \leftrightarrow S^{2-} + 2H^+$$

The proportions of H_2S in water and the levels of ions, HS^- and S^{2-}, highly depend on the pH-level, see Figure 1.

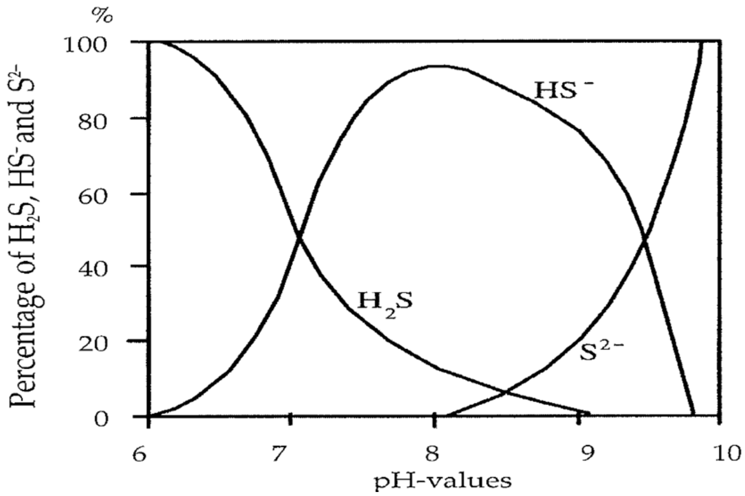


Figure 1. The level of H_2S, HS^- and H^+ in water at different pH-levels (ITT, 2014)

2.2.1. Low flows and high retention times

Bacteria in the wastewater consume oxygen to decompose the organic material in the water. The progress, which is a kind of rotting process, requires energy and uses oxygen to operate. When the oxygen is finished, an anaerobic (*living without air*) environment occurs. This mainly takes place in the slime layer, see *2.2.3 Slime layer*, on the inside of the pipe wall. In the anaerobic state bacteria consumes nitrates and then sulphur and sulphide compounds as source of energy. This order of substance is a cause of the different redox potentials for the different energy sources. The bacteria gain more energy by consuming oxygen than nitrates and sulphates. (Ledskog A. et.al, 1994)

When sulphur is oxidized, hydrogen sulphide is produced. This process is mainly biological but may be impacted by other factors like temperature, pH-level etc. (AkzoNobel, 2014) (Ledskog A. et.al, 1994)

With low flows comes high retention times which causes anaerobic environment. A typical consummation of oxygen, at 15 °C, is:

- 0.05-0.2 g O_2/m^2 h in the slime layer
- 0.002-0.01 g O_2/l h in the water phase

It takes less than 30 minutes of retention before all oxygen is used, with the consummations above. (Ledskog A. et.al, 1994)

When oxygen is used as energy source, carbon dioxide is produced and when sulphides are used, hydrogen sulphide is produced.

2.2.2. Temperature

The temperature of the sewage along with the temperature in the air has a large influence on the bacterial activity and how much H_2S that can be dissolved in the water. At higher temperatures the decomposing activity accelerates and therefor is the oxygen in the wastewater consumed faster than at lower temperatures. This consummation of oxygen leads to a faster appearance of the anaerobic environment and that bacterium consume sulphides faster than at lower temperatures, which arises the levels of hydrogen sulphide.

The gas is produced when the water temperature is above 7 ^{o}C. The coefficient multiplied with the temperature, used to calculate the turnover rate for hydrogen sulphide production, is between 1.12-1.13. (Ledskog A. et.al, 1994, p. 11)

The solubility of H_2S in water is also influenced by the temperature, see Figure 2.

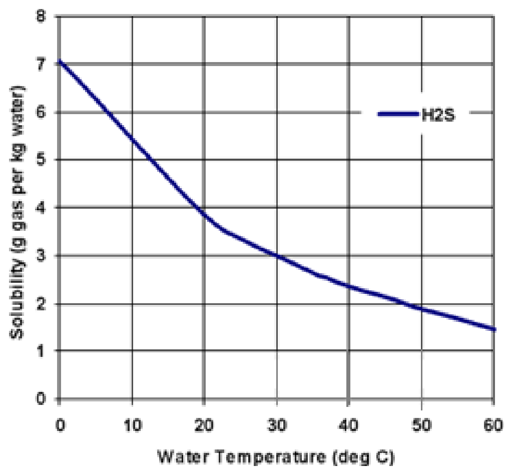


Figure 2. The solubility of H_2S in water. (EngineeringToolbox.com, 2014)

The lower temperature the more gas can be dissolved into the water.

2.2.3. Slime layer

The slime layer is a consequence from the silting organic material that travels with the wastewater. The layer is thicker at places where the flow is low and a typical width of the layer is between 0.1-1 mm. Figure 3 shows a cross section of a slime layer. The slime layer consists from one aerobic zone, one anaerobic; where sulphide compounds are produced; and one inert aerobic zone. (Hedmark P., Strandberg T., 2013)

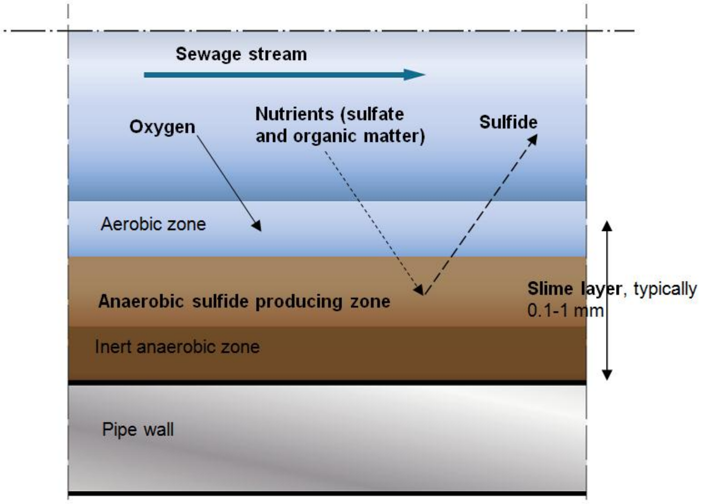


Figure 3. Cross section of slime layer (Hedmark P., Strandberg T., 2013)

Bacteria that process the organic material mainly appear in the slime layer, but to some extent in the wastewater. This process creates the anaerobic zone where hydrogen sulphide is produced.

2.2.4. BOD- Biochemical Oxygen Demand

BOD, biochemical oxygen demand, is a value that indicates how much oxygen that is demanded by the bacteria decomposing the organic material in the water. A high value indicates that much oxygen is required which can deplete water from oxygen causing changes in the ecosystem or fish killing. (Barnstable Country, 2014) A high BOD corresponds to a high level of organic material.

The BOD is given either as BOD5, how much oxygen the microorganisms consume over 5 days, or BOD7, oxygen needed during 7 days. The relationship between the levels is

$$BOD7 = 1.15 * BOD5$$

The standard BOD is BOD5 analysed at 20 °C and typical BOD5-levels for raw community wastewater is about 350 mg/l. Low level is 230 mg/l and high is 560 mg/l. Figure 4 shows representative BOD5-levels at different temperatures. (Henze M., Comeau Y., 2008)

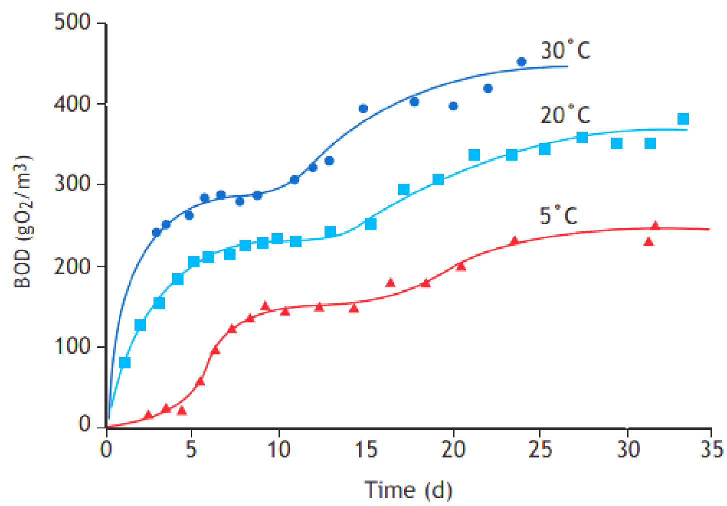


Figure 4. Typical levels of BOD5 at different temperatures (Henze M., Comeau Y., 2008)

2.3. Counteracting hydrogen sulphur

To prevent hydrogen sulphur to arise in sewage systems some kind of ventilation or wells can be installed along the pipes. Ventilation adds oxygen to the system and can prevent the anaerobic environment in some extent. These installations and can be planned when the system is designed.

Where H_2S is present, there are different approaches to reduce the problem. Hydrogen sulphide can be oxidized to sulphuric acid on uncovered, moist surfaces according to the formula shown below.

$$H_2S + 2O_2 \rightarrow H_2SO_4$$

The equation is accelerated by the bacteria *Thiobacillus* and the reaction involves a complex series of reactions. This is the basics of Odomin, which is describer further in 2.5 Odomin. For this reaction iron ions can be used as catalysis. (Richard D., 1976, 2nd edition)

Chemicals compounds can be added to the wastewater in order to reduce the levels of H_2S. There are mainly two different approaches:

- Binding sulphur
  Example: $FeCl_2$, $FeCl_3$
  Fe^{2+} binds S^{2-} (Fe^{3+} is oxidized to Fe^{2+}) and forms FeS which is black or dark brown and solid.
- pH-controller
  Example: $NaAlO_2$, $NaOH$
  The basis increases the pH-level to 12 which disables H_2S to be formed. The chemicals can increase the pH during approximately 30 minutes.
  (Akzonobel, 2014)

Other chemicals to add can be types of nitrates, chlorine or iron salts. (Hedmark P., Strandberg T., 2013) Nitrates, NO_3^-, are added since the bacteria use it as an energy source instead of sulphur preventing H_2S to be formed. The most common compound is liquid calcium nitrate solution. (US Peroxide, 2014)

Adding chemical compounds with nitrates have some drawbacks. The main disadvantage is the high costs, due to the chemical compounds and prevention mode from other influencing factors like temperature and BOD. Chemical adding systems also require maintenance and increase the nitrogen, *N*, levels in the wastewater. (US Peroxide, 2014)

Nutriox is an active dosing system, acting directly into the sewage. The system adds specific nitrates into the wastewater when the hydrogen sulphide-level reach a specific threshold. The system is controlled by a program using complex modelling, and depending on the measured H_2S-level the system doses an optimized amount of chemicals in order to reduce the gas. (Yara, 2014) The system enables the user to follow the dosing online and warns when the chemical is almost finished. According to Yara, the reseller of Nutriox, this solution can save the user 10-40% in costs compared to constant chemical dosing. (Yara.com, 2014)

One tonne of Nutriox costs 3 500 SEK and in a pump station where H_2S is a problem approximately 200-250 tonnes per year in used. This means a cost on 700 000-875 000 SEK per year. These numbers are given from a former project on Xylem.

Bio filters are used to remove the odour caused by H_2S. The principle is relative simple and efficient: a moist media bed where the gas is oxidized by microorganisms. This solution is not suitable where the levels of H_2S are very high. A disadvantage and limitation is that the media bed requires a large area to be efficient. (Spartan Environmental Technologies, 2014) There are bio filters made in a more compact way and other filters that remove the odour. Using other materials than bio, like synthetic membrane or granulate, the method can be more efficient. (Duranceau S.J. et al, 2010)

Ozone can effectively be used to oxidize H_2S and to ultimately form sulphur. (Spartan Environmental Technologies, 2005) This process is controllable, which is a benefit, but expensive. (Duranceau S.J. et al, 2010)

2.4. Corrosion of concrete

Pipes and pump stations in the sewage systems are often made of concrete. Depending on the system and present conditions the pipes can be filled with more or less water. H_2S is oxidised to H_2SO_4 on the moistly surfaces inside the pipes and stations.

The H_2SO_4 is corroding the concrete and “eats” it. In 3-5 years concrete constructions can be corrode a couple of centimetres. (Ledskog et.al, 1994)

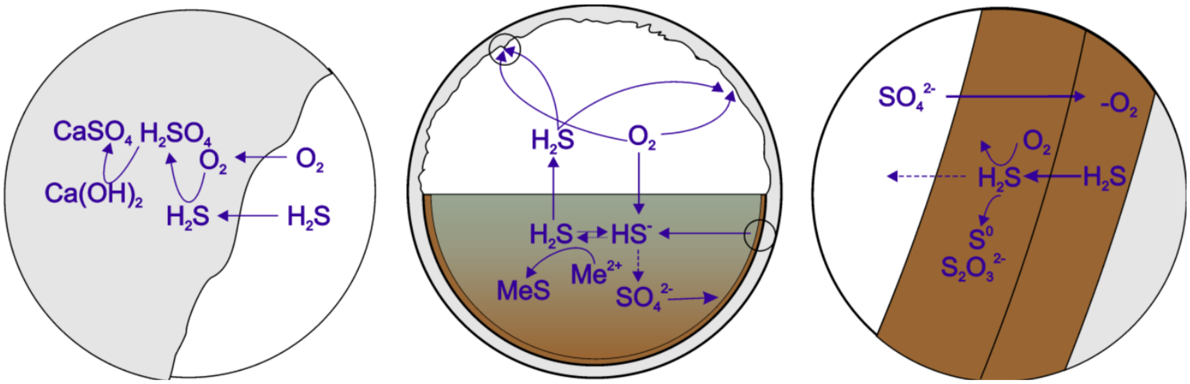


Figure 5. The different steps of the corrosion of concrete. (Stokbro Jensen H., 2009)

As shown in Figure 5 the H_2S is transformed to H_2SO_4 on the wet concrete walls. The acid corrodes the wall and makes it very fragile.

The corrosion is highly affected by the level of H_2S. At places with high retention times and low flows are the problems worse.

One way to solve the problem with corrosion is to select a corrosion resistant material for the pipes. Plastic materials have been used with a positive result in terms of resistance to corrosion. But this solution also affects the reduction rate of H_2S, see Figure 6. (Nielsen et al., 2008)

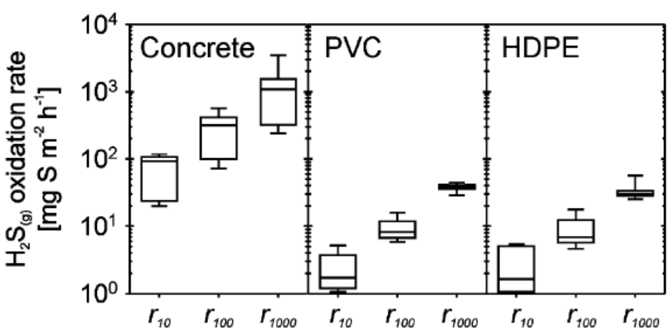


Figure 6. The oxidation-rate in pipes made from Concrete, PVC (plastic) and HDPE (plastic). (Nielsen et al., 2008)

The indexes *x* on the rate, r_x, indicates which level the area-specific oxidation rate corresponds to: 10, 100 or 1000 ppm. Since concrete is porous the oxidation-rate is better in this material compared to plastics that does not let oxygen trough.

2.5. Odomin

Odomin is a product developed by Xylem Sweden that reduces the level of hydrogen sulphide in wastewater. The principle is to oxidize H_2S, hydrogen sulphide, to H_2SO_4, sulphuric acid. In Figure 7 Odomin is shown and the passage of wastewater through it is:

1. Inlet of wastewater

2. The wastewater cascades on the plate which enables the H_2S to extricate from the water. After the release the H_2S react with the oxygen in the air to harmless concentrations of H_2SO_4
3. The wastewater containing H_2SO_4 is let out to the sewage system: a pump station or a gravity pipe.

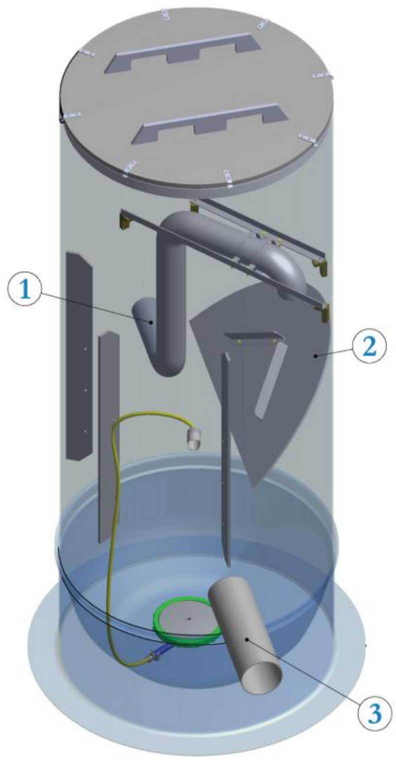


Figure 7. Odomin 65 (Flygt, 2014)

The product Odomin comes in 2 different sizes:

- Odomin 65 which has a diameter on 1 m.
- Odomin 150 L which has a diameter on 1.8 m.

The Odomin 65 was first developed and then the larger versions. The development started after it had been detected that H_2S is a large, worldwide problem in sewage systems. The bad odour and the corrosion cause many private persons and communities problems.

Odomin is developed to reduce H_2S in an easy, but effective way and requires low maintenance, since it is self-sustaining.

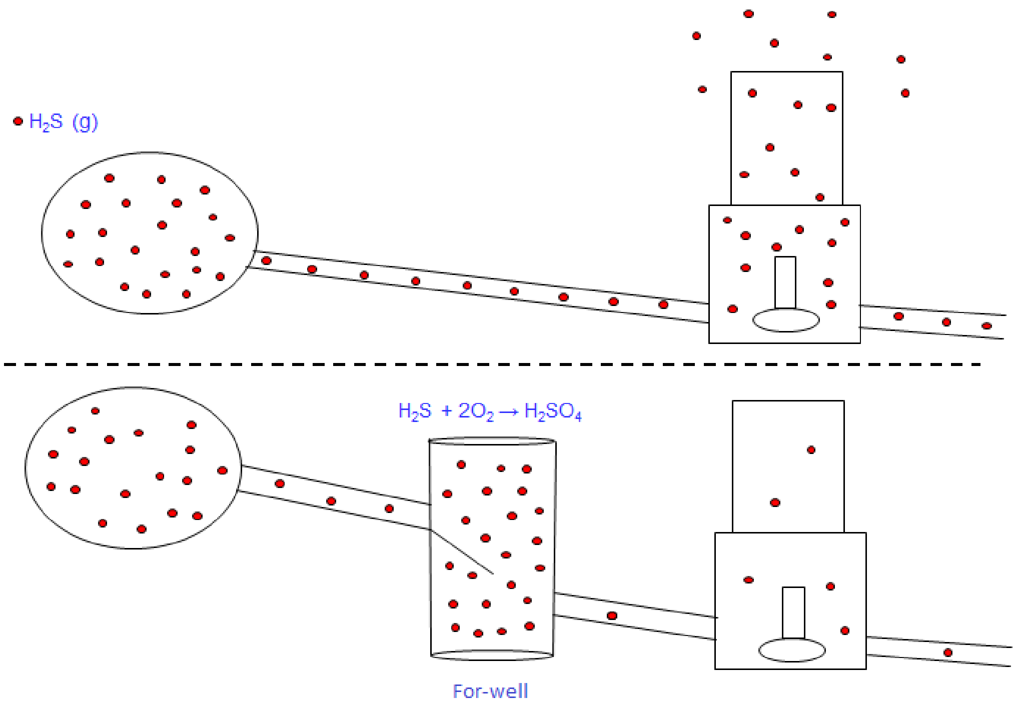


Figure 8. The principles with (below) and without (above) Odomin (Hedmark P., Strandberg T., 2013)

The principle is make the water splash in a pre-chamber or for-well, in order to set the H_2S free, instead of making this happen in the pump station, see Figure 8. Odomin should be placed upstream the pump station with a slope, to provide the water to flow back into Odomin, see Figure 9.

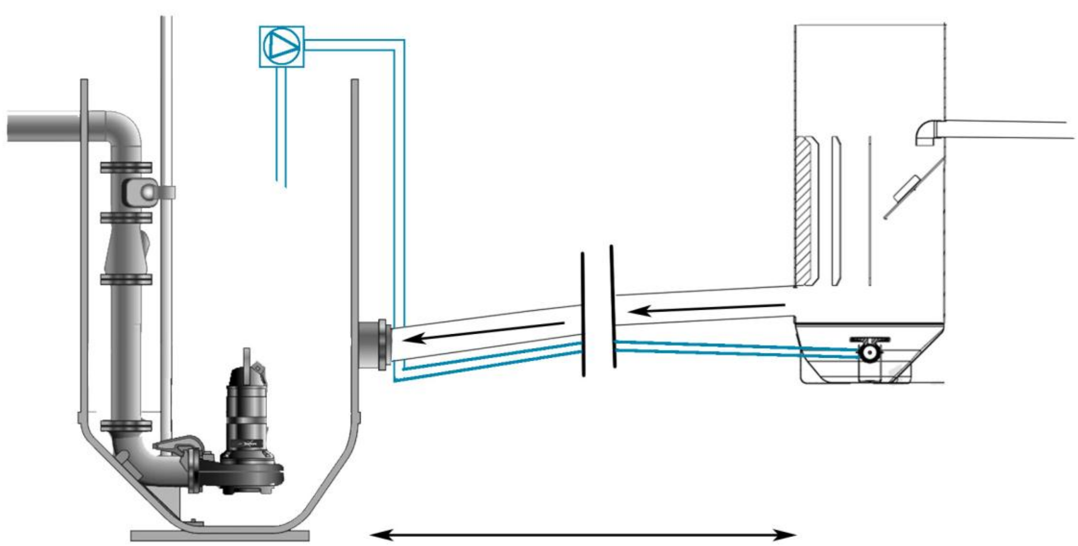


Figure 9. The pump station with an Odomin installed (Flygt, 2014).

The cost for investing in Odomin 65 and installation will pay back in about one year, compared to chemicals like Nutriox.

2.6. The Slayer model program

This program, which is made in excel, was developed for Xylem Inc. by Aalborg University and is a simulation program of the levels of H_2S in Odomin and the pump sump. The inputs to the program are the dimensions and conditions of the sewage system and the program gives an estimation of how the level of H_2S will change over the day.

The program gives an indication on how high the expected levels in Odomin and the pump sump at certain conditions. It is possible to see how different factors; like temperature, addition of air and pipe dimensions, affect the levels in Odomin and the pump sump.

The program is developed from theory and not verified.

2.7. Previous tests and results

Xylem has made previous measurements in order to increase the knowledge about H_2S and to find a method to measure the levels, in order to evaluate Odomin. Studied have been made in Tidö-Lindö, Västerås, in Ågesta and in Denmark.

2.7.1. Tidö-Lindö

In Tidö-Lindö the theory of a pre-chamber was investigated. Here there were two ventilated wells before the pump station that acts as pre-chamber. This study was made to investigate if the pre-chambers had a positive influence on the H_2S-levels in the pump sump. .

The pump station and the two manholes are shown in Figure 10 .

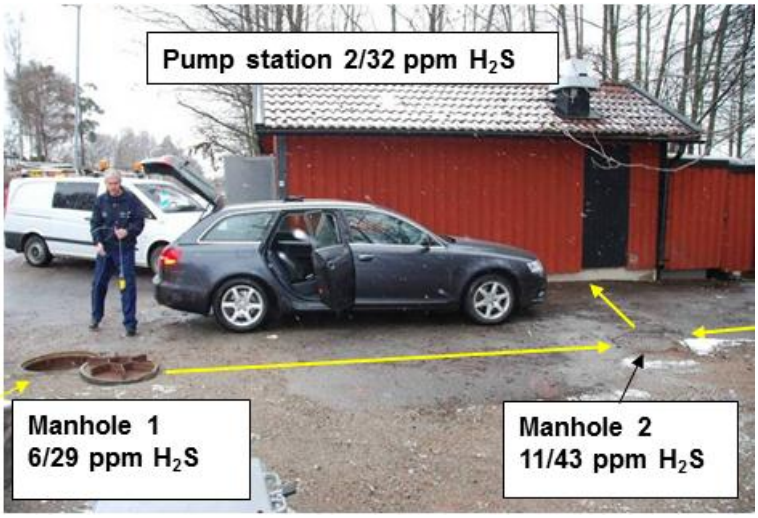


Figure 10. The pump station in Tidö-Lindö

The levels of H_2S presented in Figure 10 are the mean/maximum value that was measured. The total series of measurements are presented in Figure 11.

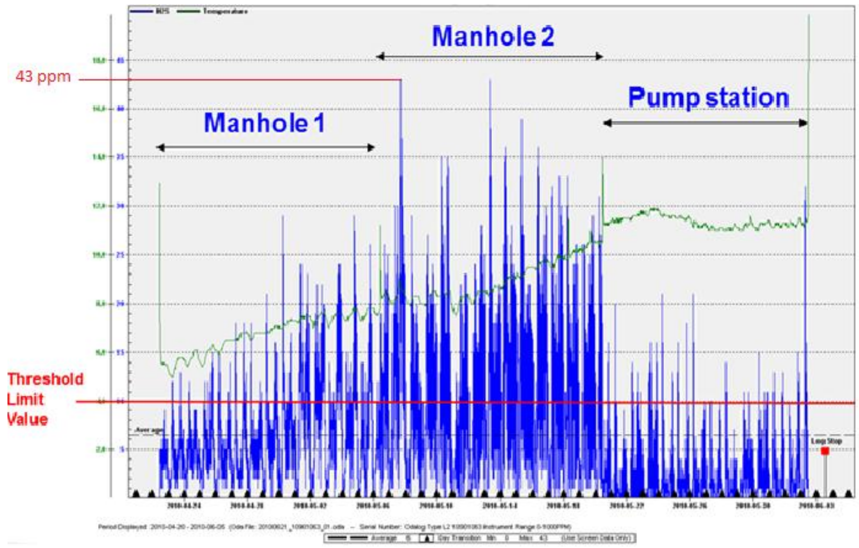


Figure 11. The measured levels from Tidö-Lindö.

The H_2S- indicator was first placed in Manhole 1, then Manhole 2 and last the pump station. The pattern presented in the graph gives a positive indication that the pre-chamber method reduces the problems of H_2S.

2.7.2. Ågesta, Mellansjö/Vidja

A pump station in Mellansjö, with approximately 200 connected households, had a lot of problems with H_2S. The system is a PSS and is planned to be connected to Vidja when the problem with H_2S is solved.

An Odomin was decided to be installed in order to reduce the problems. Before the installation the levels of H_2S was measured in the pump sump and in the manhole in front of the pump house, se Figure 12.

Figure 12. The pump station in Ågesta (Mellansjö).

The measurements in the pump sump were made in December-January, Figure 13.

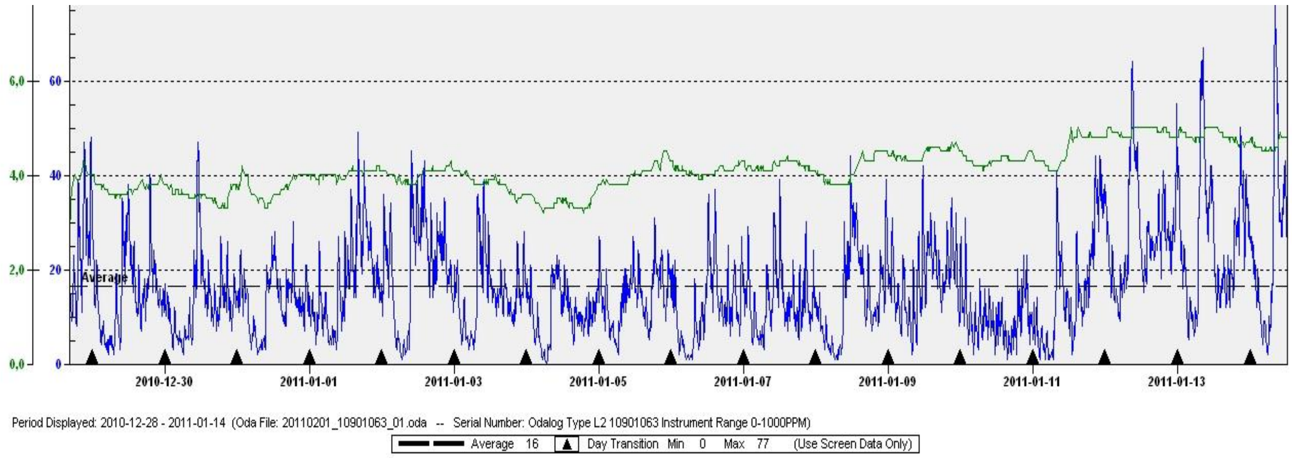


Figure 13. Results from measurement before installation of Odomin.
Mean- and maximum levels were 16 respectively 77ppm.

The temperature is around 4 °C during the measurement and the levels were registered to be 16/77 ppm (mean/max).

Odomin was installed upstream the pump station, and the levels of H_2S were logged in the pump sump and in the pre-chamber, Odomin, simultaneously.

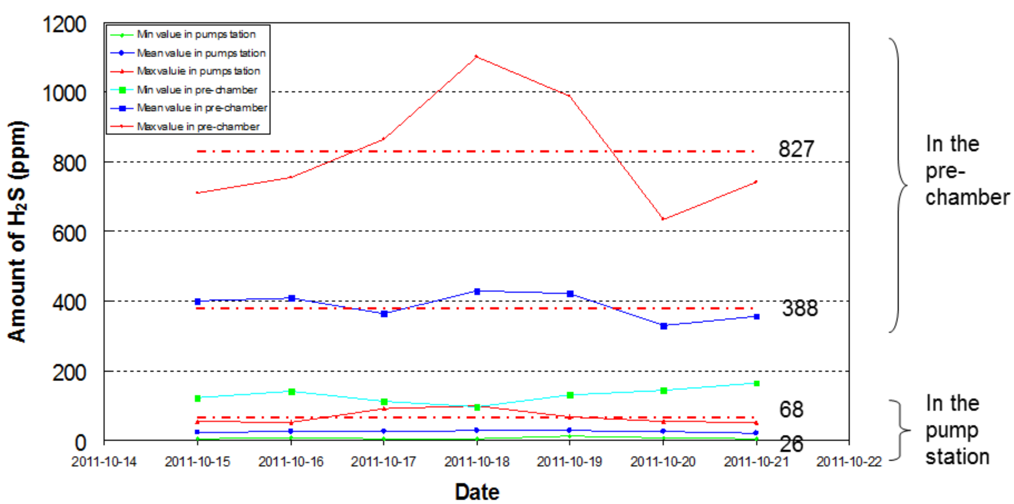


Figure 14. The measured levels in Ågesta.

In Figure 14 the measured levels are shown. It is visibly in the graph that the levels of hydrogen sulphide are reduced significantly between the pump sump and Odomin. The results show a reduction of the maximal values, between Odomin and the pump station, on 12 times. The reduction concerning the mean values was 15 times according to the registered values. The air temperature in the pump station is about 13 degrees, and it is supposed that the temperature in Odomin is the same. This information is given from Xylem Sweden that performed the tests.

The conclusion drawn from these results are that the level of H_2S is much more reduced with an Odomin installed than without. However, the levels in the pump sump do not differ very much before and after the installation, in the presented registration. This can be explained by the great differences in temperature. The registered temperature was around 4 °C during the measurements before the installation. The temperature after the installation was around 10-15 °C.

That the levels vary with the temperature can be explained by the fact that the solubility of H_2S is higher during lower temperatures than high temperatures, see Figure 15 (same as Figure 2).

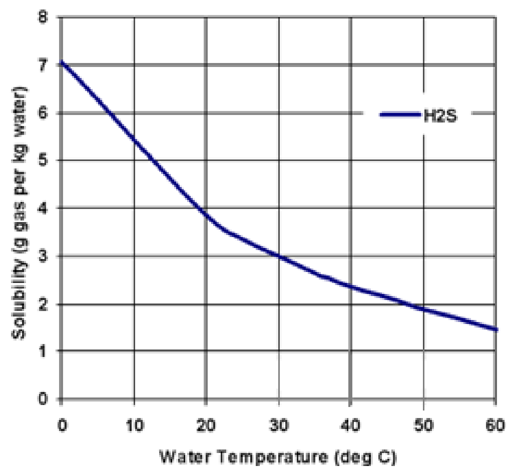


Figure 15. The solubility of H_2S in water. (EngineeringToolbox.com, 2014)

This influence of solubility makes the comparison more difficult since the difference in temperature, ΔT, is about 10 °C, which affects the levels of H_2S. The fact that H_2S is produced at temperatures above 7 °C also affects the levels. Even if the wastewater is warmer the cold air influences the build-up.

2.7.3. Denmark

A pre-chamber, not an Odomin, was installed and tested in Denmark. The levels in the pre-chamber and the pump sump were logged, shown in Figure 16.

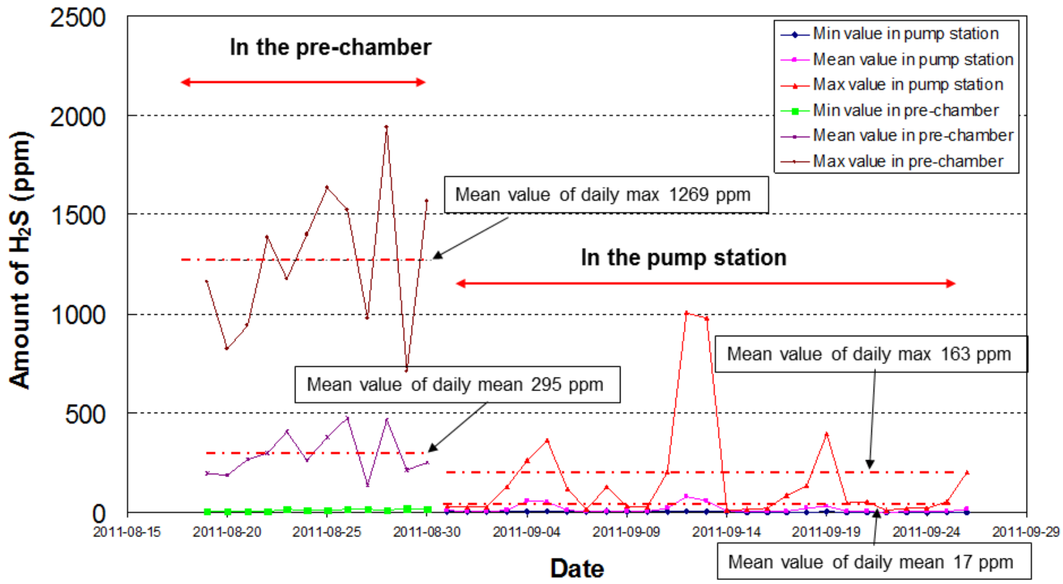


Figure 16. The measured levels in Denmark

By looking at the differences in hydrogen sulphide-levels between the pre-chamber and the pump sump the assumption can be made that the pre-chamber has a positive effect on the H_2S-levels in the pump station. Levels up to 2000 ppm have been measured in the pre-chamber and just above 1000 ppm in the pump sump.

The mean values, between pre-chamber and pump sump, show a reduction on 17 times and the maximum values have a reduction rate on 8 times.

2.7.4. Conclusion from previous tests

All of the 3 presented studies that have been made show a positive influence on the reduction of H_2S.

Table 3. The times of reduction in Ågesta and Denmark.

	Ågesta, times of reduction [-]	**Denmark** times of reduction [-]
Mean value	15	17
Maximal value	12	8

Table 3 presents the 2 cases where a pre-chamber or Odomin was installed and results have been given. The results show that the pre-chamber/Odomin has a noteworthy affect for reducing the levels of H_2S in the pump station. It is important that the levels are low in the pump station since this is where humans can be exposed to the gas and it can leak out, which spreads the odour. The high levels in the pre-chamber do not affect its environment since the chamber is gas-proof.

Unfortunately, the data found before the installation in Ågesta was taken under different temperatures (about 4 °C compared to 10-15 °C), which makes it hard to do a realistic comparison between the results. To have data taken under similar circumstances would enable a conclusion about how effective the product is.

The local authority in Ågesta, which is the owner of the pump station, has given the information that Odomin has solved their problem with H_2S.

2.8. Methods

In this study factorial design, which is a kind of DoE (Design of Experiments) method is used. It is used to analyse variations in affection factors of a test. Factorial design can be made with some different approaches as fractional design, fully performed or reduced 2^3 factorial design. In this project a 2^3 factorial design is performed and therefore this approach will be described.

2.8.1. 2^3 factorial design

The method of factorial design can be used to evaluate how different, varying factors affect a process, material or something that is of interest to evaluate. It can for example be used to test a chemical reaction, robustness of a material or how well a product can handle a critical situation under certain conditions.

Some of the properties which make factorial design an important tool are:

- A relatively low number of runs are required
- The analysis and clarifications can often be done by using common sense, computer programs and mathematics.
- In a qualitative study can determine a direction for further experiments.

(Box G.E.P. et al, 2005)

The core in factorial design is to perform one test influenced by different combinations of factors and repeat it. In Figure 17 the setup for a 2^3 testing series is described. Here are the 3 different factors are varied between two levels, one maximum and one minimum level, which gives 8 combinations. It is analysed how they affect the dependent variable: the response of the test.

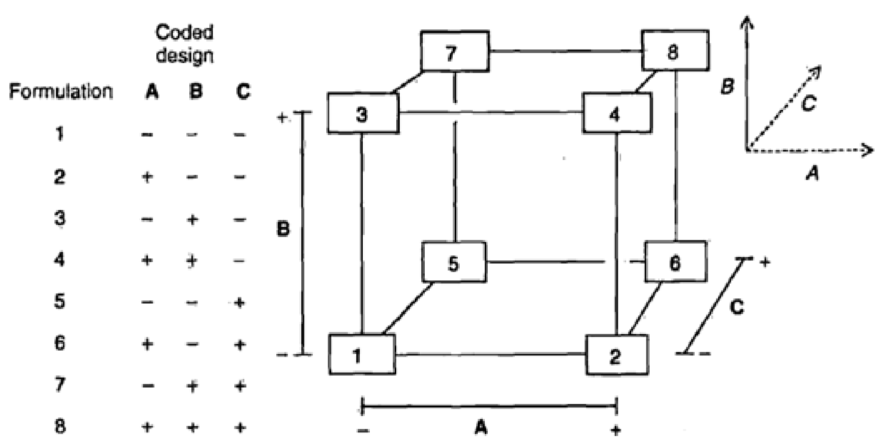


Figure 17. The principle of factorial design. (Box G.E.P. et al, 2005)

In the example, *A*, *B* and *C* are factors being varied. Each factor has a maximum level +, and a minimum level -. The levels for each of the factors are chosen and the test designed. The test is performed the same way for each run; the only difference is the combination of factor *A*, *B* and *C*.

Depending on the performance of the tests it takes more or less time for each run, which influences how many times, *n*, each of the combinations can be run. The larger number of times a test is run the better. This, since a high number on *n* decreases the risk of measurement errors.

For the calculations is a mean value from each of the 8 combinations used. The levels are then compared with each other in sense of difference between each factors minimum and maximum level when the two other are constant.

Figure 18 shows an example, where a chemical reaction is analysed. The varying factors are temperature *T*, catalyst *K* and concentration *C*.

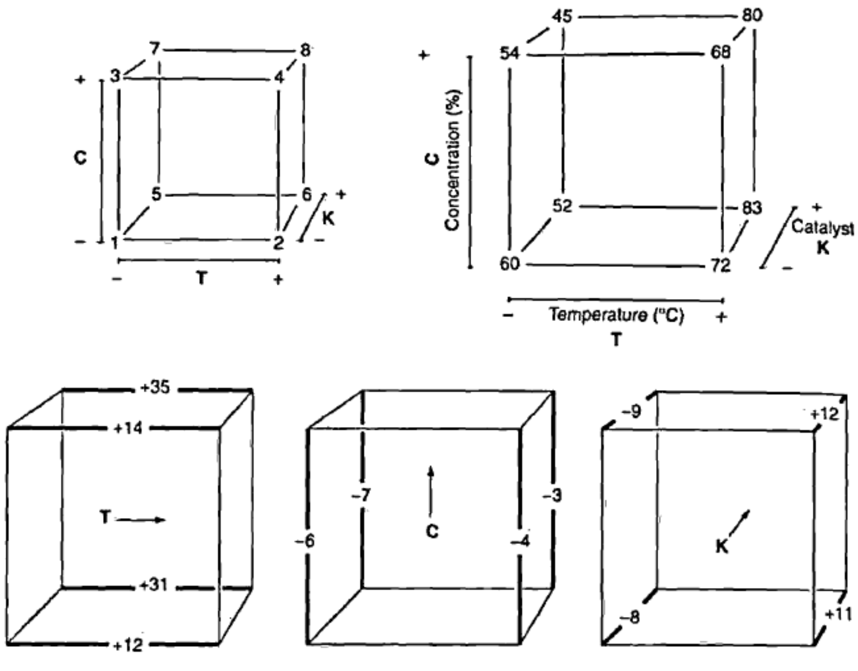


Figure 18. An example on how factorial design is used. (Box G.E.P. et al, 2005)

In the right, higher corner the different responses, a yield (mean value) from the measured levels, for each of the 8 combinations are shown. In the lower part of the picture the differences in each factor is presented. These changes in mean values are used for the factorial design analysis.

For each effect of *T*, *C* and *K*, the main effect is calculated. The main effect E_M for each factor is calculated as the difference of the mean values, when the factor goes from minus to plus:

$$E_M = \bar{y}_+ - \bar{y}_-$$

The lower and higher mean values represents by the planes shown in Figure 19.

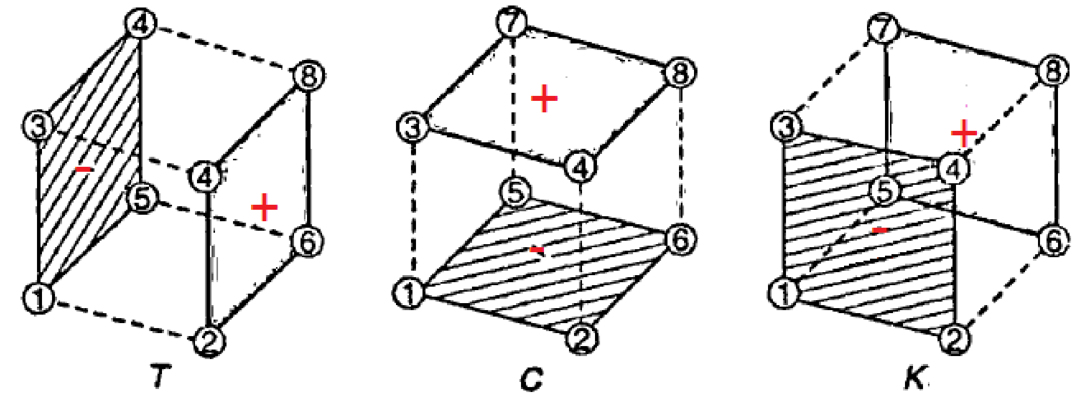


Figure 19. The lower and higher plane for each of the factors *T, C* and *K.* (Box G.E.P. et al, 2005)

The calculated main effect represents how much this factor affects the test. A large main effect represents a large influence, the sign on the effect, plus or minus, describes in which direction the test is affected: higher or lower result.

To see how the different factors interact, interaction effects can be calculated. This interaction effect is the differences of diagonal planes, see Figure 20.

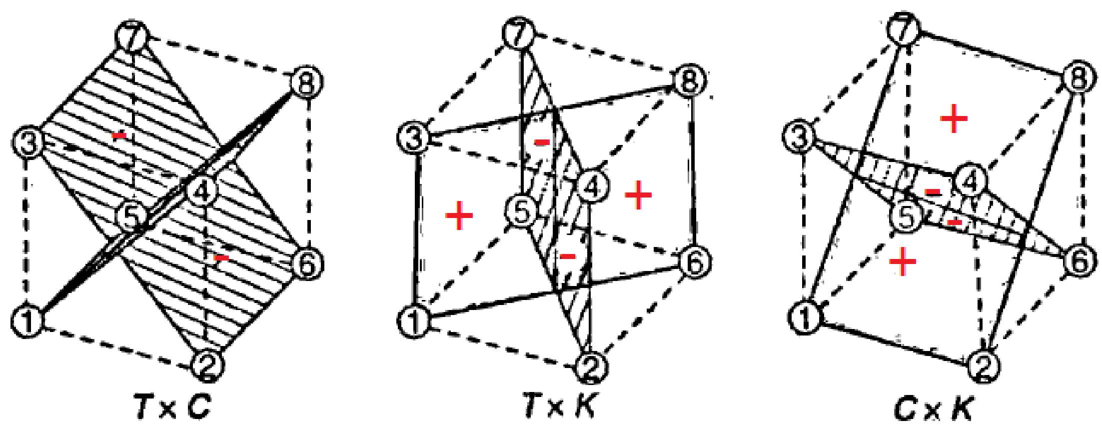


Figure 20. The planes for calculating interaction effects. (Box G.E.P. et al, 2005)

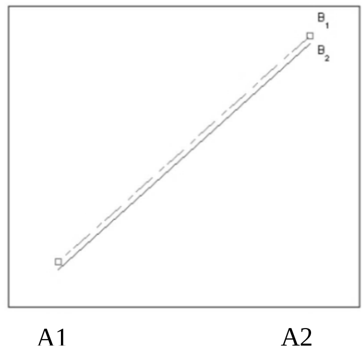
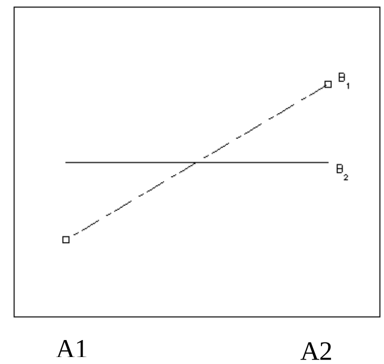
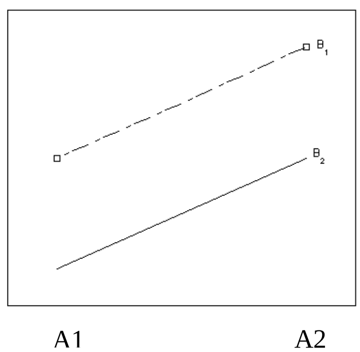
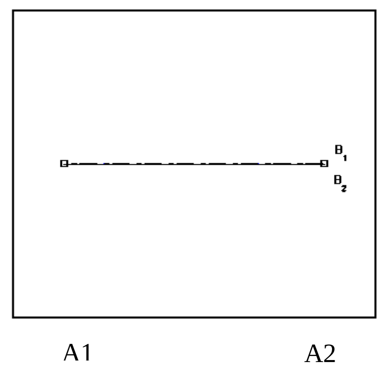
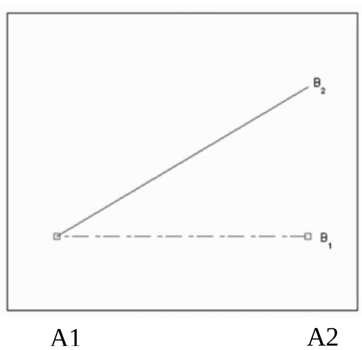
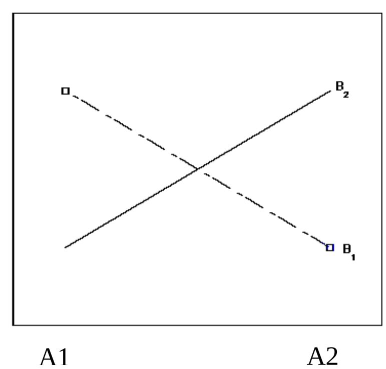
As an example the interaction for TK, temperature by catalysis interaction, is presented in equation:

$$TK = \frac{y_1 + y_3 + y_6 + y_8}{4} - \frac{y_2 + y_4 + y_5 + y_7}{4},$$

where y_x is the yield for each combination (every corner). (Box G.E.P. et al, 2005)

The interaction effects show if there is an interaction between the factors, see Table 4 for examples.

Table 4. Main effects and their interactions. (University of Washington, 2014)

Effect in A: Yes Effect in B: No Interaction: No 	Effect in A: Yes Effect in B: No Interaction: Yes 
Effect in A: Yes Effect in B: Yes Interaction: No 	Effect in A: No Effect in B: No Interaction: No 
Effect in A: Yes Effect in B: Yes Interaction: Yes 	Effect in A: No Effect in B: No Interaction: Yes 

To describe the interaction effects A1 and A2 are used as minimum and maximum for factor A, and B1 (dotted) is used as maximum and B2 (line) is minimum level for factor B, see the examples above. A negative value in the interaction effect indicates that the response to change B is stronger when A is a low level: A1. A positive interaction effect corresponds to a stronger response in B when A has a high level: A2. If there is no interaction, calculated interaction is zero; it means that B is independent of changes in A. (Andersson Ö., 2012)

A three factor interaction effect can also be calculated. This is done by calculating the interaction effect of 2 factors on one plane (+or -) of the third factor and divide it by 2.

Randomization should be taken into consideration when using factorial design. This is made to minimize any influence or prediction. Randomization, can for example be made by drawing patches, with the different numbers or combinations, and perform the series in this order.

When the series are replicated, called replicated runs, it is interesting to calculate the standard deviation of the results performed under same circumstances.

When all effects are calculated, in total 7 for each analyse, it is wished to divide the actual results from the noise. When performing this kind of analysis, factorial design, some of the results can be noise from the measurements. By plotting an error line, the measurement errors are assumed to be normal distributed, along with the effects it can be graphically shown which effects that are "real" effects. These real effects diverge from the error line. The command NORMPLOT in Matlab is used to plot these graphs. To get a reliable result a relatively large sample is required, since the error line is an estimated line from the effects. In this study only 7 effects can be calculated, which is few.

Figure 21 show an example of a normal plot with factors *A*, *B*, *C* and *D*, which means 15 effects in total. The main or interaction effects that stand out in the graph: *A*, *D*, *BD* and *B*; are the one that have a statistical significant effect on the result. The other effects follow the error line they are considered as experimental errors. (Andersson Ö., 2012)

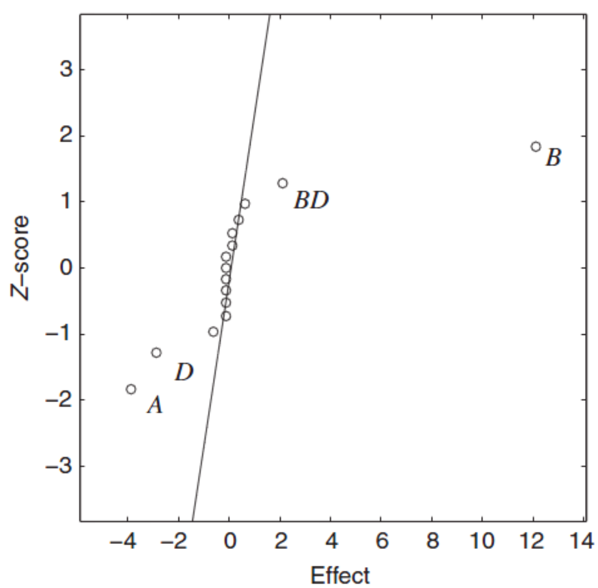


Figure 21. Example of normal plot of the main and interaction effect. (Andersson Ö., 2012)

The normal plot shows results that are on a 5% level of statistical significant.

Since there are only 7 effects calculated per factor here, it was decided to add the mean value of the 7 effects when plotting the normal distribution. This was made in order to marginally simplify diverging factors.

3. THE PROCESS

Here is the process of this project described and assumptions and choices are motivated.

3.1. Pumping station

The full-scale tests have been made in a pump station outside Uppsala where an Odomin 65 is installed.

3.1.1. Uppsala, Skarholmen

The pump station in Graneberg, Skarholmen pump station, has had a major problem with H_2S for a long time. Into the station there are two incoming pipes with wastewater. One of them mainly contains wastewater let through a long pipe, which flows under the water from the pump station in Vreta, to the pump station in Graneberg, see Figure 22. Odomin is connected onto this pipe.

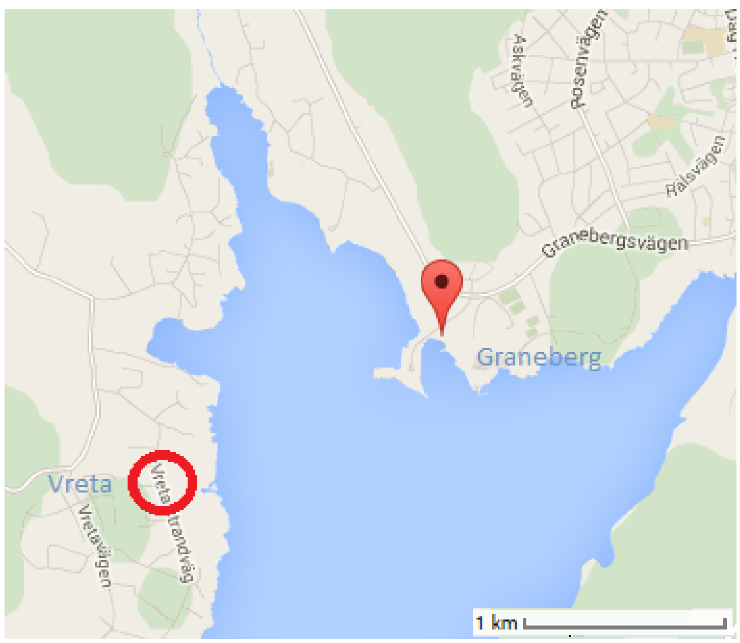


Figure 22. The location of the pump station in Graneberg and the pump station in Vreta (marked with red circle).

This pipe was considered, by Uppsala Reningsverk, to cause the problem of H_2S since this pipe has a higher retention time than the other. To Odomin there is also let a pipe from a boat club, located close to the pump station, with grinded wastewater.

The pump station is located opposite the road to some houses and the people living here have been complaining about the bad smell, which is caused by H_2S. Besides Odomin 65 the station has a Nutriox and an ozone-system to lower the H_2S levels when they rises over 5 ppm in the pumping house. These systems were installed before Odomin but not considered to be efficient enough.

The other incoming pipe is shorter and therefore not considered to cause those high H_2S-levels in the pump station. This pipe contains wastewater from different areas: one from a boat club, one from a restaurant close to the boat club and one from the community to the right of the pump station in Figure 22.

3.2. The three varying factors

To make an evaluation with factorial design 2^3, three different factors were to be changed. Different aspects were considered to investigate and 3 factors were chosen in respect to viability and suitability for the purpose of reducing the levels of hydrogen sulphide.

It was considered to have addition of air through the aerator as one factor but since the tests in Ågesta showed a negative influence, which was confirmed by the given program *Slayer Model*, this was rejected.

3.2.1. A sacrificial anode

The chemical reaction that oxidises H_2S to H_2SO_4 is a long, relative complex series of reactions that takes place. The bacteria *Thiobacillus* is accelerating the process in some extent but in order to make it faster catalysis can be added in the wastewater.

To add ion-compounds, often metal oxides, is one way of decreasing the level of hydrogen sulphur in wastewater. This is an expensive method which requires maintenance but is effective, see *2.3 Counteracting hydrogen sulphur*.

Ions that are suitable catalysis for the wanted reaction, where hydrogen sulphide is oxidized to H_2SO_4 are Fe (iron), Mn (manganese), Ni (nickel), Cu (copper) and Co (cobalt). Depending on the pH-concentration the ions are more or less effective. (Nielsen et al., 2007)

In order to affect the process chemically a sacrificial anode was added in Odomin. The added material was decided to be carbon steel, due to its high content of iron.

Carbon steel is an alloy that mainly consists from iron. There are different grades of carbon steel, from low to high, that depends on the content of carbon that can vary between 0.05-1.5 %. There is also very high carbon steel, which is not as common. Carbon steel can also contain small amounts of manganese, sulphur, phosphor, silicon or copper. Which kind of property that is wanted depends on the included alloys and the amount added. (O´Neal, 2014) (Coburn-Myers, 2014)

Iron and manganese ions are the active substance used as catalysis for the oxidization reaction. The carbon steel contains a high level of iron and includes manganese to some extent which makes it suitable as the material for a sacrificial anode.

The carbon steel used in the testing series is untreated which enables the material to corrode. This property is important in this case since this allows the ions can be released from the material.

The idea to add a sacrificial anode came from the fact that the level of oxidized hydrogen sulphide is much higher on the surfaces in pipes made from concrete than pipes made in plastic material, see Figure 24. (Nielsen et al., 2008)

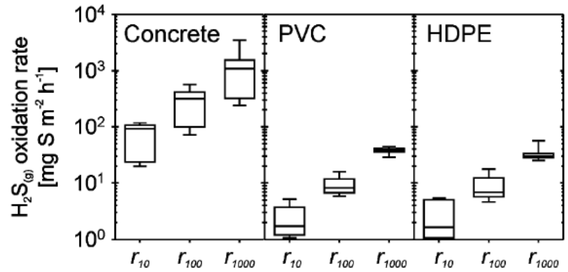


Figure 23. The oxidation-rate in pipes made from Concrete, PVC (plastic) and HDPE (plastic). (Nielsen et al., 2008)

Three different rates have been investigated: r_{10} is the oxidation-rate at a level of $H_2S_{(g)}$ of 10ppm; r_{100} a $H_2S_{(g)}$ on 100ppm and the r_{1000} is at a level of 1000ppm. As seen in Figure 23 the rate of oxidation is about 2 magnitudes (10^2) higher for pipes made from concrete than those made from plastics. (Nielsen et al., 2008)

When looking into the fact that concrete pipes are a lot more effective in reducing the level of H_2S it is also noticed that corrosion of those pipes are a large problem. In this case, where a sacrificial anode is added in Odomin, the idea is to corrode the steel in order to excrete ions that affect the oxidation positive.

It was also considered to use Ni, nickel, in the tests but due to its property of being resistance to corrosion this option was dismissed.

3.2.2. Create a greater splash effect

The plate mounted under the inlet is supposed to create a splash and the 2 holders, placed in an angle, are used to spread out the water along the plate. This plate has not been as efficient as suspected and onto the holders material from the wastewater gets stuck.

A greater splash of the inlet would allow more hydrogen sulphide to be released from the wastewater and also reduce the risk of material getting stuck on the holders, since to water spreads more.

In order to create a splash it was decided to decrease the area of the inlet. This would create a higher inlet velocity and a superior splash when the water passes the edge of the inlet. The splash enables H_2S to dissolve from the water and it spreads the water on a larger area where the oxidation can take place.

The oxidation process is more effective when the surfaces inside Odomin is wet, which is also shown in the *Slayer model* program.

A lot of other alternatives to create a splash were considered before choosing this concept. It was ideas from waterwheels to a concept built on Pythagorean cup. The problem with these concepts was how it was mountable on an Odomin in operation. Therefore it was chosen to use the reducer: it filled its purpose and was easy to mount.

3.2.3. Increasing the inner surface

The oxidation reaction from hydrogen sulphide, H_2S, to sulphuric acid, H_2SO_4, takes place on moisture surfaces, which causes corrosion on concrete and iron pipes.

Raising the possibility of oxidizing H_2S to H_2SO_4 the second factor was chosen to increase the inner area. This fact was also suggested in the *Slayer model* program.

To increase the inner area normal plastic roof, for balconies or porches, was used. The plastic roof was made in PVC material and chosen since it is folded. The formation of the porch ceiling enables a large area and a relative small volume.

The plastics are hung inside Odomin as curtains in such a way so it enables the splashed water to oxidize, on wet surfaces, to a greater extent.

In the beginning another alternative of the design was also developed. This idea was to make circular rolls, in two or more sections, to hang down. This concept was considered not as efficient, since the water were not as easily splashed onto the surfaces, and it had a more complex design compared to the curtains.

3.3. Controllable and uncontrollable factors

The test series is made under real conditions, which means that the tests were made in reality. Influencing factors that are uncontrollable are:

- Air and water temperature
- pH-level
- BOD
- Incoming levels of H_2S
- Inflow from Vreta (pumping hours and volume/hour)

Controllable factors

- Inlet diameter
- Distance between Odomin and the pump station
- Exposed inner area of Odomin

3.4. Measuring equipment

In the tests some of the factors influencing the production of H_2S will be measured. The level of H_2S, temperature, pH-level and the conductivity in the outlet water will be measured. From the pump station the flow of water or frequency of the pumps will be given.

3.4.1. OdaLog

OdaLog L2 is developed from App-Tek and is a logging instrument for hydrogen sulphide. It logs the H_2S concentration in the air along with the temperature and has a memory for up to 42 000 values. (OdaLog, 2014)

The indicators are regulated to log the value every minute respectively every 5 minutes and have accuracy on 1% on full scale, 0-1000 ppm.

3.4.2. pH-indicator

To measure the pH-level in the wastewater an indicator from Hanna instruments is used. To calibrate the instrument a solution with a specific pH-level is used.

The pH-level is noticed since it was considered to be an interesting factor to see if it changed or not after the installation Odomin and the new pump station.

With the pH-indicator it is also possible to measure the momentum temperature in the wastewater.

3.5. Performance of the tests

The test series are designed after the method of factorial design. The 3 factors that are tested will all be changed between a maximum and minimum level. In this case the maximum (+) level will be when the factor is present and the minimum (-) level is without any influence of the factor, which means no change from the normal condition in Odomin.

The tests in Uppsala were performed as shown in Table 5.

Table 5. The time table of the factorial design

Test series	Sacrificial anode	Splash	Surface
7	+	+	+
2	+	-	+
5	+	+	-
1	+	-	-
6	-	+	+
3	-	-	+
8	-	+	-
4	-	-	-

The series are partly randomized, this since it was not possible to perform a totally randomized series. The italicized numbers in the table were made in a selected order since these factors were easier to perform or make, and could be made first. The bold numbers were randomly selected by drawing patches with the different combinations. This order made all the splash-tests to be after each other, which was positive since the reducer was a bit tricky to mount.

Every testing series was planned to be approximately one week. This time period was decided since the level of H_2S can vary much during the 24 hours of the day and between weekdays and weekends. It is also important that the time period is not too short, since the effect of the varying factors must be detectable. It is not known if the factors require time to show an effect, for example when adding the sacrificial anode, so having longer testing intervals is a safety issue for reliable data.

When performing the tests each combination of factors is placed inside Odomin. A logger of H_2S, Odalog, was hung down inside Odomin, approximately 0.5 m above the water. One logger was also places in the pump station and hung approximately 1.5 m down in the pump sump, see Figure 24. The pump sump is just below a door in the floor.

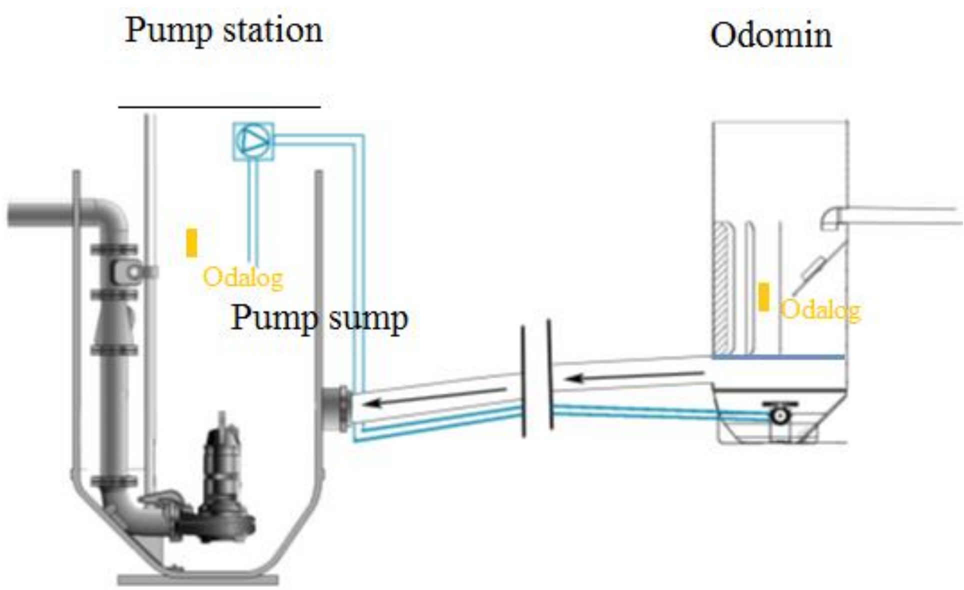


Figure 24. Schematic picture of where the Odaloga are ung in Odmin and the pump sump.

The data will show how the H_2S-level changes over the week and which temperature the air has. When the comparison is made it is possible to tell which factor/factors that have the biggest influence on the reduction of H_2S between the pump sump and Odomin.

The flow through Odomin was estimated from the data collected in Vreta, see Table 6.

Table 6. The volume and time per pumping to Odomin 65.

	Volume per pumping	**Minutes per pumping**
Pump 1	0.68 m^3	2.14
Pump 2	0.79 m^3	2.5

Sacrificial anode
The sacrificial anode was hung inside Odomin in such a way so the material came in contact with air and wastewater, see Figure 25.

Figure 25. The sacrificial anode inside Odomin.

The piece of carbon steel that was used weighted 6.35 kg.

Splash
The reducer that was mounted is shown in Figure 26.

Figure 26. The reducer mounted in Odomin to create a greater splash.

It was mounted onto the inlet, see Figure 27, and decreases the area in order to create a greater splash.

Figure 27. The splash mounted at the inlet in Odomin.

The diameter of the inlet was decreased from 110 mm to 75 mm. This corresponds to a decrease with 46.5 % of the inlet area.

To decrease the area of an inlet is not permitted to do permanently but under these circumstances it was considered not to be a problem, since it was placed there under a short period of time.

<u>Area</u>

The plastic folded material was 1 090 mm wide which was suitable to use as length of the pieces.

Three plastic pieces were made and fastened as curtains inside Odomin. They all hung perpendicular to the plate onto which the inlet water splashes, see Figure 28.

Figure 28. The plastic curtains hung inside Odomin.

The length in 1090 mm was calculated to correspond to an effective length on 1 440 mm. The pieces were cut to a width on 500 mm. With these measures the curtains gives an extra inner area to Odomin on 4.32 m^2. The total inner area in Odomin is 9.4 m^2 and along with the added area it increases with 46%, to 13.72 m^2.

3.6. Calculating comparable levels

In order to analyse the data in a reasonable way it was decided to calculate one mean value during the active hours of the day and one mean during the night. This was decided since it is a large difference in H_2S-levels during the daytime and the night. The active hours is put to 06.45-23.45 and the passive interval to 23.46-06.44. These intervals were chosen after analysis of the data.

The reduction rate between Odomin and the pump sump will be calculated since it is of interest to see how many times the levels of H_2S are reduced by using Odomin. The analysis will mainly focus on the reduction of the mean value.

An extreme mean value will also be calculated between the 10 highest tips during 1 day.

This approach was chosen since there were no guidelines found about how to calculate the H_2S-levels of exposure. The information found, about directions of H_2S-levels, is from Arbetsmiljöverket, the Swedish working environment institute. These levels are 10 ppm for 1-day exposure, corresponds to 8 hours, and an exposure on 15 ppm during 15 minutes. The level for 1-day exposure can, generalized, be compared to the active mean value and the maximum for 15 minutes to the extreme mean value.

4. RESULTS

In this chapter all the results from the test series and the factorial design are presented.

4.1. Testing series in Uppsala

Every variation, of the total 8, was tested for 1 week. The whole test session in Uppsala was supposed to be 8 weeks long but the logger malfunctioned during the 4th week, when NA was tested, hence the testing was delayed.

Every week there was a visit to Odomin 65 and the pump station. During the visits data was collected and the factorial combination was changed. The temperature in the water and the pH-level was measured in Odomin at every visit, see Table 7.

Table 7. The pH levels and the temperatures at certain times.

Time	pH	Sewage temperature in Odomin [°C]	Air temperature in Odomin (mean value) [°C]	Present factor when measuring
Start, 20/8	7,6	18	17.6	NA
27/8	8,3	21	16.8	Anode
3/9	7,6	19	15.1	Anode/area
10/9	7.4	19	15.6	Area
17/9	7,5	21	14.2	NA
26/9	7,4	16	13.8	Splash/anode
1/10	7,6	17	11.4	Splash/area
8/10	7,5	16	11.9	Splash/area/anode
20/10	7,6	17	10.4	Splash
28/10	7,4	17	8.6	NA

The level of H_2S in Odomin was registered by Xylem and the levels in the pump sump the Uppsala community.

The collected data was processed in Matlab and the results are presented in graphs. In Figure 29 are the active and passive mean values for the whole testing series shown.

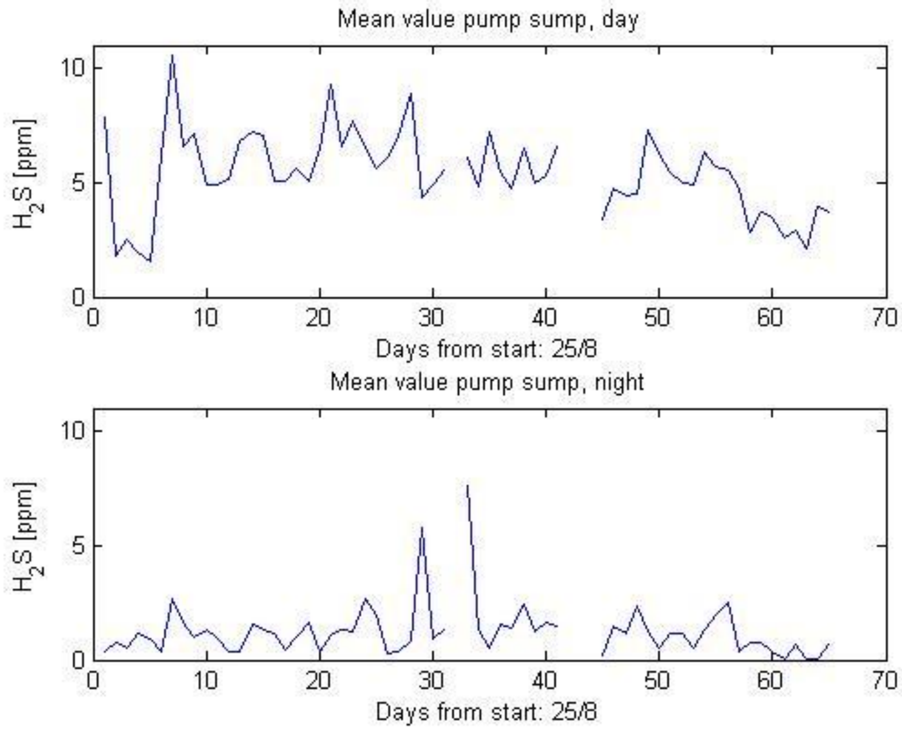


Figure 29. The active and passive mean value during the whole testing period [ppm].
The x-axis shows the number of days from start, 25 August.

The gaps mean that no data was collected that day. The *x*-axis shows the number of days from start, which was the 25th of August. The graphs show that the daily mean value is of more interest for the analysis due to the higher values and the risk of exposure for people working with the pump station during day time.

Following intervals corresponds to the factorial combinations:

- 0-3: anode (+ - -)
- 4-10: anode & area (+ - +)
- 11-17: area (- - +)
- 18-24: none (- - -)
- 25-33: anode & splash (+ + -)
- 34-38: splash & area (- + +)
- 39-45: anode, splash & area (+ + +)
- 46-55: splash (- + -)
- 56-65: none (- - -)

The reference factor, none, is made two times. This is because the logger measuring the H_2S -levels in Odomin malfunctioned during the 4th week. Data from the pump station was however logged and is used for the analyses. Therefore the intervals 18-24 and 56-65 in the pump station can be equally compared.

Figure 30 shows the mean value from Odomin and the pump sump.

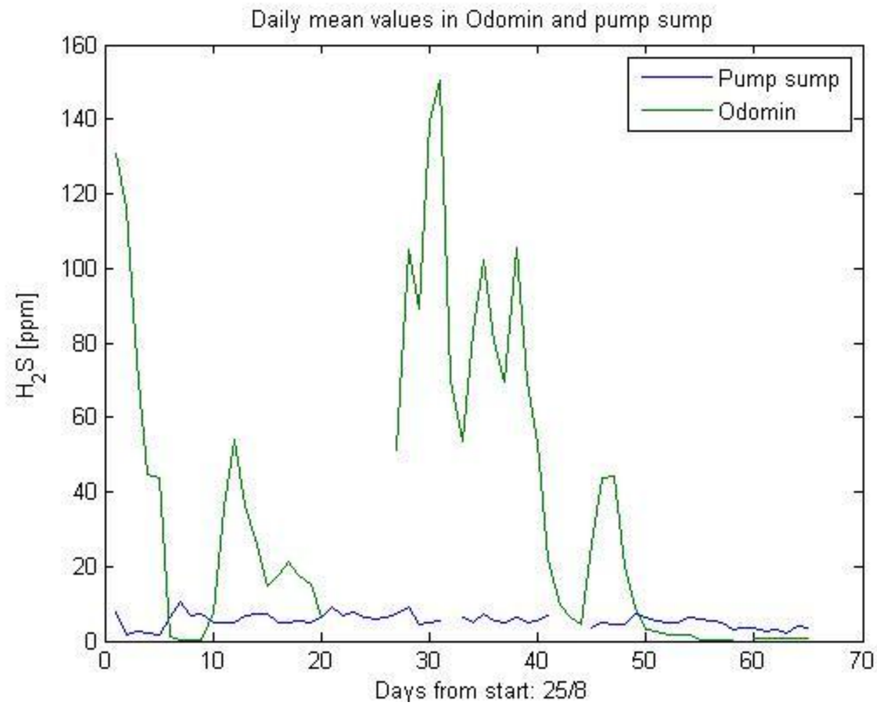


Figure 30. The mean values in Odomin and the pump sump.

In Figure 31 are the extreme mean values, the mean from the 10 highest values every day, from the pump sump shown.

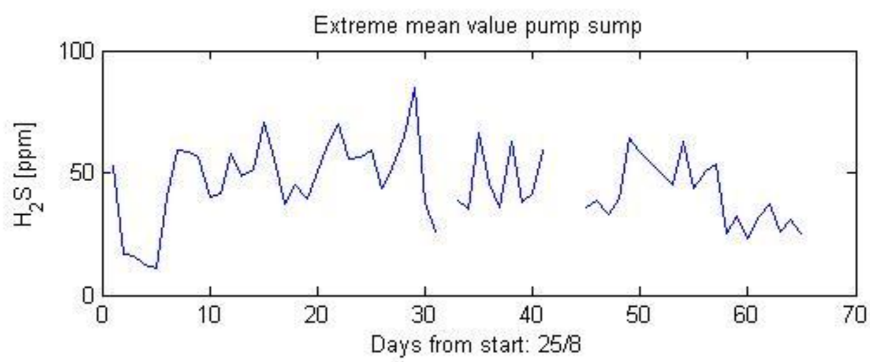


Figure 31. The extreme mean values from the pump sump [ppm].

Figure 32 shows the graphs of the active and passive reduction rates. This is calculated from the mean values in the pump sump and in Odomin.

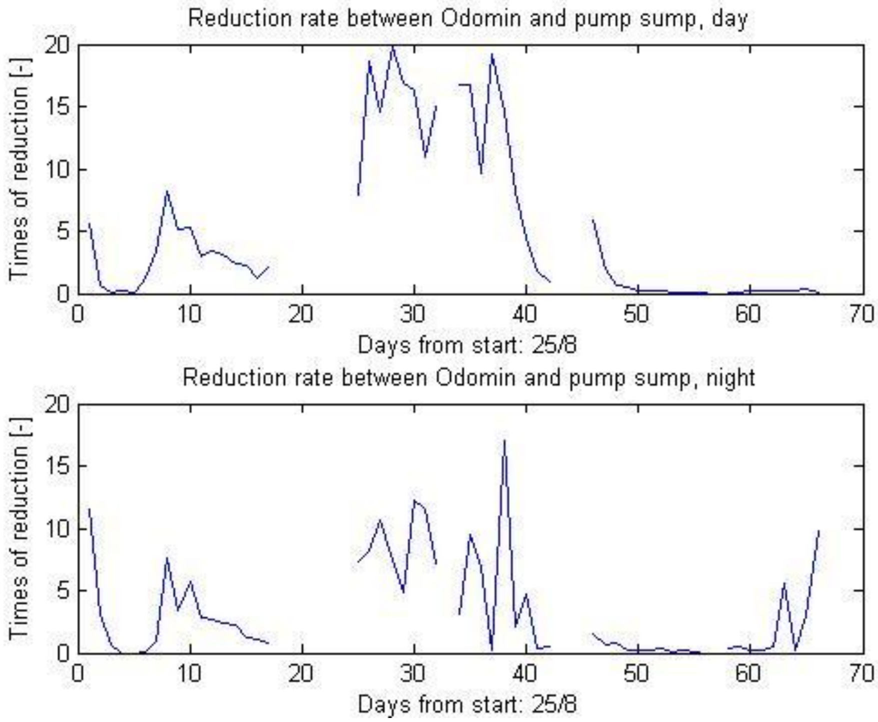


Figure 32. The calculated reduction ratio [-] between Odomin and the pump sump.

Figure 33 shows the reduction rate for the extreme values.

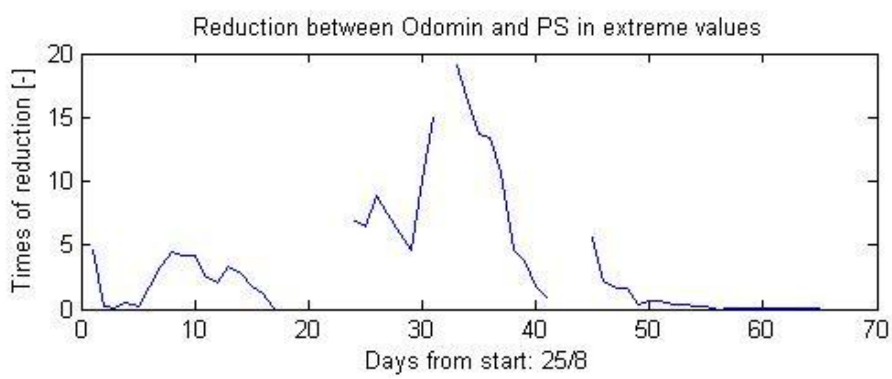


Figure 33. Reduction rate in extreme values [-].

The reduction rates of the daily mean value and the extreme value show relatively similar pattern and same sizes in reduction rate.

Unfortunately the levels in Odomin during one interval: anode and splash, was measured with a logger dimensioned for lower levels. The logger was only able to register levels up to 387 ppm, see Figure 34.

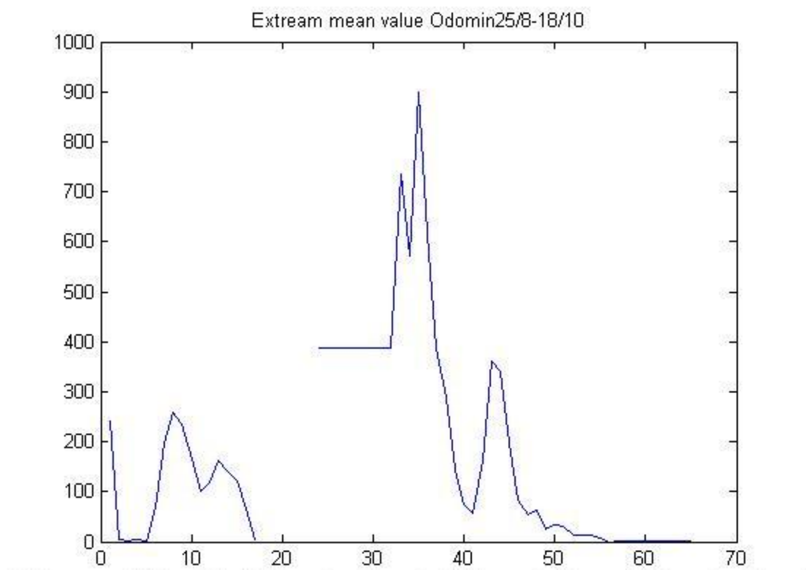


Figure 34. The extreme values measured in Odomin.

Therefore all levels above this are put to 387 ppm, which affects all the analysed aspects: the mean and extreme values and the reduction rate.

4.2. Factorial design

Factorial design was used to perform analyses on the collected data. Every factorial combination is placed in a corner and every axis: *x*, *y* and *z*; corresponds to the two levels of each factor, see Figure 35.

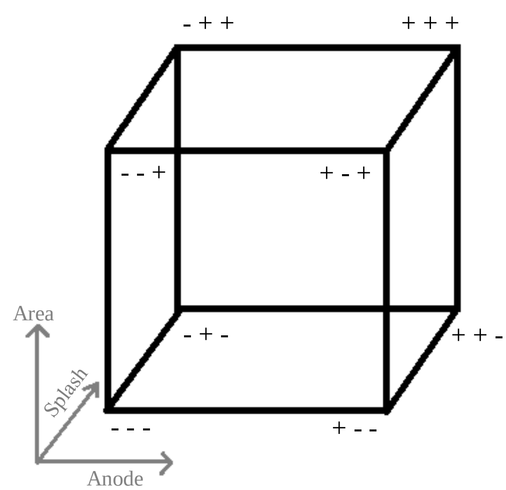


Figure 35. The factorial design and the combinations between anode, splash and area.

Here is the two levels of the anode placed along the *x*-axis, splash along the *y*-axis and area the *z*-axis. In coordinates this can be represented as:

- Anode: (1, 0, 0)
- Splash: (0, 1, 0)
- Area: (0, 0, 1)

These 3 factors form 8 different combinations which are represented by each corner.

4.2.1. Mean value

The mean values of the eight combinations, along with its standard deviation, are presented in Table 8.

Table 8. The daily mean value and the standard deviations.

Factorial combination	Mean value [ppm]	Standard deviation [ppm]
Anode (+ - -)	3.87	3.48
Anode & area (+ - +)	5.53	3.11
Area (- - +)	5.71	1.11
Anode & splash (+ + -)	6.11	1.42
Splash& area (- + +)	5.93	1.30
Anode, splash & area (+ + +)	5.16	1.17
Splash (- + -)	5.46	0.94
None (- - -)	4.75	1.99

The common mean value, including all data from the measurement, is 5.32 ppm. Note that the null combination none (- - -) was measured two times. The presented value is the mean value from these measurements:

- 6.55 ± 1.54 ppm
- 3.35 ± 0.79 ppm

The results are presented as a cub in Figure 36.

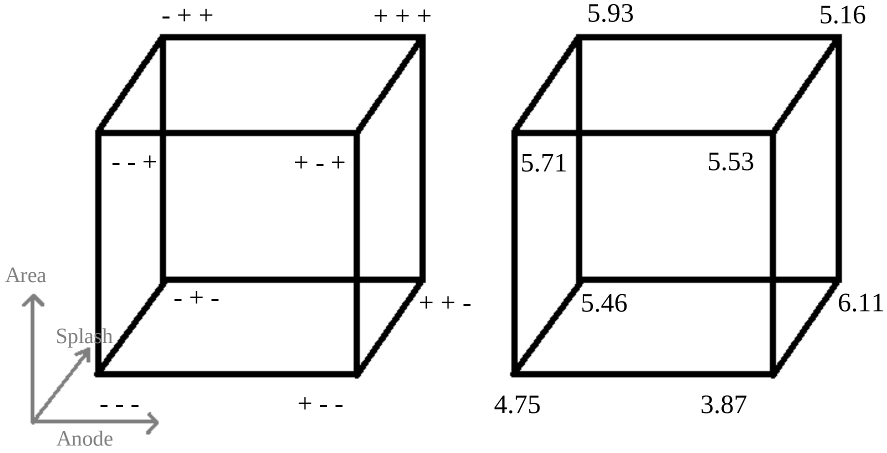


Figure 36. The daily mean values [ppm] for each of the 8 combinations.

The calculated main effects of the mean value in the pump sump are presented in Table 9.

Table 9. The main effects on the daily mean value.

Factor	Main effect on mean value, pump sump [ppm]
Anode	-0.30
Splash	0.69
Area	0.53

The main effect is calculated when the factors are varied from plus to minus, or from present to non-present. It can be seen that the anode has the largest influence alone on the mean value of H_2S in the pump sump, but the area is the one factor decreasing the mean value. A positive main effect means it increases the mean value and a negative effect decreases it. In this case it is wished to have as low mean value as possible.

The interaction effects are presented in Table 10.

Table 10. The interaction effects on the daily mean value.

Factor	Interaction effect
Anode & splash	0.23
Anode & area	-0.18
Splash & area	-0.78
Anode, splash & area	0.53

In Figure 37 the three 2-way interactions are shown, to give a graphical image on how the factors are affected by each other.

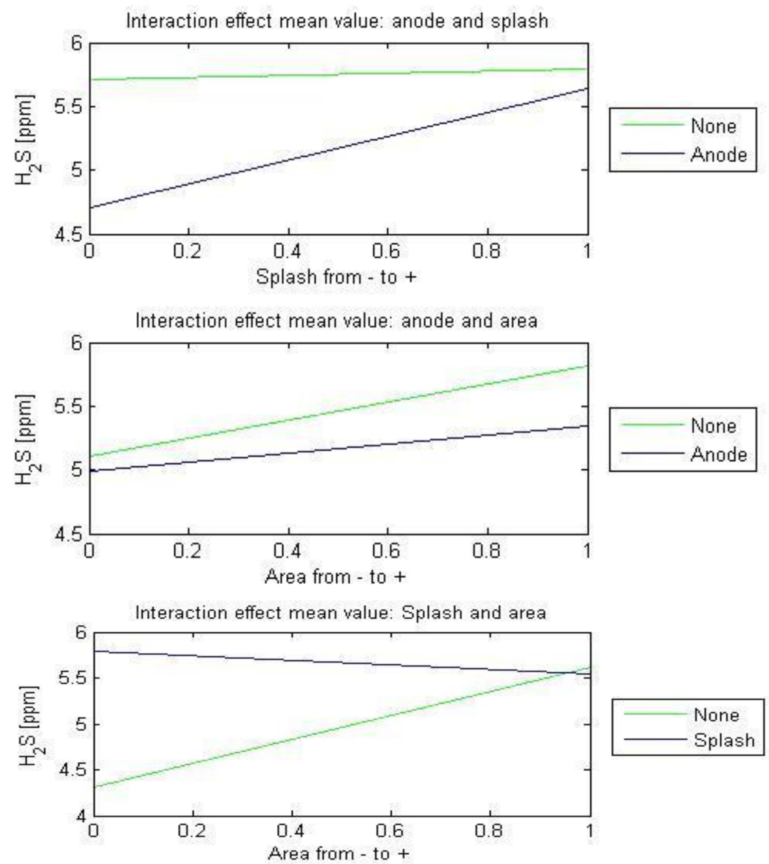


Figure 37. The three 2-way interaction effects on the mean value in the pump sump.

The effects from the analysis, both the three main effects and the four interaction effects, are plotted in a graph to analyse if the effects are normal distributed. This is of interest since the errors of a measurement are normal distributed. A factor is only of statistical significance if it deviates from the "error line", see Figure 38. If a point shows a clear deviation from the error line is has a statistical significance on a 5% level.

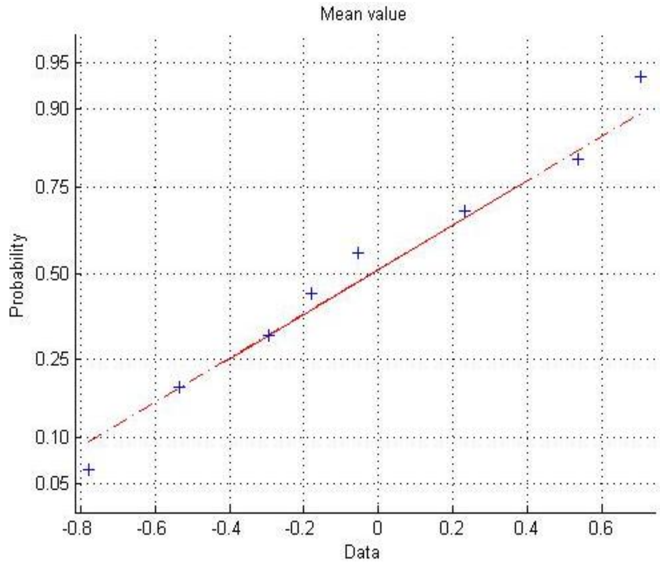


Figure 38. The normal plot of the mean value interactions in the pump sump.

This is analysed with Matlab and the results are plotted with the linear line, which corresponds to the normal distribution or the "error line".

4.2.2. Reduction rate

The same analyses are made of the reduction rate between Odomin 65 and the pump sump. The reduction rate is calculated as the quotient of the daily mean values in Odomin (dividend) and the pump sump (divisor). The results are calculated for the reduction rate between Odomin and the pump sump, see Table 11. The reduction rates from of the different factorial combinations.

Table 11. The reduction rates from of the different factorial combinations.

Factorial combination	Reduction rate [-]	Standard deviation [-]
Anode (+ - -)	2.09	2.98
Anode & area (+ - +)	2.94	3.03
Area (- - +)	2.87	1.18
Anode & splash (+ + -)	15.20	3.72
Splash& area (- + +)	14.20	4.38
Anode, splash & area (+ + +)	4.25	2.98
Splash (- + -)	0.91	1.74
None (- - -)	0.19	0.07

The common mean value of the reduction rate is 5.33. In are the differences in the reduction values when a factor is changes from – to + shown. The results are represented in a cube in Figure 39.

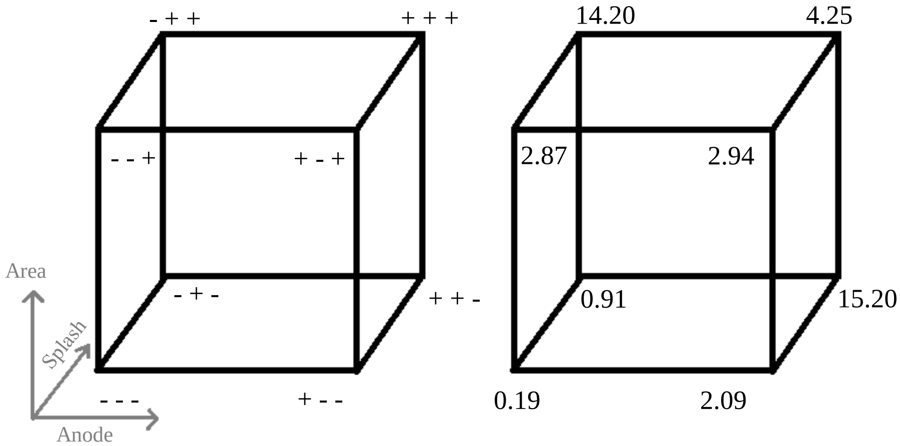


Figure 39. The reduction rates [-] for each of the 8 combinations

The main effects on the reduction are shown in Table 12.

Table 12. The main effects on the reduction rate.

Factor	Main effect, reduction rate [-]
Anode	1.58
Splash	6.62
Area	1.47

In this case it is the Splash that has the largest influence in increasing the reduction rate between Odomin and the pump sump.

Interaction effects are shown in Table 13.

Table 13. The interaction effects on the reduction rate.

Factor	Interaction effect
Anode & splash	0.59
Anode & area	-6.52
Splash & area	-0.30
Anode, splash & area	-5.61

The 2-way interactions are graphically shown in Figure 40.

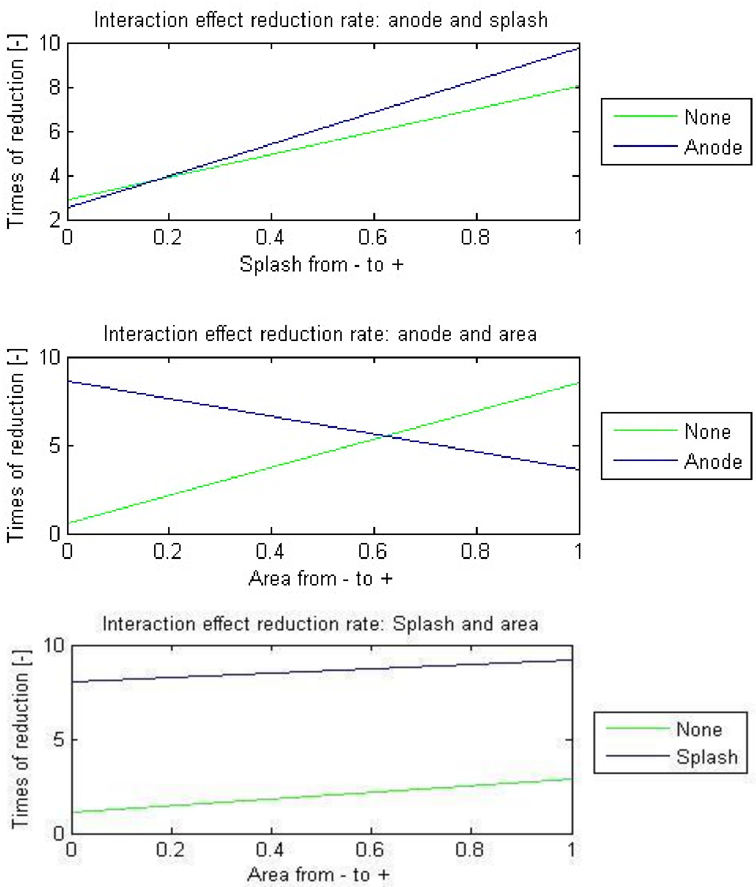


Figure 40. The 2-way interactions on the reduction rate.

The normal plot of the effects is shown in Figure 41.

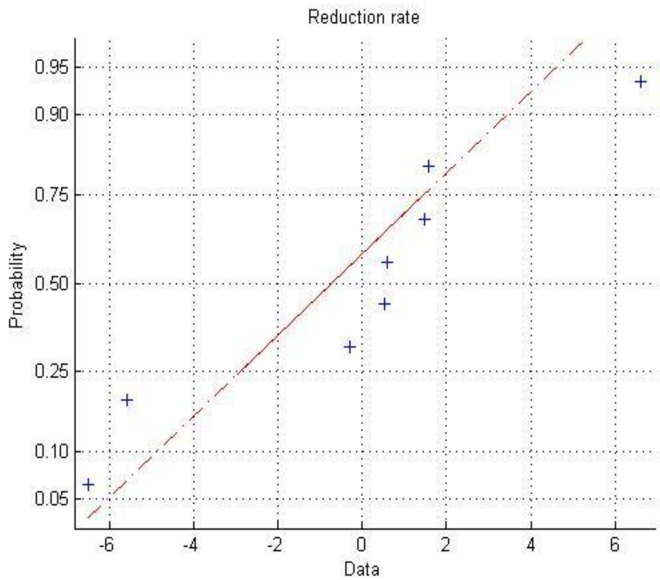


Figure 41. The normal plot of effects of the reduction rate.

4.2.3. Extreme mean value

The eight different extreme values measured in the pump sump are presented in Table 14.

Table 14. The extreme values in the pump sump.

Factorial combination	Extreme value [ppm]	Standard deviation [ppm]
Anode (+ - -)	28.49	20.91
Anode & area (+ - +)	36.76	21.05
Area (- - +)	50.48	11.03
Anode & splash (+ + -)	51.60	17.37
Splash& area (- + +)	47.44	13.72
Anode, splash & area (+ + +)	47.47	12.74
Splash (- + -)	47.66	10.96
None (- - -)	42.19	14.47

The common mean value of the extreme value is 44.01 ppm. The factorial combinations and the results of the extreme value are presented in Figure 42.

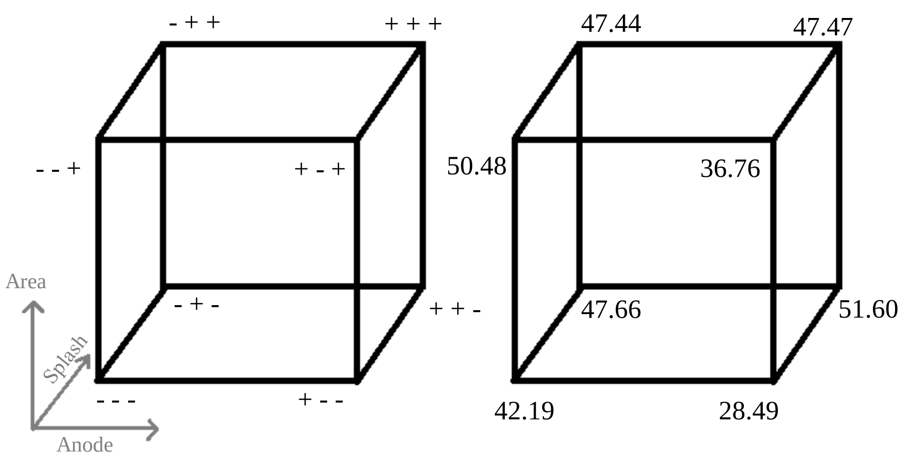


Figure 42. The extreme values [ppm] for each of the 8 combinations

The main effects from the extreme mean values from the pump sump are presented in Table 15.

Table 15. The main effects on the extreme mean value

Factor	Main effect, extreme mean value pump sump [ppm]
Anode	-5.86
Splash	9.06
Area	3.05

According to these effects has the anode the largest influence on the level of H_2S. The interaction effects are shown in Table 16.

Table 16. The interaction effects on the extreme mean value

Factor	Interaction effect
Anode & splash	7.85
Anode & area	-0.99
Splash & area	-5.23
Anode, splash & area	-0.97

The interaction effects are graphcally shown in Figure 43.

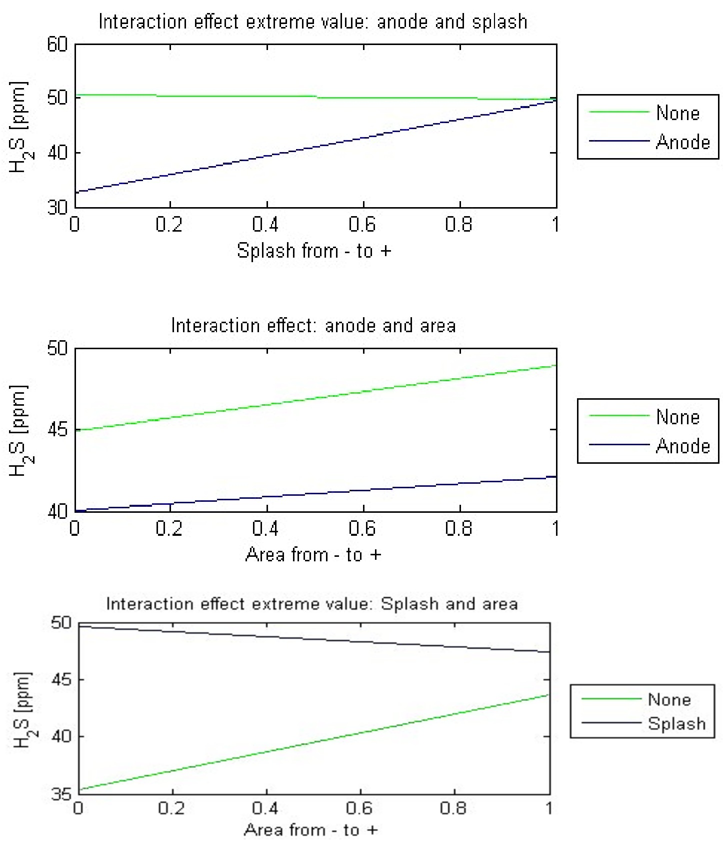


Figure 43. The 2-way interaction effects on the extreme mean vaule in the pump sump.

Figure 44 shows the normal plot of the extreme values.

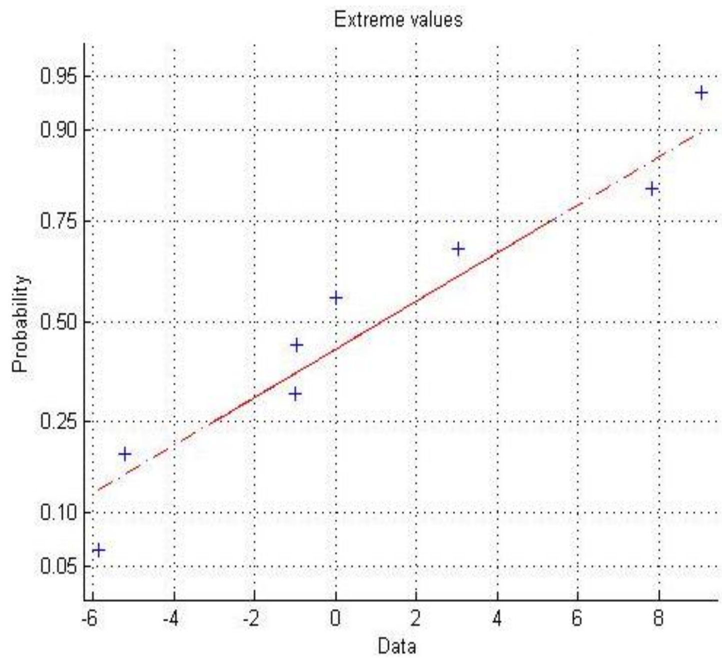


Figure 44. The normal plot of the main and interaction effects of the extreme values in the pump sump.

The Matlab program for these calculations can be found in Appendix A.

4.3. Uncontrollable circumstances

The first collection of these data gave an indication on how the levels in Odomin and the pump sump look at the same time; see Figure 45 and Figure 46.

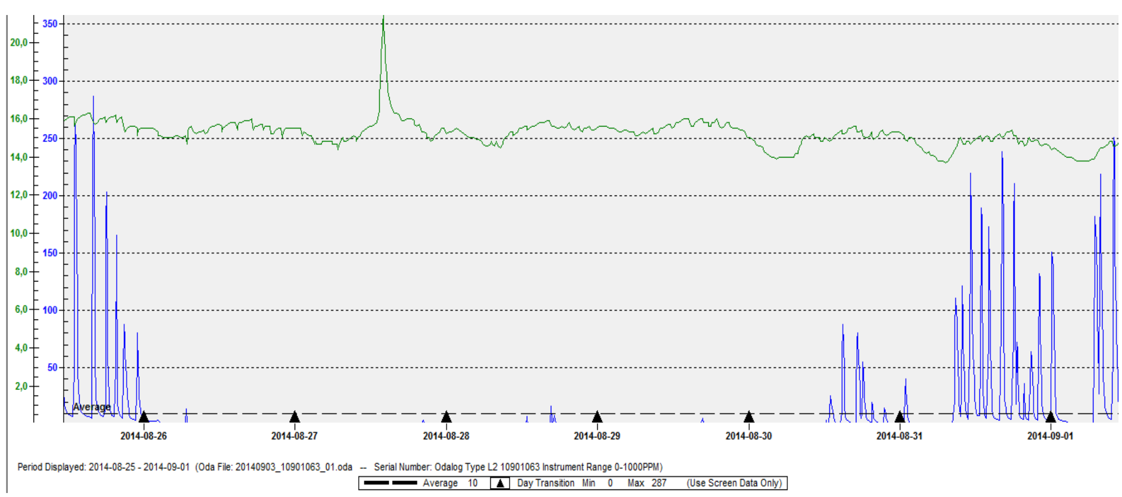


Figure 45. The logged data from Odomin during 25/8-1/9.

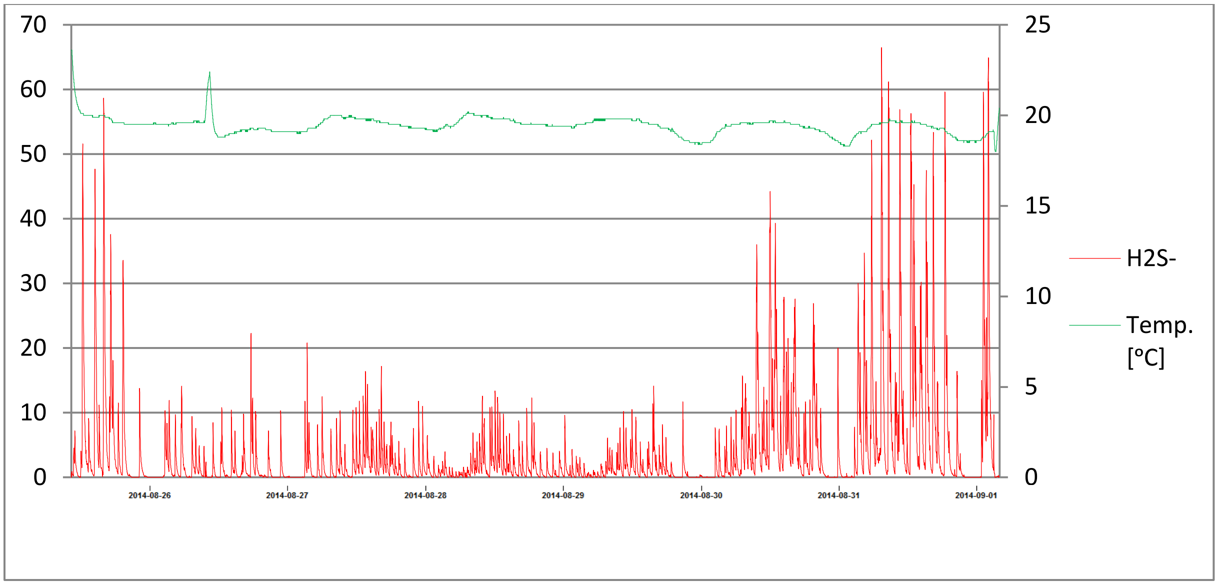


Figure 46. The logged data from the pump sump during 25/8-2/9.

The drastic decrease in H_2S-levels was caused by an unplanned dosing of Nutriox in the pump station in Vreta, which pumps to Odomin. A closer look at the levels in Odomin during the dosing, a few peaks occur at about 5-10 ppm. These few peaks do not cause the higher levels in the pump sump. This accidental dosing show that H_2S also comes from another pipe, otherwise the levels in the pump station would be close to zero during this period.

The 2 curves do follow the same pattern so it is obvious that the most of the H_2S comes through Odomin.

4.4. BOD

The BOD5-level was measured 2 times in that wastewater from Odomin, see Table 17. The mean values in the pump sump from those days are also displayed.

Table 17. The measured BOD levels from wastewater from Odomin.

	BOD5 Odomin [mg/l]	Mean value in pump sump [ppm]
2014-10-20	450 ± 72	5.52
2014-10-28	300 ± 47	3.69

4.5. Maintenance

It is wished to reduce the amount of organic material that gets stuck onto the mounted angles on the angular plate. Along with the splash it was investigated if this factor could reduce the amount of organic material.

Figure 47. The cloth of organic material before installation of splash.

Figure 47 shows two examples on how the angular plate looked before the installation of the splash. Figure 48 shows the plate when the splash was just removed. After the installation it actually looks like more organic material has get stuck than before.

Figure 48. The cloth of organic material after installation of splash.

5. DISCUSSION AND CONCLUSIONS

The measurements in Uppsala give information about the mean and the extreme values in the pump sump and the reduction between Odomin and the pump sump. A lot of data has been collected under a long period of time. Unfortunately the temperature, which has varied during the testing period, showed a strong influence of the hydrogen sulphide, H_2S, levels. This fact gives some doubt on how reliable these results are and the recommendation is to make further tests to confirm it.

5.1. Discussion

In Table 18. The common daily mean value, reduction rate and extreme mean value. the total mean value of the three analysed aspects are shown. This mean value is calculated from the data of the entire testing series.

Table 18. The common daily mean value, reduction rate and extreme mean value.

	Daily mean value, pump sump [ppm]	Reduction rate on mean value [-]	Extreme mean value, pump sump [ppm]
Total mean value	5.32	5.33	44.01

When these values are compared to the prior studies it is observed that the reduction rate here is lower: 5.33 compared to 15 and 17, which was measured in Ågesta, Sweden, and Denmark, see chapter *2.7 Previous tests and results*. The daily mean/max value is 16/77 ppm in Ågesta and 17/163 ppm in Denmark. In Uppsala it is 5.32/44.01 ppm. The levels in Uppsala are lower, which can lead to a lower reduction rate, see Figure 49. Left: The daily mean values in Odomin and pump sump. Right: reduction rate of daily mean values. When levels are high in Odomin the reduction rate is high. The mean value in the pump sump is in Uppsala relative constant.

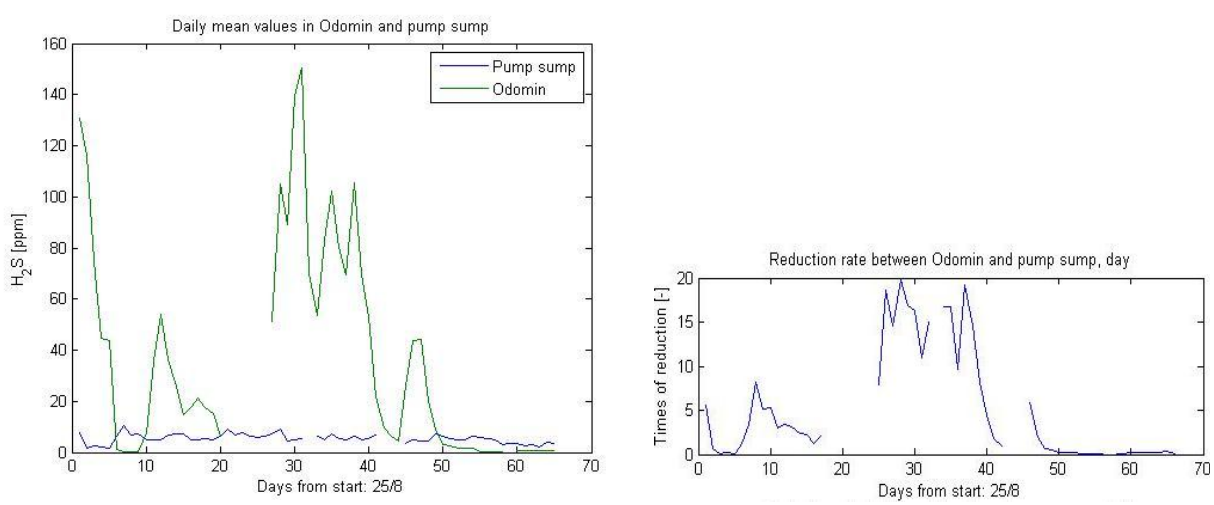


Figure 49. Left: The daily mean values in Odomin and pump sump. Right: reduction rate of daily mean values.

The lower reduction rate in Uppsala might depend on that H_2S also comes from another pipe. That affects the reduction rate since the rate depends on the levels in the pump sump. The calculated common reduction rate (5.33) therefore shows a less efficient number than it would if only the pipe through Odomin was causing the H_2S levels.

The results of the calculated main effects are summarized in Table 19 the 3 marked cells have the largest influences on the outcome of the test.

Table 19. The factor effects from factorial design.

	Effect mean value, pump sump [ppm]	Effect reduction rate [-]	Effect extreme mean value, pump sump [ppm]
Anode	-0.30	1.58	-5.86
Splash	0.69	6.62	9.06
Area	0.53	1.47	3.05

These results show that the anode is the only factor decreasing both the mean and extreme value in the pump sump. The anode has an outstanding reduction on the extreme value. The splash increases the reduction rate almost 7 units but show an increase of mean and extreme value in pump sump.

In Table 20. The interaction effects from factorial design the interaction effects are summarized. The cells marked with blue have large influence of the responses.

Table 20. The interaction effects from factorial design

	Effect mean value, pump sump [-]	Effect reduction rate [-]	Effect extreme mean value, pump sump [-]
Anode & splash	0.23	0.59	7.85
Anode & area	-0.18	-6.52	-0.99
Splash & area	-0.78	-0.30	-5.23
Anode, splash & area	0.53	-5.61	-0.97

Mean values

The three graphs shown in Figure 37, chapter *4.2.1 Mean value*, are compared to the examples in Table 4. Main effects and their interactions. (University of Washington, 2014) it can be concluded that the factors have slightly influencing main effects but, only one interaction effect: splash & area. The main effect of the area is positive, which is clearly visible in the picture.

When looking at the normal plot of the mean differ a lot from the error line. A noticeable deviation is seen in:

- Splash (0.69)
- Splash & area (-0.78)

The interaction between the splash &area show an interaction in the plot, see Figure 50.

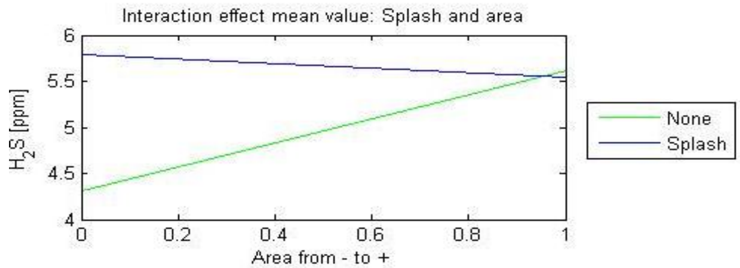


Figure 50. The 2-way interaction between splash & area.

This shows that there is an effect on from both factors. The mean value increases when the area is added and decreases when the splash is used. However, the splash alone increases the mean value, positive effect.

Reduction rate of daily mean value

The reduction rate has clearly an interaction effect between the anode & splash, and the anode & area. There is no interaction between the splash and area.

The normal plot show that the following affects, in order of impact, influences the reduction rate:

- Splash (6.62)
- Anode & area (-6.52)
- Anode, splash & area (-5.61)

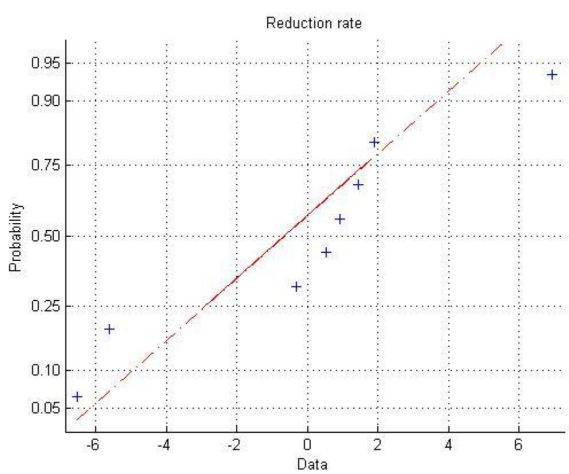


Figure 51. The probability plot of reduction rate.

By looking at the probability plot, Figure 51, it can be observed that the errors are concentrated between -0.5 and 2 on the x-axis. Since there are so few points, the deviating effects have a large influence on the normal plot and the deviation from the line looks smaller than it actually is.

The highest reduction rates are during the interactions of anode & splash (15.20) and anode & area (14.20), see Figure 32 in chapter *4.1 Testing series in Uppsala*. These two combinations are outstanding in reduction rate. These levels are probably exceptional high due to high levels measured in Odomin and high temperatures. The low reduction rates, at the end of the testing series, is probably caused by the low air temperature, see the graph to the right in Figure 49.

The reduction rate is wished to be as high as possible and the splash is the strongest significant factor, on a 5% level, that shows an increase in the reduction. The anode & area and anode, splash & area show negative interactions. This means that the factors counteract each other, see the example of anode & area in Figure 52.

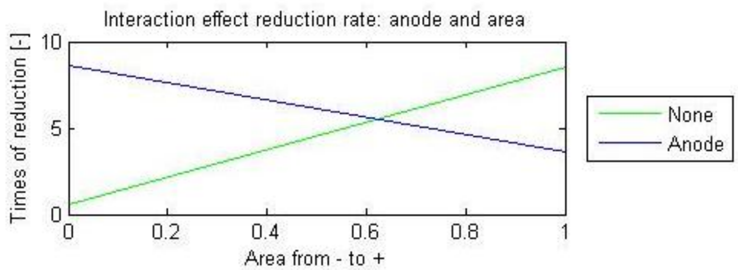


Figure 52. The interaction effect between anode and area.

When this interaction is compared with the examples in *2.8.1 23 factorial design* the conclusion can be made that none of the main effects are strong but there in an interesting interaction effect: the reduction rate is high when the two factors are opposite each other, one + and the other - (therefore the negative sign).

Extreme mean value

The interaction effects for the extreme values look similar to the once for the mean value. But there is an interactions between the anode & splash and splash & area, show a tendency to interaction.

The anode clearly decreases the extreme mean values and the H_2S level is lower when neither the splash nor area is present. This can be seen in Figure 53, the first 2 graphs. The blue line represents the anode.

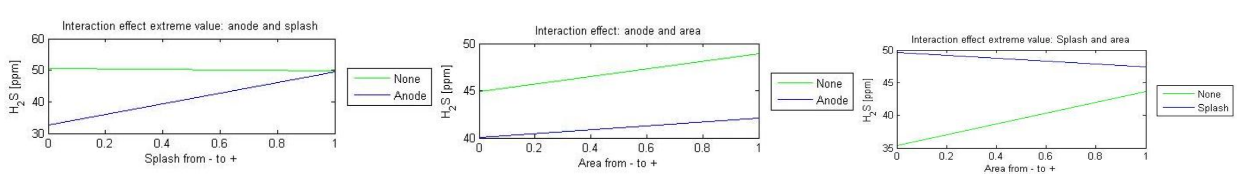


Figure 53. The three 2-way interactions on the extreme value.

The normal plot of the extreme mean values show that the anode is the only factor clearly deviating from the error line, see Figure 44 in chapter *4.2.3 Extreme mean value*.

- Anode (-5.86)

The anode is statistical significant and show a decrease in extreme values. The splash, which slightly deviates from the error line, shows a tendency to increases the extreme value, which is not whished.

Analyse

The results are a bit surprising: the offer anode is the only factor actually decreasing the extreme values, and the mean value (but not proven to be statistical significant in the mean value). This was not an expected outcome. It was expected that the area or splash would have the largest influences of the reduction of H_2S. The offer anode was more of a “wild card” that was proven to be efficient. One reason to this positive indication of the offer anode is the dosing of Nutriox in Vreta, which was made during the intervals: anode and anode & area. This fact complicates the analysis of Odomin since these levels of H_2S can be misleading and the consequence is unreliable results. The dosing also shows that the H_2S-level in the pump sump not only depends on the H_2S levels in Odomin but also is affected from another incoming pipe. This has not been further investigated.

The offer anode was weighted before, during and after the whole measurement. During the tests the weight decreased with 70 grams, from 6.35 kg to 6.27 kg. After the testing series is was back at 6.35 kg, which indicates that the offer anode did not decrease in weight. Since the anode show indications in reducing the mean and extreme value it could be possible it lost weight by giving ions. The same scale was used for all measurements.

The splash has the largest reduction rate, which was expected. The splash initiates to set the H_2S free from the water inside Odomin, which results in a high level of H_2S here. The levels in the pump sump are not lower than normal, the effect on the mean value is positive (0.69), but not considerably high. The reduction rate is large: a higher level of H_2S in Odomin than normal causes this.

The supposed reason that the area did not show as good results as expected, is that it was only increased with 46%. A greater increase could give better results.

Uppsala was not the ideal place to perform the tests: the temperature in the air affected the results and H_2S also arises from the other incoming pipe. This affects the reduction rate negative since the H_2S-levels became higher in the pump sump than if only the pipe from Vreta had caused the problem.

When the tests started the air temperature was about 17.6 °C and at the end 8.6 °C. This had a high impact on the levels of H_2S, which is confirmed by the reference level (- - -) that were, by accident, measured twice. The mean values from these two periods are:

- 18-24: 6.55 ppm
- 56-65: 3.35 ppm

This is a difference in 3.2 ppm, almost 49%. It is known that the temperature affects the levels of H_2S is known and these values confirm how important this factor is. Detected affections from the investigated factors are:

- Splash on reduction rate (compared with common value): 55 %
- Offer anode on extreme mean value: reduction 20%

This shows that the temperature has almost as large influence on the H_2S-levels as the splash for the reduction rate.

Another factor that complicates this analysis, apart from uncontrollable factors, is that the results are taken under a long time with no replicates. A better way to perform this series is to test each factor for 2-4 days, and make 2-3 randomized replicates. This would enable to see variations from the factors and not those caused by temperature differences and chemicals.

The recommendation from Arbetsmiljöverket of 1-day exposure, 10 ppm, can in general be compared to the daily mean value. The daily mean was once measured higher: 10.55 ppm. This was just after the Nutriox dose, when the anode & area was present. The fact that the highest value was measured at this time emphasizes the assumption that the offer anode shows better results, due to the dosing, than it should.

The maximum exposure for 15 minutes is recommended to 15 ppm. More or less all of the extreme values are much higher than 15 ppm and the mean value is 44.01 ppm in the pump sump. This maximal exposure cannot exactly be compared to the calculated extreme maximum level. The peaks last for 1-3 minutes and then it slowly drops. Analysing the pattern of the data it can be seen that levels over 15 ppm in the pump sump appears for about 10 minutes. This indicated that the levels are just below the recommended ones. The levels in the pump station, just above the pump sump, are even lower. These levels have not been logged.

The measured levels of BOD: 450 ± 72 mg/l and 300 ± 47 mg/l are relative medium compared with the high and medium levels mentioned in the chapter about BOD: 560 and 350 mg/l. At the first measurement the temperature was 10.4 °C and at the second measurement it was 8.6 °C. The mean values in the pump sump from these days were 5.52 ppm and 3.69 ppm, which shows that the BOD-level has an important influence on the levels of H_2S in the pump sump. More samples needs to be analysed to confirm this and this is an interesting factor for further studies.

The splash was also designed to reduce the amount of organic material getting stuck on the mounted angles on the angular plate. There were no indications that the splash did it better. To enable the water to spread circularly inside Odomin would decrees the risk of material getting stuck and increase the amount of H_2S that oxidizes on wet surfaces. A better designed nozzle for the inlet could improve this.

5.2. Conclusion

- The common reduction rate of the daily mean value is 5.33 between Odomin and the pump sump: Odomin shows a decreasing effect.
- The reduction rate decreases with decreasing temperature.
- The splash can increase the reduction rate 6.62 units according to the factorial design. This factor is statistical significant at a 5% level. If can affect the reduction rate with up to 55%.
- The interaction effect between the anode and area is significant for the reduction rate.
- The anode is the only factor decreasing the mean and extreme value in the pump sump.
    - The main effect of the anode is large (-5.86) on the extreme value but not clearly statistical significant.
    - The main effect on the mean value is not statistical significant but show a decreasing effect.
    - The results are probably better than they should be due to a dosing (by mistake) of Nutriox in Vreta.
- The levels of the mean value in the pump sump are normally distributed and no factor shows a significant effect.
- The splash did not decrease the amount of organic material that got stuck onto the angular plate.
- The air and wastewater temperature has a large influence on the levels of H_2S in the pump sump and can affect the levels up to 49%.
- The levels in the pump station in Graneberg are on the limit for what is recommended by Arbetsmiljöverket.
- The analysis is affected by uncontrollable factors, like differences in temperature and added chemicals, which affects the trustworthiness of this evaluation.
- Due to the uncontrollable factors that affected the results this study needs to be verified.

6. RECOMMENDATIONS AND FUTURE WORK

These are the recommendations from the author after performing this study.

- Dampen the inlet to the pump station, after the outlet of Odomin. This can further decrease the H_2S-level in the pump station/sump. (Ledskog A. et al., 1994, p 19)
- The tests should be made again and under a shorter timer period. The temperature in the air changed a lot during the test series which is not optimal when the results are compared. Recommendation is to test every factor 2-4 days, and make 2-3 randomized replicates.
- Investigate how the BOD5-level affects the levels of H_2S in the pump sump and the reduction rate. Can this factor be affected inside Odomin?
- Design a nozzle that spreads the water more inside Odomin.

7. References

Akzonobel, https://www.akzonobel.com/ic/system/images/AkzoNobel_sewer_Swe_tcm18-10183.pdf, read 2014-07-08

Andersson Ö. *Experiment! : Planning, Implementing and Interpreting*, ISBN0-470-68825-4; ISBN0-470-68826-2, Hoboken John Wiley & Sons, 2012

Arbetsmiljöverket, *Hygieniska gränsvärden*, ISBN 978-91-7930-559-8, AFS2011:18, 2011

Box G.E.P., Hunter J.S., Hunter W.G., *Statistics for Experiments*, 2nd edition, ISBN-13-978-0471-71813-0, John Wiley & Sons, USA, 2005

Barnstable Country, http://www.barnstablecountyhealth.org/ia-systems/information-center/compendium-of-information-on-alternative-onsite-septic-system-technology/basics-of-wastewater-treatment, read 2014-11-05

Coburn_myers, http://www.coburnmyers.com/materials-carbon-steel/, read 2014-08-18

Duranceau S.J., Trupiano V.M., Lowenstine M., Whidden S., Hopp J., *Innovative Hydrogen Sulfide TreatmentMethods: Moving Beyond Packed Tower Aeration*, Florida Water Resources Journal, July 2010

EngineeringToolbox.com, http://www.engineeringtoolbox.com/gases-solubility-water-d_1148.html, read 2014-09-02

Flygt, *Flygt Odomin svavelvätereduktionstank*, http://www.xylemwatersolutions.com/scs/sweden/sv-se/produkter/pumpstationer-och-avloppsnat/ODOmin_svavelvatereduktion/Sidor/Odomin%20Svavelv%C3%A4tereduktion.aspx, read 2014-07-10

Hedmark P., Strandberg T.; Svavelväte*/vätesulfid- egenskaper och metoder att minimera problemen*, presentation on Xylem, 2013

Henze M., Comeau Y., *Wastewater Characterization*, ISBN: 9781843391883. Published by IWA Publishing, London, UK, 2008

ITT, *Minimering av svavelväte i LTA-system*, presentation on Xylem by Hedmark P., Strandberg T, 2014-06-10

Jensen H. S., *Hydrogen sulfide induced concrete corrosion of sewer networks*, Ph.D. Dissertation, Aalborg University; Section of Environmental Engineering, Aalborg, 2009

Ledskog A., Larsson S-G., Lindqvist B.G., *Svavelväteproblem i avloppsledningar-drifterfarenheter och tillämpbara anvisningar*, VA-Forsk, juli 1994

Nielsen A. H., Hvitved-Jacobsen T., Vollertsen J., *Effects of Iron on Chemical Sulfode Oxidation in Wastewater from Sewer Networks*, Journal of environmental engineering, June 2007

Nielsen A. H., Vollertsen J., Jensen H. S., Wium-Andersen T., Hvitved-Jacobsen T., *Influence of pipe material and surface on sulfide related odor and corrosion in sewers*, published in *Elsevier*, Aalborg University; Section of Environmental Engineering, Aalborg, 2008,

OSAH, *OSAH Fact Sheet: Hydrogen Sulfide*, https://www.osha.gov/OshDoc/data_Hurricane_Facts/hydrogen_sulfide_fact.pdf read 2014-07-08

O´Neal, http://www.onealsteel.com/carbon-and-alloy-steel.html, read 2014-08-18

OdaLog, *L2 Brochure*, http://www.odalog.com/odalog/odalog-l2.htm, read 2014-08-23

Spartan Environmental Technologies, http://www.spartanwatertreatment.com/hydrogen-sulfide-removal.html, 2005, read 2014-09-18

Spartan Environmental Technologies, http://www.spartanwatertreatment.com/odor-control-sewage-municipal-wastewater.html, 2014, read 2014-11-07

Stokbro Jensen H., *Hydrogen sulfide induced concrete corrosion of sewer networks*, Aalborg University Section of Environmental Engineering, 2009

Strandberg T., *Handbok om tryckavloppsystem (LTA)*, Xylem Water and Wastewater Solutions AB, 2012

US Peroxide, http://www.h2o2.com/products-and-services/us-peroxide-technologies.aspx?pid=114&name=Nitrates, read 2014-11-07

University of Washington, http://courses.washington.edu/smartpsy/interactions.htm, read 2014-11-22

Xylem, Odomin, http://www.xylemwatersolutions.com/scs/sweden/sv-se/produkter/pumpstationer-och-avloppsnat/ODOmin_svavelvatereduktion/Sidor/Odomin%20Svavelv%C3%A4tereduktion.aspx, read 2014-07-10

Yara, http://www.yara.co.uk/chemicals/odour-nuisance-and-h2s-prevention/, read 2014-11-07

Yara.com, http://www.yara.com.au/chemicals/odor-nuisance-and-h2s-prevention/H2S-prevention/optimizing-your-consumption/, read 2014-11-13

APPENDIX A

Matlab code

```
clc

% DDMM is each day of the test series.
% every 24-hours are devided in day and night, since the levels of H2S
% varies a lot between the active and passive hours.
fn1= 'PS.xlsx';
data = xlsread(fn1);



%from Pumpsump.
% [H2S-level temp]
p25_8= data(1:608,2);    % data(1:608,3)
p26_8= data(1:1440,7); % data(1:1440,8)
p27_8= data(1:1440,12); % data(1:1440,13)];
p28_8= data(1:1440,17); % data(1:1440,18)];
p29_8= data(1:1440,22); % data(1:1440,23)];
p30_8= data(1:1440,27); % data(1:1440,28)];
p31_8= data(1:1440,32); % data(1:1440,33)];
p1_9_= data(1:1440,37); % data(1:1440,38)];
p2_9= data(1:1440,42); % data(1:1440,43)];
p3_9= data(1:1440,47); % data(1:1440,48)];
p4_9= data(1:1440,52); % data(1:1440,53)];
p5_9= data(1:1440,57); % data(1:1440,58)];
p6_9=data(1:1440,62); % data(1:1440,63)];
p7_9=data(1:1440,67); % data(1:1440,68)];
p8_9= data(1:1440,72); % data(1:1440,73)];
p9_9= data(1:1440,77); % data(1:1440,78)];
p10_9= data(1:1440,82); % data(1:1440,83)];
p11_9= data(1:1440,87);
p12_9= data(1:1440,92);
p13_9= data(1:1440,97);
p14_9= data(1:1440,102);
p15_9= data(1:1440,107);
p16_9= data(1:1440,112);
p17_9= data(1:766,117);
p18_9= data(709:1440,121);
p19_9= data(1:1440,126);
p20_9= data(1:1440,131);
p21_9= data(1:1440,136);
p22_9= data(1:1440,141);
p23_9= data(1:1440,146);
p24_9= data(1:601,151);
p26_9= data(705:1440,156);
p27_9= data(1:1440,161);
p28_9= data(1:1440,166);
p29_9= data(1:1440,171);
p30_9= data(1:1440,176);
p1_10= data(1:1440,181);
p2_10= data(1:1440,186);
```

```
p3_10= data(1:1440,191);
p4_10= data(1:1229,196);
p8_10= data(823:1440,201);
p9_10= data(1:1440,206);
p10_10= data(1:1440,211);
p11_10= data(1:1440,216);
p12_10= data(1:1440,221);
p13_10= data(1:1440,226);
p14_10= data(1:1440,231);
p15_10= data(1:1440,236);
p16_10= data(1:1440,241);
p17_10= data(1:1440,246);
p18_10= data(1:1440,251);
p19_10= data(1:1440,256);
p20_10= data(1:1440,261);
p21_10= data(1:1440,266);
p22_10= data(1:1440,271);
p23_10= data(1:1440,276);
p24_10= data(1:1440,281);
p25_10= data(1:1440,286);
p26_10= data(1:1440,291);
p27_10= data(1:1440,296);
p28_10= data(1:898,301);

%%
% 25/8, 1/9, 17/9, 18/9, 24/9, 26/9, 4/10, 8/10  är inte hela dagar av
mätningar, de räknas separat
%alla punkter
PP = [ p26_8 p27_8 p28_8 p29_8 p30_8 p31_8 p2_9 p3_9 p4_9 p5_9 p6_9 p7_9 p8_9
p9_9 p10_9 p11_9 p12_9 p13_9 p14_9 p15_9 p16_9 p19_9 p20_9 p21_9 p22_9 p23_9
...
    p27_9 p28_9 p29_9 p30_9 p1_10 p2_10 p3_10 p9_10 p10_10 p11_10 p12_10
p13_10 p14_10 p15_10 p16_10 p17_10 p18_10 p19_10 p20_10 p21_10 p22_10 p23_10
p24_10 p25_10 p26_10 p27_10] ;


%formate the correct arreys for the active and passive parts
PM = [];
PMn= [];
N=size(PP);
n=N(2);
for i= 1:n;
    pp = PP(:,i);
    pma = mean(pp(406:1426)); %mellan 06.45-23.44
    pmna = mean ([pp(1:405) ; pp(1427:end)]); %00.00-06.44 samt 23.45-24-00

    PM = [PM pma];
    PMn = [PMn pmna];
end

pm25_8 = [ mean(p25_8(1:593)) mean(p25_8(594:end))];
p1_9 = [ p1_9_(406:583) ; p1_9_(673:1426) ];
pm1_9 = [ mean(p1_9) mean(p1_9_(1427:end)) ];
pm17_9 = [ mean(p17_9(406:end)) mean(p17_9(1:405))];
pm18_9 = [ mean(p18_9(1:end-16)) mean(p18_9(end-15:end))];
pm24_9 = [mean(p24_9(406:601)) mean(p24_9(1:405))];
```

```
pm26_9 = [mean(p26_9(1:end-16)) mean(p26_9(end-15:end))];
pm4_10 = [ mean(p4_10(406:end)) mean(p4_10(1:405))];
pm8_10 = [ mean(p8_10(1:end-16)) mean(p8_10(end-15:end))];
% pm20_10 = [ mean(p20_10(406:end)) mean(p20_10(1:405))];
pm28_10= [ mean(p28_10(406:end)) mean(p28_10(1:405))];

% Specialare:
pm27_81 = [mean(p27_8(406:831)) mean(p27_8(1:405)) ];
pm27_82 = [mean(p27_8(832:1426)) mean(p27_8(1427:end)) ];
pm3_91 = [mean(p3_9(406:570)) mean(p3_9(1:405))];
pm3_92 = [mean(p3_9(571:1426)) mean(p3_9(1427:end))];

pm1_101 =  [mean(p1_10(406:878)) mean(p1_10(1:405))];
pm1_102 = [mean(p1_10(886:1426)) mean(p3_9(1427:end))];


% PP_odd= [pm25_8' pm1_9' pm17_9' pm18_9' pm24_9' pm26_9' pm4_10' pm8_10'
pm20_10'];

P= [PM ; PMn];
disp('Pump Sump')
disp('active mean value '); disp('passsive mean value')
 disp('25/8 ps'); disp(pm25_8')
 disp('26/8 ps'); disp(P(:,1))
 disp('27/8 ps'); disp(P(:,2))
 disp('28/8 ps'); disp(P(:,3))
 disp('29/8 ps'); disp(P(:,4))
 disp('30/8 ps'); disp(P(:,5))
 disp('31/8 ps'); disp(P(:,6))
 disp('1/9 ps'); disp(pm1_9')
 disp('2/9 ps'); disp(P(:,7))
 disp('3/9 ps'); disp(P(:,8))
 disp('4/9 ps'); disp(P(:,9))
 disp('5/9 ps'); disp(P(:,10))
 disp('6/9 ps'); disp(P(:,11))
 disp('7/9 ps'); disp(P(:,12))
 disp('8/9 ps'); disp(P(:,13))
 disp('9/9 ps'); disp(P(:,14))
 disp('10/9 ps'); disp(P(:,15))
 disp('11/9 ps'); disp(P(:,16))
 disp('12/9 ps'); disp(P(:,17))
 disp('13/9 ps'); disp(P(:,18))
 disp('14/9 ps'); disp(P(:,19))
 disp('15/9 ps'); disp(P(:,20))
 disp('16/9 ps'); disp(P(:,21))
 disp('17/9 ps'); disp(pm17_9')
 disp('18/9 ps'); disp(pm18_9')
 disp('19/9 ps'); disp(P(:,22))
 disp('20/9 ps'); disp(P(:,23))
 disp('21/9 ps'); disp(P(:,24))
 disp('22/9 ps'); disp(P(:,25))
 disp('23/9 ps'); disp(P(:,26))
 disp('24/9 ps'); disp(pm24_9')
 disp('26/9 ps'); disp(pm26_9')
 disp('27/9 ps'); disp(P(:,27))
 disp('28/9 ps'); disp(P(:,28))
```

```
 disp('29/9 ps'); disp(P(:,29))
 disp('30/9 ps'); disp(P(:,30))
 disp('1/10 ps'); disp(P(:,31))
 disp('2/10 ps'); disp(P(:,32))
 disp('3/10 ps'); disp(P(:,33))
 disp('4/10 ps'); disp(pm4_10')
 disp('8/10 ps'); disp(pm8_10')
 disp('9/10 ps'); disp(P(:,34))
 disp('10/10 ps'); disp(P(:,35))
 disp('11/10 ps'); disp(P(:,36))
 disp('12/10 ps'); disp(P(:,37))
 disp('13/10 ps'); disp(P(:,38))
 disp('14/10 ps'); disp(P(:,39))
 disp('15/10 ps'); disp(P(:,40))
 disp('16/10 ps'); disp(P(:,41))
 disp('17/10 ps'); disp(P(:,42))
 disp('18/10 ps'); disp(P(:,43))
 disp('19/10 ps'); disp(P(:,44))
 disp('20/10 ps'); disp(P(:,45))
 disp('21/10 ps'); disp(P(:,46))
 disp('22/10 ps'); disp(P(:,47))
 disp('23/10 ps'); disp(P(:,48))
 disp('24/10 ps'); disp(P(:,49))
 disp('25/10 ps'); disp(P(:,50))
 disp('26/10 ps'); disp(P(:,51))
 disp('27/10 ps'); disp(P(:,52))
 disp('28/10 ps'); disp(pm28_10')

 null= [Inf ; Inf];

 pump= [pm25_8' P(:, 1:6) pm1_9' P(:, 7:21) pm17_9' pm18_9' P(:, 22:26)
pm24_9' null pm26_9' P(:, 27:33) pm4_10' null null null pm8_10' P(:, 34:52)
pm28_10'];

 % PL = [pm25_8' P(:,1) P(:,2) P(:,3) P(:,4) P(:,5) P(:,6) pm1_9']

s=size(pump);

 x_time= 1:s(2);

 clf
 figure(1)
 subplot(211); plot(x_time, pump(1,:))
 title('Mean value pump sump, day')
 xlabel('Days from start: 25/8')
%  legend('Active/day')
 ylabel('H_2S [ppm]')
 xlabel('Days from start: 25/8')
 axis([0 70 0 11])
 subplot(212); plot(x_time, pump(2,:))
 title('Mean value pump sump, night')
 xlabel('Days from start: 25/8')
 ylabel('H_2S [ppm]')
  axis([0 70 0 11])
% legend('Passive/night')
 % datetick('x', 'dd-mmm-yyyy', 'keeplimits') %('x', 'dd','mm', 'keeplimits')
```

```
%% Maximal values
M= [];
MM=[];
N=size(PP);
n=N(2);
t=10;
% ändrar till 15 st värden
for i= 1:n;
 m = sort(PP(:,i));
 mm= m(end-t:end);
 MAX= mean(mm);
 MM =[MM mm];
 M = [M MAX];
end
% PP_odd= [p25_8 p1_9 p17_9 p18_9 p24_9 p26_9 p4_10 p8_10 p20_10];
m1 = sort(p25_8);
mm1= m1(end-t:end);
MAXX(1)= mean(mm1);

m2 = sort(p1_9);
mm2= m2(end-t:end);
MAXX(2)= mean(mm2);

m3 = sort(p17_9);
mm3= m3(end-t:end);
MAXX(3)= mean(mm3);

m4 = sort(p18_9);
mm4= m4(end-t:end);
MAXX(4)= mean(mm4);

m5 = sort(p24_9);
mm5= m5(end-t:end);
MAXX(5)= mean(mm5);

m6 = sort(p26_9);
mm6= m6(end-t:end);
MAXX(6)= mean(mm6);

m7 = sort(p4_10);
mm7= m7(end-t:end);
MAXX(7)= mean(mm7);

m8 = sort(p8_10);
mm8= m8(end-t:end);
MAXX(8)= mean(mm8);

m9 = sort(p28_10);
mm9= m9(end-t:end);
MAXX(9)= mean(mm9);

MAX_PS= [MAXX(1) M(1:6) MAXX(2) M(7:21) MAXX(3:4) M(22:26) MAXX(5) inf
MAXX(6) M(27:33) MAXX(7) inf inf inf MAXX(8) M(34:52) MAXX(9)];
```

```
disp('extreme mean values pump sump 25/8 -20/10')
disp(MAX_PS')

% disp('exm mean values pump sump 25/8, 1/9, 17/9, 18/9, 24/9, 26/9, 4/10,
8/10 ')
% disp(MAXX')

%%
% from Odomin
fn2 = 'odo65.xlsx';
oda = xlsread(fn2);

% o20_8 = oda(123:288, 2);
o21_8 = oda(1:288, 7);
o22_8 = oda(1:288, 12);
o23_8 = oda(1:288, 17);
o24_8 = oda(1:288, 22);
o25_8 = oda(1:288, 27);
o26_8 = oda(1:288, 32);
o27_8 = oda(1:288, 37);
o28_8 = oda(1:288, 42);
o29_8 = oda(1:288, 47);
o30_8 = oda(1:288, 52);
o31_8 = oda(1:288, 57);
o1_9 = oda(1:288, 62);
o2_9 = oda(1:288, 67);
o3_9 = oda(1:288, 72);
o4_9 = oda(1:288, 77);
o5_9 = oda(1:288, 82);
o6_9 = oda(1:288, 87);
o7_9 = oda(1:288, 92);
o8_9 = oda(1:288, 97);
o9_9 = oda(1:288, 102);
o10_9 = oda(1:120, 107);

o17_9 = oda(768:1440, 112);
o18_9 = oda(1:1440, 117);
o19_9 = oda(1:1440, 122);
o20_9 = oda(1:1440, 127);
o21_9 = oda(1:1440, 132);
o22_9 = oda(1:1440, 137);
o23_9 = oda(1:1440, 142);
o24_9 = oda(1:1440, 147);
o25_9 = oda(1:1440, 152);
o26_9 = oda(1:1440, 157);
o27_9 = oda(1:1440, 162);
o28_9 = oda(1:1440, 167);
o29_9 = oda(1:1440, 172);
o30_9 = oda(1:1440, 177);
o1_10 = oda(1:1440, 182);
o2_10 = oda(1:1440, 187);
o3_10 = oda(1:1440, 192);
o4_10 = oda(1:1440, 197);
o5_10 = oda(1:1440, 202);
o6_10 = oda(1:1440, 207);
o7_10 = oda(1:1440, 212);
```

```
o8_10 = oda(1:1440, 217);
o9_10 = oda(1:1440, 222);
o10_10 = oda(1:1440, 227);
o11_10 = oda(1:1440, 232);
o12_10 = oda(1:1440, 237);
o13_10 = oda(1:1440, 242);
o14_10 = oda(1:1440, 247);
o15_10 = oda(1:1440, 252);
o16_10 = oda(1:1440, 257);
o17_10 = oda(1:1440, 262);
o18_10 = oda(1:1402, 267);
o20_10 = oda(628:1440, 271);
o21_10 = oda(1:1440, 276);
o22_10 = oda(1:1440, 281);
o23_10 = oda(1:1440, 286);
o24_10 = oda(1:1440, 291);
o25_10 = oda(1:1440, 296);
o26_10 = oda(1:1440, 301);
o27_10 = oda(1:1440, 306);
o28_10 = oda(1:922, 311);

Od= [o21_8 o22_8 o23_8 o24_8 o25_8 o26_8 o27_8 o28_8 o29_8 o30_8 o31_8 o1_9
o2_9 o3_9 o4_9 o5_9 o6_9 o7_9 o8_9 o9_9] ;

% Calculates the mean values, active and passive
OM = [];
Omn= [];
N=size(Od);
n=N(2);
for i= 1:n;
    odo = Od(:,i);
    om = mean(odo(81:285)); %mellan 06.45-23.44
    omn = mean ([odo(1:80) ; odo(286:end)]); %00.00-06.44 samt 23.45-24-00

    OM = [OM om];
    Omn = [Omn omn];
end

O = [OM; Omn];
disp('21/8 odomin'); disp(O(:,1));
disp('22/8 odomin'); disp(O(:,2));
disp('23/8 odomin'); disp(O(:,3));
disp('24/8 odomin'); disp(O(:,4));
disp('25/8 odomin'); disp(O(:,5));
disp('26/8 odomin'); disp(O(:,6));
disp('27/8 odomin'); disp(O(:,7));
disp('28/8 odomin'); disp(O(:,8));
disp('29/8 odomin'); disp(O(:,9));
disp('30/8 odomin'); disp(O(:,10));
disp('31/8 odomin'); disp(O(:,11));
disp('1/9 odomin'); disp(O(:,12));
disp('2/9 odomin'); disp(O(:,13));
disp('3/9 odomin'); disp(O(:,14));
disp('4/9 odomin'); disp(O(:,15));
disp('5/9 odomin'); disp(O(:,16));
disp('6/9 odomin'); disp(O(:,17));
```

```
disp('7/9 odomin'); disp(O(:,18));
disp('8/9 odomin'); disp(O(:,19));
disp('9/9 odomin'); disp(O(:,20));

om10_9 = [mean(o10_9(82:end)) mean(o10_9(1:81)) ];
disp('10/9 odomin'); disp(om10_9');
null7= [inf inf inf inf inf inf;inf inf inf inf inf inf];
% beräknas här pga annan storlek
Od1= [o18_9 o19_9 o20_9 o21_9 o22_9 o23_9 o24_9 o25_9 o26_9 o27_9 o28_9 o29_9
o30_9 o1_10 o2_10 o3_10 o4_10 o5_10 o6_10 o7_10 o8_10 o9_10 o10_10 o11_10
o12_10 o13_10 o14_10 o15_10 o16_10 o17_10 o21_10 o22_10 o23_10 o24_10 o25_10
o26_10 o27_10];

OM1 = [];
Omn1= [];
N1=size(Od1);
n1=N1(2);
for i= 1:n1;
    pp = Od1(:,i);
    om1 = mean(pp(406:1426)); %mellan 06.45-23.44
    oma1 = mean ([pp(1:405) ; pp(1427:end)]); %00.00-06.44 samt 23.45-24-00

    OM1 = [OM1 om1];
    Omn1 = [Omn1 oma1];
end
 O1 = [OM1; Omn1];

 %20/8 och 10/9 , 17/9, 18/10 beräknas separat pga anda antalet element
 om17_9 = [ mean(o17_9(1:end-14)) mean(o17_9(end-15:end))];
 om18_10 = [ mean(o18_10(406:end)) mean(o18_10(1:405))];
 om20_10 = [ mean(o20_10(1:end-14)) mean(o20_10(end-15:end))];
 om28_10 = [ mean(o28_10(1:end-14)) mean(o28_10(end-15:end))];

 disp('17/9 odomin'); disp(om17_9');
 disp('18/9 odomin'); disp(O1(:,1));
 disp('19/9 odomin'); disp(O1(:,2));
 disp('20/9 odomin'); disp(O1(:,3));
 disp('21/9 odomin'); disp(O1(:,4));
 disp('22/9 odomin'); disp(O1(:,5));
 disp('23/9 odomin'); disp(O1(:,6));
 disp('24/9 odomin'); disp(O1(:,7));
 disp('25/9 odomin'); disp(O1(:,8));
 disp('26/9 odomin'); disp(O1(:,9));
 disp('27/9 odomin'); disp(O1(:,10));
 disp('28/9 odomin'); disp(O1(:,11));
 disp('29/9 odomin'); disp(O1(:,12));
 disp('30/9 odomin'); disp(O1(:,13));
 disp('1/10 odomin'); disp(O1(:,14));
 disp('2/10 odomin'); disp(O1(:,15));
 disp('3/10 odomin'); disp(O1(:,16));
 disp('4/10 odomin'); disp(O1(:,17));
 disp('5/10 odomin'); disp(O1(:,18));
 disp('6/10 odomin'); disp(O1(:,19));
 disp('7/10 odomin'); disp(O1(:,20));
 disp('8/10 odomin'); disp(O1(:,21));
 disp('9/10 odomin'); disp(O1(:,22));
```

```
 disp('10/10 odomin'); disp(O1(:,23));
 disp('11/10 odomin'); disp(O1(:,24));
 disp('12/10 odomin'); disp(O1(:,25));
 disp('13/10 odomin'); disp(O1(:,26));
 disp('14/10 odomin'); disp(O1(:,27));
 disp('15/10 odomin'); disp(O1(:,28));
 disp('16/10 odomin'); disp(O1(:,29));
 disp('17/10 odomin'); disp(O1(:,30));
 disp('18/10 odomin'); disp(om18_10');
 disp('20/10 odomin'); disp(om20_10');
 disp('21/10 odomin'); disp(O1(:,31));
 disp('22/10 odomin'); disp(O1(:,32));
 disp('23/10 odomin'); disp(O1(:,33));
 disp('24/10 odomin'); disp(O1(:,34));
 disp('25/10 odomin'); disp(O1(:,35));
 disp('26/10 odomin'); disp(O1(:,36));
 disp('27/10 odomin'); disp(O1(:,37));
 disp('28/10 odomin'); disp(om28_10');


 odomin=[O om10_9' null7 om17_9' O1(:,1:30) om18_10' null7(:,1) om20_10'
O1(:, 31:37) om28_10'];

%%
OM= [];
OdM=[];

N=size(Od);
n=N(2);
tt=10;
for i= 1:n;
 o = sort(Od(:,i));
 om= o(end-t:end);
 MAX_o= mean(om);
 OM =[OM om];
 OdM = [OdM MAX_o];
end

OM1= [];
OdM1=[];

N1=size(Od1);
n=N1(2);

for i= 1:n;
 o1 = sort(Od1(:,i));
 om1= o1(end-tt:end);
 MAX_o1= mean(om1);
 OM1 =[OM1 om1];     %The 10 largest values
 OdM1 = [OdM1 MAX_o1];   %the maximum mean
end

o1 = sort(o10_9);
oo1= o1(end-tt:end);
O_max1= mean(o1);
```

```
O_max2=[Inf Inf Inf Inf Inf Inf];

o2 = sort(o17_9);
oo2= o2(end-tt:end);
O_max3= mean(oo2);

o3 = sort(o18_10);
oo3= o3(end-tt:end);
O3= mean(oo3);

o4 = sort(o20_10);
oo4= o4(end-tt:end);
O4= mean(oo4);

o5 = sort(o28_10);
oo5= o5(end-tt:end);
O5= mean(oo5);


O_max= [O_max1 O_max2 O_max3];

OMax= [OdM(5:end) O_max OdM1(1:30) O3 0 O4 OdM1(31:end) O5];
disp('extream mean values Odomin from 25/9 - 17/19: (11-16 sept is gone)')
disp(OMax')

%%
d25_8= O(:,5)./pm25_8';
d26_8= O(:,6)./P(:,1);
d27_8= O(:,7)./P(:,2);
d28_8= O(:,8)./P(:,3);
d29_8= O(:,9)./P(:,4);
d30_8= O(:,10)./P(:,5);
d31_8= O(:,11)./P(:,6);
d1_9= O(:,12)./pm1_9';
d2_9= O(:,13)./P(:,7);
d3_9= O(:,14)./P(:,8);
d4_9= O(:,15)./P(:,9);
d5_9= O(:,16)./P(:,10);
d6_9=O(:,17)./P(:,11);
d7_9= O(:,18)./P(:,12);
d8_9= O(:,19)./P(:,13);
d9_9= O(:,20)./P(:,14);
d10_9= om10_9'./P(:,15);
d17_9= om17_9'./pm17_9';
d18_9= O1(:,1)./pm18_9';
d19_9= O1(:,2)./P(:,22);
d20_9= O1(:,3)./P(:,23);
d21_9= O1(:,4)./P(:,24);
d22_9= O1(:,5)./P(:,25);
d23_9= O1(:,6)./P(:,26);
d24_9= O1(:,7)./pm24_9';
d26_9= O1(:,8)./pm26_9';
d27_9= O1(:,9)./P(:,27);
d28_9= O1(:,10)./P(:,28);
```

```
d29_9= O1(:,11)./P(:,29);
d30_9= O1(:,12)./P(:,30);
d1_10= O1(:,13)./P(:,31);
d2_10= O1(:,14)./P(:,32);
d3_10= O1(:,15)./P(:,33);
d4_10= O1(:,16)./pm4_10';
d8_10= O1(:,21)./pm8_10';
d9_10= O1(:,22)./P(:,34);
d10_10= O1(:,23)./P(:,35);
d11_10= O1(:,24)./P(:,36);
d12_10= O1(:,25)./P(:,37);
d13_10= O1(:,26)./P(:,38);
d14_10= O1(:,27)./P(:,39);
d15_10= O1(:,28)./P(:,40);
d16_10= O1(:,29)./P(:,41);
d17_10= O1(:,30)./P(:,42);
d18_10= om18_10'./P(:,43);

d20_10= om20_10'./P(:,44);
d21_10= O1(:,31)./P(:,45);
d22_10= O1(:,32)./P(:,46);
d23_10= O1(:,33)./P(:,47);
d24_10= O1(:,34)./P(:,48);
d25_10= O1(:,35)./P(:,49);
d26_10= O1(:,36)./P(:,50);
d27_10= O1(:,37)./P(:,51);
d28_10= om28_10'./P(:,52);

me= [inf; inf];
nu= [0;0];
diff= [d25_8 d26_8 d27_8 d28_8 d29_8 d30_8 d31_8 d1_9 d2_9 d3_9 d4_9 d5_9
d6_9 d7_9 d8_9 d9_9 d10_9...
     me me me me me me me d17_9 d18_9 d19_9 d20_9 d21_9 d22_9 d23_9 d24_9  me
d26_9 d27_9 d28_9 d29_9 d30_9 ...
    d1_10 d2_10 d3_10 d4_10 me me me d8_10 d9_10 d10_10 d11_10 d12_10 d13_10
d14_10 d15_10 d16_10 d17_10 d18_10 me d20_10 d21_10 d22_10 d23_10 d24_10
d25_10 d26_10 d27_10 d28_10];

s2=size(diff);
xt= 1:s2(2);

figure(2)
subplot(211); plot(xt, diff(1,:))
title('Reduction rate between Odomin and pump sump, day')
% xlabel('0-3 = anode, 4-10 = anode+area, 11-17 = area, 18-24 =  none, 24-33
= anode+splash, ')
xlabel('Days from start: 25/8')
ylabel('Times of reduction [-]')
subplot(212); plot(xt, diff(2,:))
%title('34-38 = splash+area, 39-45 = splash+area+anode, 46-55 = splash, none
= 56-65')
title('Reduction rate between Odomin and pump sump, night')
 xlabel('Days from start: 25/8')
 ylabel('Times of reduction [-]')
% legend('Passive/night')
```

```
figure(3)
subplot(211);plot(1:numel(MAX_PS), MAX_PS)
title('Extreme mean value pump sump')
xlabel('Days from start: 25/8')
ylabel('H_2S [ppm]')

figure(4)
subplot(211); plot(1:numel(OMax), OMax)
title('Extreme mean value Odomin25/8-18/10')
% xlabel('0-2 = anode, 3-9 = anode+area, 10-17 = area, 18-24 =  NA, 25-34 =
splash+anode, 35-39 = splash+area, 40-46 = splash+area+anode, 47-56 =
splash')
xlabel('Days from start: 25/8')

% 0-2 = 25-27/8 anode, 3-10 = 28/8-3/9 anode+area, 11-18= 4-10/9 area, 19-25=
11-16/9 NA, 26-35=17-26/9 splash+anode, 36-40=27/9-1/10 splash+area, 41-'
s3=size(odomin);
x_t= 1:s3(2);

figure(5)
subplot(211); plot(x_t, odomin(1,:))
title('Mean value Odomin, day')
% xlabel('0-3 = anode, 4-10 = anode+area, 11-17 = area, 18-24 =  none, 25-34
= splash+anode')
subplot(212); plot(x_t, odomin(2,:))
title('Mean value Odomin, night')
xlabel('Days from start: 25/8')

figure (10)
plot(1:numel(pump(1,:)), pump(1,:), 1:numel(pump(1,:)), odomin(1, 5:end))
title('Daily mean values in Odomin and pump sump')
legend('Pump sump', 'Odomin')
xlabel('Days from start: 25/8')
ylabel('H_2S [ppm]')

DE = [];
MAX_PS1= [MAXX(1) M(1:6) MAXX(2) M(7:21) MAXX(3:4) M(22:26) MAXX(5) 0 MAXX(6)
M(27:33) MAXX(7) 0 0 0 MAXX(8) M(34:52) MAXX(9)];

for i=1:numel(OMax)
    diff_e = OMax(i)/MAX_PS1(i);
    DE = [DE diff_e];
end



figure(6)
subplot(211);plot(1:numel(OMax), DE)
title('Reduction between Odomin and PS in extreme values')
ylabel('Times of reduction [-]')
xlabel('Days from start: 25/8')
```

```
%% Effects
% using the mean values: daily and extreme
% anode (1,0,0)
% Splash (0,1,0)
% area (0,0,1)

% 25-27/8 anode
% 27/8-3/9 anode + area
% 3-10/9 Area
% NA 10-17
% 17-26/9 Splash + anode
% 26/9 -1/10 Splash + area
% 1-8/10 Splash+ area+ anode
% 8-18/10 Splash
% 20-28/10 N/A

% för att beräkna effekterna måste de olika medelvärdena läggas ihop!
% PS
clf
yy_pnn= [pm25_8(1) P(1) pm27_81(1)];
yy_pnp= [pm27_82(1) P(1,3:7)  pm1_9(1) pm3_91(1)] ;
yy_nnp= [ pm3_92(1) P(1,9:15)];
yy_ppn = [pm17_9(1) pm18_9(1) P(1,22:26) pm24_9(1)];
yy_npp = [P(1,27:30)  pm1_101(1)];
yy_ppp = [ pm1_102(1) P(1,32:33)  pm4_10(1) pm8_10(1)];
yy_npn = P(1,34:43);
yy_nnn = [P(1,15:21) P(1,45:52) pm28_10(1)];
% yy_nnn = (y_nnn1+y_nnn2)/2

% yy_tot = [ yy_pnn; yy_pnp ; yy_nnp ; yy_ppn ; yy_npp ; yy_ppp ; yy_npn ;
yy_nnn];

[mu(1), sigma(1)]=normfit(yy_pnn);
[mu(2), sigma(2)]=normfit(yy_pnp);
[mu(3), sigma(3)]=normfit(yy_nnp);
[mu(4), sigma(4)]=normfit(yy_ppn);
[mu(5), sigma(5)]=normfit(yy_npp);
[mu(6), sigma(6)]=normfit(yy_ppp);
[mu(7), sigma(7)]=normfit(yy_npn);
[mu(8), sigma(8)]=normfit(yy_nnn);
is = [mu' sigma'];

y_pnn = mu(1);
y_pnp = mu(2);
y_nnp = mu(3);
y_ppn = mu(4);
y_npp = mu(5);
y_ppp = mu(6);
y_npn = mu(7);
y_nnn = mu(8);

% (0,0,0)
y_p_3 = (y_pnp+y_nnp+y_npp+y_ppp)/4;
```

```
y_n_3 = (y_pnn+y_ppn+y_npn+y_nnn) /4;
y_p_2 = (y_ppn+ y_npp+ y_ppp+y_npn)/4;
y_n_2 = (y_pnn+y_pnp+y_nnp+y_nnn)/4;
y_p_1 = (y_pnn+y_pnp+y_ppn+y_ppp)/4;
y_n_1 = (y_nnp+y_npp+y_npn+y_nnn)/4;

y_mean = (y_pnn+y_ppn+y_npn+y_pnp+y_npp+y_ppp+y_nnp+y_nnn)/8;

YY= [y_pnn; y_pnp; y_nnp; y_ppn; y_npp; y_ppp; y_npn; y_nnn];
A = [ 1; 1; -1; 1;-1; 1; -1; -1]; % anode
B = [-1; -1; -1; 1;1;1;1;-1];% splash
C = [-1; 1;1;-1;1;1;-1;-1]; % area

ab = A.*B.*YY;
AB = sum(ab)/4;

ac=A.*C.*YY;
AC = sum(ac)/4;

bc= B.*C.*YY;
BC = sum(bc)/4;

abp = (y_ppp-y_npp-y_pnp+y_nnp)/2;
abn = (y_ppn-y_npn- y_pnn+y_nnn)/2;
ABC = (abp-abn)/2;

me_anode = ((y_pnn-y_nnn)+(y_ppn-y_npn)+(y_pnp-y_nnp) +(y_ppp-y_npp))/4;
me_splash = ((y_npn-y_nnn) + (y_ppn-y_pnn) + (y_ppp-y_pnp) + (y_npp-
y_nnp))/4;
me_area = ((y_nnp-y_nnn) + (y_pnp-y_pnn) + (y_ppp-y_ppn) + (y_npp-y_npn))/4;

MV = [me_anode me_splash me_area AB AC BC ABC -0.0552];
figure(7)
normplot(MV)
title('Mean value')

% Doing facotial design on the reduction rate, active,daily

rr_pnn= diff(1,1:3);
rr_pnp= diff(1,3:10) ;
rr_nnp= diff(1,10:17);
rr_ppn = [diff(1,25:32)  diff(1,34)];
rr_npp = diff(1,34:39);
rr_ppp = [ diff(1,39:42) diff(1,46)];
rr_npn = diff(1,46:56);
rr_nnn = diff(1,58:end);

[mu2(1), sigma2(1)]=normfit(rr_pnn);
[mu2(2), sigma2(2)]=normfit(rr_pnp);
[mu2(3), sigma2(3)]=normfit(rr_nnp);
[mu2(4), sigma2(4)]=normfit(rr_ppn);
[mu2(5), sigma2(5)]=normfit(rr_npp);
[mu2(6), sigma2(6)]=normfit(rr_ppp);
[mu2(7), sigma2(7)]=normfit(rr_npn);
[mu2(8), sigma2(8)]=normfit(rr_nnn);
```

```
is_r = [mu2' sigma2'];

r_pnn = mu2(1);
r_pnp = mu2(2);
r_nnp = mu2(3);
r_ppn = mu2(4);
r_npp = mu2(5);
r_ppp = mu2(6);
r_npn = mu2(7);
r_nnn = mu2(8);

r_p_1 = (r_pnn+r_pnp+r_ppn+r_ppp)/4;
r_n_1 = (r_nnp+r_npp+r_npn+r_nnn)/4;
r_p_3 = (r_pnp+r_nnp+r_npp+r_ppp)/4;
r_n_3 = (r_pnn+r_ppn+r_npn+r_nnn)/4;
r_p_2 = (r_ppn+r_npp+r_ppp+r_npn)/4;
r_n_2 = (r_pnn+r_pnp+r_nnp+r_nnn)/4;

r_mean = (r_pnn+r_ppn+r_npn+r_nnn+r_pnp+r_npp+r_ppp+r_nnp)/8;

r1= r_p_1-r_n_1;

r_me_anode = (r_pnn+r_ppn+r_pnp+r_ppp)/4 -(r_nnn+r_nnp+r_npp+r_npn)/4;
r_me_splash = (r_npn+r_ppn+r_npp+r_ppp)/4 - (r_nnn+r_pnn+r_nnp+r_pnp)/4;
r_me_area = (r_nnp+r_pnp+r_npp+r_ppp)/4 - (r_nnn+r_pnn+r_ppn+r_npn)/4;
A = [ 1; 1; -1; 1;-1; 1; -1; -1]; % anode
B = [-1; -1; -1; 1;1;1;1;-1];% splash
C = [-1; 1;1;-1;1;1;-1;-1]; % area

YY_r= [r_pnn; r_pnp; r_nnp; r_ppn; r_npp; r_ppp; r_npn; r_nnn];
ab_r = A.*B.*YY_r;
AB_r = sum(ab_r)/4;

ac_r=A.*C.*YY_r;
AC_r = sum(ac_r)/4;

bc_r= B.*C.*YY_r;
BC_r = sum(bc_r)/4;

acp_r = (r_ppp-r_npp-r_pnp+r_nnp)/2;
acn_r = (r_ppn-r_npn- r_pnn+r_nnn)/2;
ABC_r = (acp_r-acn_r)/2;

ME = [r_me_anode r_me_splash r_me_area AB_r AC_r BC_r ABC_r 0.5300];
figure(8)
normplot(ME)
title('Reduction rate')

% Calculating the changes in maximum value


mm_pnn= MAX_PS(1:3);
mm_pnp = MAX_PS(3:10);
mm_nnp = MAX_PS(10:17);
```

```
mm_ppn = [MAX_PS(24:31) MAX_PS(33)];
mm_npp = MAX_PS(33:38);
mm_ppp = [MAX_PS(38:41) MAX_PS(45)];
mm_npn = MAX_PS(45:55);
mm_nnn = [MAX_PS(18:24) MAX_PS(56:end)];

[mu3(1), sigma3(1)]=normfit(mm_pnn);
[mu3(2), sigma3(2)]=normfit(mm_pnp);
[mu3(3), sigma3(3)]=normfit(mm_nnp);
[mu3(4), sigma3(4)]=normfit(mm_ppn);
[mu3(5), sigma3(5)]=normfit(mm_npp);
[mu3(6), sigma3(6)]=normfit(mm_ppp);
[mu3(7), sigma3(7)]=normfit(mm_npn);
[mu3(8), sigma3(8)]=normfit(mm_nnn);
is_m = [mu3' sigma3'];

m_pnn = mu3(1);
m_pnp = mu3(2);
m_nnp = mu3(3);
m_ppn = mu3(4);
m_npp = mu3(5);
m_ppp = mu3(6);
m_npn = mu3(7);
m_nnn = mu3(8);

m_p_1 = (m_pnn+m_pnp+m_ppn+m_ppp)/4;
m_n_1 = (m_nnp+m_npp+m_npn+m_nnn)/4;
m_p_3 = (m_pnp+m_nnp+m_npp+m_ppp)/4;
m_n_3 = (m_pnn+m_ppn+m_npn+m_nnn)/4;
m_p_2 = (m_ppn+m_npp+m_ppp+m_npn)/4;
m_n_2 = (m_pnn+m_pnp+m_nnp+m_nnn)/4;

m_me_anode = (m_pnn+m_ppn+m_pnp+m_ppp)/4 -(m_nnn+m_nnp+m_npp+m_npn)/4;
m_me_splash = (m_npn+m_ppn+m_npp+m_ppp)/4 - (m_nnn+m_pnn+m_nnp+m_pnp)/4;
m_me_area = (m_nnp+m_pnp+m_npp+m_ppp)/4 - (m_nnn+m_pnn+m_ppn+m_npn)/4;

m_mean = (m_pnn+m_ppn+m_npn+m_nnn+m_pnp+m_npp+m_ppp+m_nnp)/8;

YY_m= [m_pnn; m_pnp; m_nnp; m_ppn; m_npp; m_ppp; m_npn; m_nnn];
ab_m = A.*B.*YY_m;
AB_m = sum(ab_m)/4;

ac_m=A.*C.*YY_m;
AC_m = sum(ac_m)/4;

bc_m= B.*C.*YY_m;
BC_m = sum(bc_m)/4;

acp_m = (m_ppp-m_npp-m_pnp+m_nnp)/2;
acn_m = (m_ppn-m_npn- m_pnn+m_nnn)/2;
ABC_m = (acp_m-acn_m)/2;

NN = [m_me_anode m_me_splash m_me_area AB_m AC_m BC_m ABC_m 0.0039];
MM= sort(NN);
figure(9)
```

```
normplot(MM)
title('Extreme values')
%
% calculating interaction effects:
% Mean value

an_pn= (y_pnn+y_pnp)/2;
an_pp= (y_ppn+y_ppp)/2;
an_nn= (y_nnp+y_nnp)/2;
an_np= (y_npn+y_ppn)/2;
xx=[0 1];
an_p=[an_pn, an_pp]; an_n=[an_nn, an_np];
figure(14)
subplot(211); plot(xx, an_n,'g', xx, an_p,'b')
title('Interaction effect mean value: anode and splash')
legend('None','Anode','Location', 'EastOutside')
xlabel('Splash from - to +')
ylabel('H_2S [ppm]')
hold on

ano_pn=(y_pnn+y_ppn)/2;
ano_pp=(y_pnp+y_ppp)/2;
ano_np=(y_npp+y_nnp)/2;
ano_nn=(y_npn+y_nnn)/2;

ar_pn=(y_nnp+y_npp)/2;
ar_pp=(y_pnp+y_ppp)/2;
ar_np=(y_pnn+y_ppn)/2;
ar_nn=(y_npn+y_nnn)/2;
ano_p=[ano_pn, ano_pp]; ano_n=[ano_nn, ano_np];
ar_p = [ar_pn, ar_pp]; ar_n= [ar_nn, ar_np];

subplot(212); plot(xx, ano_n,'g', xx, ano_p,'b')
title('Interaction effect mean value: anode and area')
legend('None','Anode','Location', 'EastOutside')
xlabel('Area from - to +')
ylabel('H_2S [ppm]')
% subplot(212); plot(xx,ar_n, xx, ar_p)

sp_pn=(y_ppn+y_npn)/2;
sp_nn=(y_pnn+y_nnn)/2;
sp_np=(y_pnp+y_nnp)/2;
sp_pp= (y_ppp+y_npp)/2;
sp_p=[sp_pn, sp_pp];
sp_n=[sp_nn, sp_np];
figure(15)
subplot(211); plot(xx, sp_n,'g', xx, sp_p,'b')
title('Interaction effect mean value: Splash and area')
legend('None','Splash','Location', 'EastOutside')
xlabel('Area from - to +')
ylabel('H_2S [ppm]')
hold off
% reduction rate

anr_pn= (r_pnn+r_pnp)/2;
anr_pp= (r_ppn+r_ppp)/2;
```

```
anr_nn= (r_nnp+r_nnp)/2;
anr_np= (r_npn+r_ppn)/2;
xx=[0 1];
anr_p=[anr_pn, anr_pp]; anr_n=[anr_nn, anr_np];
figure(16)
subplot(211); plot(xx, anr_n,'g', xx, anr_p,'b')
title('Interaction effect reduction rate: anode and splash')
legend('None','Anode','Location', 'EastOutside')
xlabel('Splash from - to +')
ylabel('Times of reduction [-]')
hold on
anor_pn=(r_pnn+r_ppn)/2;
anor_pp=(r_pnp+r_ppp)/2;
anor_np=(r_npp+r_nnp)/2;
anor_nn=(r_npn+r_nnn)/2;

anor_p=[anor_pn, anor_pp]; anor_n=[anor_nn, anor_np];

subplot(212); plot(xx, anor_n,'g', xx, anor_p,'b')
title('Interaction effect reduction rate: anode and area')
legend('None','Anode','Location', 'EastOutside')
xlabel('Area from - to +')
ylabel('Times of reduction [-]')
% subplot(212); plot(xx,ar_n, xx, ar_p)
hold off

spr_pn=(r_ppn+r_npn)/2;
spr_nn=(r_pnn+r_nnn)/2;
spr_np=(r_pnp+r_nnp)/2;
spr_pp=(r_ppp+r_npp)/2;
spr_p=[spr_pn, spr_pp];
spr_n=[spr_nn, spr_np];
figure(17)
subplot(211); plot(xx, spr_n,'g', xx, spr_p,'b')
title('Interaction effect reduction rate: Splash and area')
legend('None','Splash','Location', 'EastOutside')
xlabel('Area from - to +')
ylabel('Times of reduction [-]')

% extreme mean value

anm_pn= (m_pnn+m_pnp)/2;
anm_pp= (m_ppn+m_ppp)/2;
anm_nn= (m_nnp+m_nnp)/2;
anm_np= (m_npn+m_ppn)/2;
xx=[0 1];
anm_p=[anm_pn, anm_pp]; anm_n=[anm_nn, anm_np];
figure(18)
subplot(211); plot(xx, anm_n,'g', xx, anm_p,'b')
title('Interaction effect extreme value: anode and splash')
legend('None','Anode','Location', 'EastOutside')
xlabel('Splash from - to +')
ylabel('H_2S [ppm]')
hold on
anom_pn=(m_pnn+m_ppn)/2;
anom_pp=(m_pnp+m_ppp)/2;
```

```
anom_np=(m_npp+m_nnp)/2;
anom_nn=(m_npn+m_nnn)/2;

anom_p=[anom_pn, anom_pp]; anom_n=[anom_nn, anom_np];

subplot(212); plot(xx, anom_n,'g', xx, anom_p,'b')
title('Interaction effect: anode and area')
legend('None','Anode','Location', 'EastOutside')
xlabel('Area from - to +')
ylabel('H_2S [ppm]')
% subplot(212); plot(xx,ar_n, xx, ar_p)

hold off
spm_pn=(m_ppn+m_npn)/2;
spm_nn=(m_pnn+m_nnn)/2;
spm_np=(m_pnp+m_nnp)/2;
spm_pp=(m_ppp+m_npp)/2;
spm_p=[spm_pn, spm_pp];
spm_n=[spm_nn, spm_np];

figure(19)
subplot(211); plot(xx, spm_n,'g', xx, spm_p,'b')
title('Interaction effect extreme value: Splash and area')
legend('None','Splash','Location', 'EastOutside')
xlabel('Area from - to +')
ylabel('H_2S [ppm]')
```