Flocculation and filtration of sludge

Operational comparison between the wastewater treatment plants in Garmerwolde and Heerenveen

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Abstract

This report is written in order to get insight in the processes present at the wastewater treatment plants in Garmerwolde and Heerenveen. A literature study is done to make an operational comparison between the two plants. The comparison consists of a description of the hardware present including how is it used and controlled. The comparison is mainly focused on flocculation and filtration. Both processes are used to dewater sludge, which is a side product from the purification of sewage water. The main difference in flocculation between the two plants is the concentration of the added polyelectrolyte (PE) and the mixing of this PE with the sludge stream. Garmerwolde uses a 1 wt% PE solution and a dynamic mixing system. On the other hand Heerenveen uses a 0.15 wt% PE solution and a static mixing system. It is expected that the way of mixing has much influence on the properties of the flakes and therefore the dewatering ability during filtration. In both plants filtration is done by chamber filter presses. The presses are operated in the same way; however Garmerwolde (25.87% DSC) achieves a higher dry solid content of the sludge cake than Heerenveen (23.69% DSC). This is the result of a higher dry solid content of the sludge stream into the presses due to digestion. However, also the efficiency of the chamber filter press is higher in Garmerwolde. In addition, experiments are conducted with a flocculation set-up. This is done to see if the process conditions for flocculation are the optimal conditions. The result for Garmerwolde (145 gram $FeCl_3$/kg D.S.; 12.5 gram PE/kg D.S.) was quite different than the current coagulant and flocculent dosage (65 gram $FeCl_3$/kg D.S.; 7.5 gram PE/kg D.S.), but for Heerenveen the results (75 gram $FeCl_3$/kg D.S.; 7 gram PE/kg D.S.) were almost similar (55 gram $FeCl_3$/kg D.S.; 7 gram PE/kg D.S.). However, the flocculation set-up is a quantitative method and is primarily used to determine the range where coagulation and flocculation occurs.

Preface

This report is a thesis written for my bachelor assignment. The thesis should reflect the acquired learned skills in the bachelor degree program of Chemical Engineering at the University of Groningen. The project started at 22 April 2013 and it took three months to complete this thesis. Half the time was spend on experiments with a flocculation set-up. The other half was used to gather background information and to do a comparative literature study between wastewater treatment plants in Garmerwolde and Heerenveen. Multiple trips were made to the plants for information from engineers and process operators.

I would like to thank Prof. Ir. M.W.M. Boesten for the given guidance and the fundamental for this thesis. Furthermore I would like to thank A. Haijer from Water and Energy Solutions for extra support and for assistance with the equipment and the chemicals. I also want to thank O. Bouius, W.G. Poiesz, D. van der Elst and S. Slump for their information about the WWTP in Garmerwolde and Heerenveen. Without their help, this thesis couldn't have been written.

Marc Meijerink

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Abbreviations

DSC - Dry Solid Content

D.S. – Dry Solid

PE – Polyelectrolyte; a flocculation compound

WWTP – Wastewater Treatment Plant

COD – Chemical Oxygen Demand (gram O_2/m^3)

TOD – Total Oxygen Demand (gram O_2/m^3)

BOD – Biological Oxygen Demand (gram O_2/m^3)

DWD – Dry Weather Drain

RWD – Rain Weather Drain

wt% - weight percent

PSD – Particle Size Distribution

SDP – Sludge Dewatering Plant

OBD –Overall Block Diagram

PDB – Process Block Diagram

PFD- Process Flow Diagram

P&ID – Piping and Instrumentation Diagram

WKK (CHP) – Combined Heat and Power

1. Introduction

A water board is a regional organisation for the management of water resources at a local level. Water boards are i.a. responsible for the treatment of sewage water and the resulting sludge. The purification of sewage water is done by wastewater treatment plants (WWTP), which purifies water from households and industry that is supplied via the sewers. The incoming sewage water is called the influent and the purified water, which is discharged to the surface, is called the effluent. The wastewater treatment plant has to operate at the lowest possible cost, thus efficiently and effectively. All inhabitants of the Netherlands have to pay a so called purification tax. This tax is used to clean the sewage water of hazardous and organic compounds, waste and chemicals. Sewage water consists of high concentrations of nitrogen, phosphate and ammonium. According to Dutch regulation, the concentrations of these contaminants in the effluent should be below a certain limit (Ministry of Transport, 2013). The regulations are shown in figure 1.

Regulations	limit
Biological oxygen demand without nitrification	20 mg/l O2
Chemical oxygen demand (COD)	125 mg/l O2
Total amount undissolved particles	30 mg/l
Total-phosporus (more than 100000 i.e.)	1 mg/l P
Total-phosporus (2000 - 100000 i.e.)	2 mg/l P
Total-nitrogen (more than 20000 i.e.)	10 mg/l N
Total-nitrogen (2000 - 20000 i.e.)	15 mg/l N

Figure 1: Effluent regulations for a WWTP

In this thesis two wastewater treatments plants are compared; the WWTP in Heerenveen under supervision of water board Wetterskip Fryslan and the WWTP in Garmerwolde under supervision of water board Noorderzijlvest. Both plants purifies for more than 100.000 population equivalents (i.e.) and therefore the effluent should contain less than 10 mg/L N and 1 mg/L P. A i.e. is the average amount of pollution of wastewater that a person causes per day. At the WWTP in Heerenveen, the effluent requirements were satisfied in the past few years. In 2011, the plant had yields of 88 % and 93 % for nitrogen and phosphate removal, respectively (waterzuivering, 2012). The WWTP in Garmerwolde has difficulties to achieve the regulations, due to capacity problems. Therefore the limit for the nitrogen concentration is 15 mg/L N instead of the required 10 mg/L N. In 2014 the wastewater treatment plant will be expanded with a new innovative purification technology, called Nereda® (Noorderzijlvest, Uitbreiding RWZI Garmerwolde, 2010). This should solve the effluent concentration problems.

1.1 WWTP Garmerwolde

The wastewater treatment plant in Garmerwolde processes an average of 70.000 m^3 sewage water every day (Noorderzijlvest, Rioolwaterzuiveringsinstallatie Garmerwolde). Sewage water from the city Groningen and surrounding suburbs is cleaned using mechanical, biological and chemical treatment. The purified water is discharged in the Eemskanaal. Sludge is used for the biological purification, but afterwards sludge is contaminated with toxic organic and inorganic compounds. Therefore sludge is also treated at the WWTP. The goal of sludge treatment is to dewater the sludge as much as possible. All the sludge from the wastewater treatment plants supervised by Noorderzijlvest and sludge from water board Hunze & Aa's is transported to Garmerwolde where sludge is mechanically dewatered using chamber filter presses. Around 306153 ton (4.36% DSC) is dewatered every year and around 50251 ton (25.87% DSC) sludge cake is produced. The resulting sludge cake is transported to a drying company; Swiss Combi. Swiss Combi is located at the same location as WWTP Garmerwolde. After drying, the sludge granulates are transported (90% DSC) to ENCI in Maastricht, where granulates are burned to produce energy. General information of WWTP Garmerwolde is shown in the figure below.

Properties WWTP Garmerwolde	
year	**1979**
type	**AB system**
discharge surface	**Eemskanaal**
biological capacity	**375161 i.e. á 136 gr.TOD/day**
	340146 i.e. á 150 gr.TOD/day
	237000 i.e. á 54 gr.BOD/day
hydraulic capacity DWD	**4106 m^3/h**
hydraulic capacity RWD	**13500 m^3/h**

Figure 2: General information WWTP Garmerwolde

1.2 WWTP Heerenveen

Water Board Wetterskip Fryslan has 28 WWTPs under her supervision (see appendix J) and together they process 275000 m^3 sewage water every day. By itself, the WWTP in Heerenveen processes around 17000 m^3 sewage water every day (Fryslan, 2008). The effluent is released in the Nieuwe Heerenveense Kanaal. Sludge from the wastewater treatment plants under supervision of Wetterskip Fryslan is transported by boat or truck to Heerenveen for further dewatering. In 2012, the sludge dewatering plant (SDP) in Heerenveen dewatered 401161 ton wet sludge (3.65% DSC) and produced 62541 ton (23.69% DSC) sludge cake. The sludge cake is also transported to Swiss Combi for further drying (waterzuivering, 2012). General information of WWTP Heerenveen is shown in figure 3.

properties WWTP Heerenveen	
year	2000
type	Carrousel
discharge surface	Nieuw Heerenveens Kanaal
biological capacity	143000 i.e. á 136 gr.TOD/day
	129653 i.e. á 150 gr.TOD/day
	93000 i.e. á 54 gr.BOD/day
hydraulic capacity RWD	4700 m^3/h

Figure 3: General information WWTP Heerenveen

A simple process chart for the treatment of sludge is given in figure 4. The area surrounded by a dashed line is executed by the wastewater treatment plant.

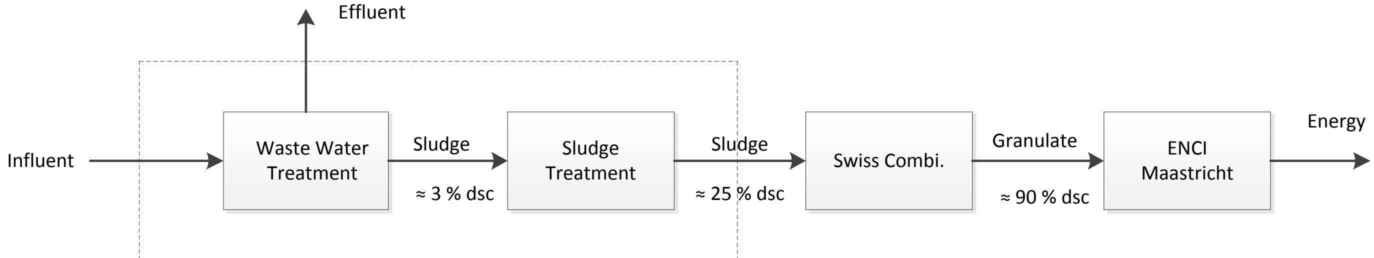


Figure 4: Process chart WWTP Garmerwolde & Heerenveen

1.3 Previous work

In the last few years water board Noorderzijlvest has been collaborating with the University of Groningen and the engineering company Water and Energy Solutions to gain more insight in optimizing the wastewater treatment plant. In 2009 Gijsbert Haaksman and in 2010 Martin Meelker and Olivier Burgering did their master research on the WWTP in Garmerwolde focusing on the possibility to add coal to sludge to improve dewatering. Sludge dewatering is a very important process, because a large proportion of the costs are associated with the final processing of the dewatered sludge cake. An improvement of 1% DSC/year results in a cost reduction of 326757.12 euro/year (Meelker, 2010). In 2012 a few bachelor students did their bachelor research on this subject but they used ash instead of coal. It was found that adding ash can upgrade the dry solid content of the sludge cake to an additional improvement of 2 kg water removed/kg dry sludge (Hofstee, 2012). The student T. Stoffelsma developed a flocculation methodology, where coagulation and flocculation was made visible.

1.4 Assignment

The last few years a lot of research has already been done by students and water boards at wastewater treatment plants, especially on mechanically dewatering sludge. The goal of my research is to do an operational comparison between the wastewater treatment plants in Garmerwolde and Heerenveen. These plants have in common that they also dewater sludge instead of just purifying sewage water, which is done by the other wastewater treatment plants in their water board district. The focus of the comparison will lie on sludge processing with flocculation and filtration as main subjects. Research questions that will be answered are:

- What hardware is present at both plants?
- How is it used, controlled and what are the procedures?
- What are the main process differences between Heerenveen and Garmerwolde?
- What is the optimal process design?
- Are there any adjustments in the procedure of filtration that can improve mechanically dewatering?

In addition, experiments with a flocculation setup based on the flocculation methodology designed by T. Stoffelsma will be done (Stoffelsma, 2012). The process conditions for sludge conditioning will be simulated and with the flocculation methodology an optimum for both wastewater treatment plants will be found.

2. Theory

2.1 Sludge

Probably the most important compound at a WWTP is sludge. Sludge is a viscous suspension and is produced during treatment of sewage water. Sludge has two basic forms: primary and secondary sludge. In addition, different side forms exists such as mixed sludge, digested sludge and physical-chemical sludge (Floerger S. , 2003). Sludge consists mainly of water and suspended solids. The dry solid content is an indication of the amount of solids and varies through the plant. The goal for the WWTP is to get the highest DSC of the sludge cake as possible after mechanically dewatering. The various sludge forms will be described below.

Primary sludge is produced through mechanical wastewater processing and consists of undissolved wastewater contaminations. The sludge has a high amount of organic matters such as faeces, textiles etc. Most of the primary sludge is amassed at the bottom of the primary sedimentation basin. In Garmerwolde and Heerenveen there is no primary sludge because the sedimentation tank is placed after the biological purification. However at WWTP Garmerwolde the name primary sludge is given to the sludge in the primary sedimentation tank, which is placed between the two biological purification steps. The dewatering ability of primary sludge is very good. The DSC of primary sludge lies between 0.2-4% (Man, 1998).

Secondary sludge or also called activated sludge is formed at the biological treatment step. There the removal of dissolved organic matter and nutrients from the wastewater takes place. The activated sludge contains living and dead biomass and exists normally in the form of flakes. Secondary sludge is collected at the bottom of the second sedimentation tank. The dewatering ability of secondary sludge is less good than primary sludge. The DSC of secondary sludge lies between 0.4-1% (Man, 1998).

Mixed sludge is a blend of primary and secondary sludge, which is the largest amount of sludge in Garmerwolde and Heerenveen. Digested sludge is mixed sludge that is formed during the anaerobic digestion process. The DSC of digested sludge lies between 3-5 %. Generally the mechanically dewatering ability of digested sludge is moderate. Physical-chemical sludge is the result of coagulation and flocculation. It is composed of flakes produced by the chemical treatment. After filtration a solid sludge cake is produced. The DSC lies between the 20-30 % (J.Nieuwlands, 2012) .

Sludge consists mainly of water, which is bound on different ways. The strength of these interactions determines the way sludge and water can be separated. Water in the sludge can be divided in four forms: free water, interstitial water, surface water and chemically bound water. Free water is found between the flakes, isn't bound and can therefore be easily removed. Interstitial water can be found in the small spaces between flakes and is bound by capillary forces. Surface water is the water bound at the surface of a flake and interacts by absorption forces. Chemical bound water can be found in the cell mass, is chemically bound and can therefore only be removed by thermal heating. Fortunately sludge has the highest percentage of free water, because only this water can be separated by mechanical dewatering. The various interactions are shown in figure 5.

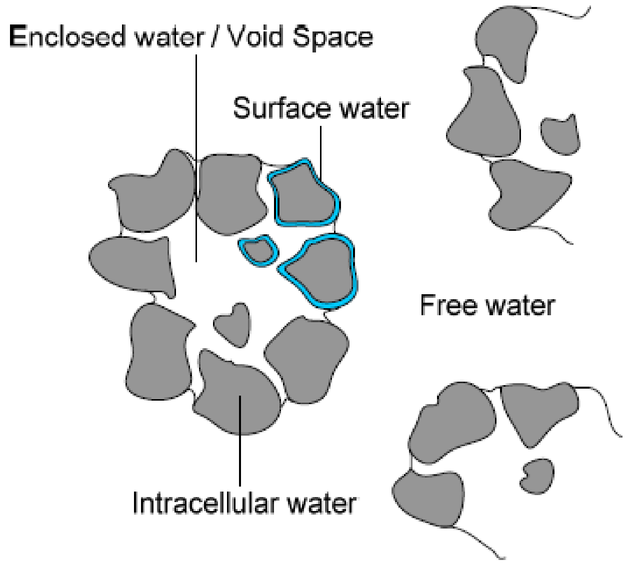


Figure 5: Water interaction within sludge

2.2 Digestion

At WWTP Garmerwolde anaerobic digestion is an essential part in the process of sludge dewatering. It is important for sludge stabilisation, sludge reduction and the energy and heat supply for the wastewater treatment plant. Digestion is a biological process where organic substances from the sludge are converted in methane, carbon dioxide and water. The produced gas is called biogas. Biogas is converted with a WWK (combined Heat and Power) into electricity (35%) and heat (65%) (W.Poiesz, 2013).

Before digestion, sludge consists of 33% inorganic and 67% organic substances. After digestion, sludge consists of 45 % inorganic and 55% organic substances (Vito, 2011). The decomposition of organic material can be divided into four phases; hydrolysis, acidogenesis, acetogenesis and methanogenesis (Man, 1998). The four steps are shown in figure 6.

Hydrolysis

Hydrolysis is the slowest process and therefore the rate-limiting step. During hydrolysis, complex undissolved organic substances like carbohydrates, fats and proteins are converted into dissolved organic substances like sugars, fatty acids and amino acids.

Acidogenesis & acetogenesis

Together, acidogenesis and acetogenesis are called the digestion step. During acidogenesis the dissolved organic substances are degraded by bacteria to simple components like alcohols and carbonic acids. The end products differ according to the process conditions. During acetogenesis the components are further degraded to acetic acid, carbon dioxide and hydrogen. Both processes are relatively insensitive for temperature and pH.

Methanogenesis

The final step in sludge digestion is methanogenesis. Hydrogen, acetic acid and carbon dioxide are converted into methane and carbon dioxide. This step is the most sensitive for changes in temperature and pH. The optimum temperature is 33-35 °C and the pH should be between 6 and 8. In a conventional digestion process there are two types of methanogene bacteria. One group converts hydrogen and carbon dioxide into methane. The other group converts acetate into methane and carbon dioxide. See Appendix K for a safety analysis of methane.

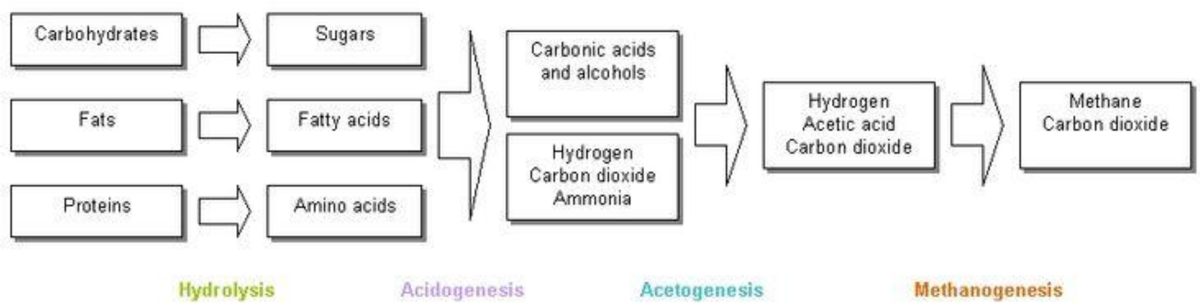


Figure 6: Digestion phases

2.3 Sludge Conditioning

Before sludge is mechanically dewatered it should be conditioned for improved dewatering. This is done by adding a coagulant and a flocculent. The coagulant used at Garmerwolde and Heerenveen is ferric chloride ($FeCl_3$) which provides coagulation by destabilizing particles by neutralizing their charge. This is done by adding a 40 wt% $FeCl_3$ solution in the piping trough dosing equipment at a dosage of 65 gram/kg sludge D.S. at Garmerwolde and at a dosage of 55 gram/kg sludge D.S. at Heerenveen. These are average numbers but the dosage may vary due to parameters such as dry solid content, weather conditions and sludge origin. The flocculent used, is a biodegradable polyelectrolyte (PE), which provides aggregation of destabilized particles and consequently formation of larger particles. In Garmerwolde a solution of 1 wt% PE is added before the dewatering process through dosing equipment at a dosage of 7.5 gram/kg sludge D.S.. In Heerenveen a solution of 0.15 % PE is added at a dosage of 7.0 gram/kg sludge D.S.. To understand the principle of coagulation and flocculation the theory should be understood. This is described in the next chapter.

2.4 Coagulation

To understand coagulation and flocculation the understanding of how individual colloids interact with each other is important. Sludge is made of a suspension of free colloidal particles. The behaviour of these particles is influenced by their electro kinetic charge. Every particle carries a charge which is usually negative. The adjacent particles repel each other and this prevents effective agglomeration and flocculation. Coagulation is the destabilization of the colloidal particles by essentially neutralizing the electrical charge present on the surface. This facilitates the agglomeration of the colloids (Floerger, 2003).

The double layer model is used to visualize the ionic environment in the vicinity of a charged colloid and explains how electrical repulsive forced occur. The colloid can be seen as a highly negative charged sphere. The negative charge attracts counter-ions that form a firmly attached layer around the surface of a colloid. This layer is called the Stern layer. Additional positive ions are also attracted by the colloid but are however repelled by the Stern layer and other positive ions trying to approach the colloid. This results in a dynamic equilibrium (Ravina, 1993). The decrease in positive ion concentration from the colloid to the normal concentration in the solution can be seen in figure 7.

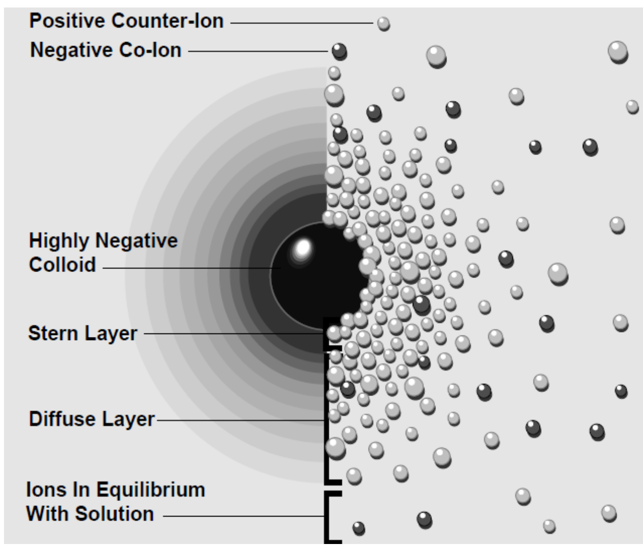


Figure 7: Two ways to visualize the double layer

The attached counter-ions in the Stern layer and the charged atmosphere in the diffuse layer are called the double layer. The thickness of this layer depends upon the concentration of ions in the solution. Also the type of counter-ion influences the double layer thickness. For example an Al^{3+} ion will be more effective than a Na^{+} in neutralizing the colloidal charge (Ravina, 1993). To form agglomeration the colloids must be brought together. The colloids can be either repulsed or attracted to each other. When the van der Waals attraction curve and the electrostatic repulsion curve are combined, the following figure is obtained.

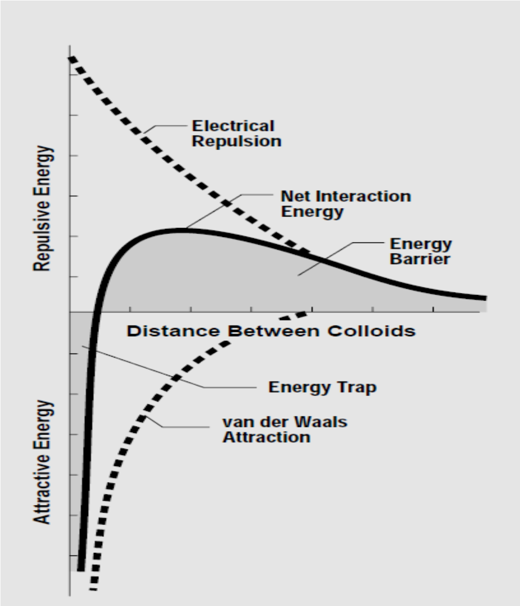


Figure 8: The net interaction curve

In order to agglomerate two particles on a collision must have sufficient kinetic energy to jump over the energy barrier. When the energy barrier is cleared, no repulsive areas are encountered. For good coagulation the energy barrier should be lowered. The best way is to remove the barrier so that the net interaction is always attractive. The barrier is lowered by compressing the double layer or reducing the surface charge. The most common way is to add a salt (coagulant) to the system. As the ionic concentration increases, the double layer and the repulsion energy curves are compressed. The energy barrier is lowered or eventually removed. In practice the following happens. Sludge has a pH value of 7. By adding $FeCl_3$ the pH is lowered to a value of 3-5. Then two and three trivalent iron hydroxide complexes exist, which interact with the negative colloidal particles. The sludge particles are neutralized

2.5 Flocculation

Flocculation is the agglomeration of the destabilized colloids with polyelectrolyte to form large flakes. This often occurs due to bridging; polymer molecules may be long and flexible enough to absorb onto several particles (Ravina, 1993). The precise nature of attachment between polymer and particle surface depends on the nature of the surfaces of particle and polymer. Various types of interaction between polymer segments and particle surfaces may be envisaged. The strongest interaction for polyelectrolytes is the ionic association between charged sites on the surface an oppositely charged polymer segments. Higher molecular weights of the polymer mean longer molecules and more effective bridging. Bridging is also enhanced by charge neutralization due to a coagulant. A negatively charged polyelectrolyte will interact with the positive ions (Stern layer) when the negative colloid is stabilized by ions from a salt such as $AlCl_3$ or $FeCl_3$. The resulting flakes are sensitive to external forces and therefore the shear forces should be low. Also the polymer should not be overdosed because this results in settling problems (Floerger, 2003). A summary of coagulation and flocculation is shown in figure 9.

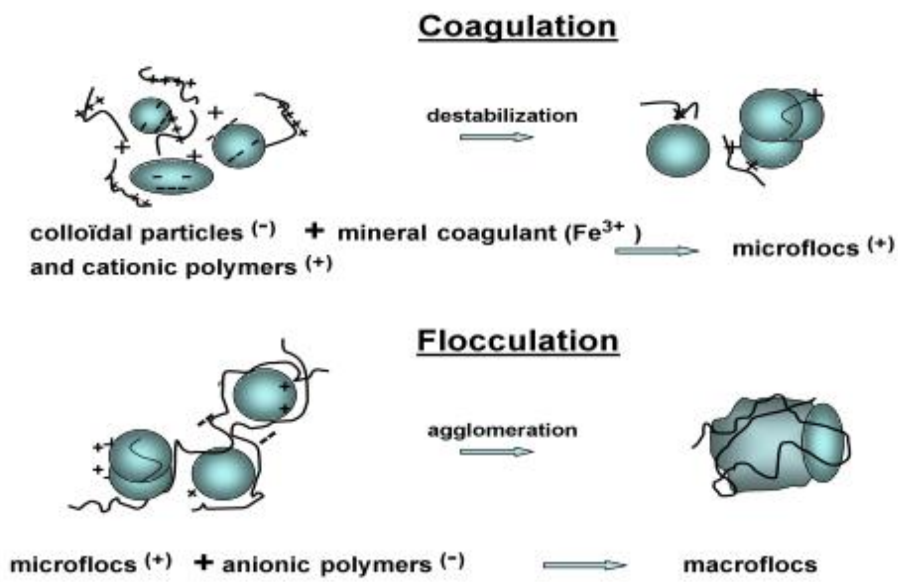


Figure 9: Coagulation and flocculation

2.6 Filtration

The separation of solids from a suspension in a liquid by a screen which retains the solids and allows the liquid to pass is termed filtration. In the laboratory often a Buchner funnel is used where the liquid is sucked through the thin layer of particles using vacuum. In the industry different techniques are used such as filter presses, vacuum filters, centrifuges, membrane filters and belt filters**.** First the theory of filtration shall be described. Then the different techniques of industrial filtration will be summoned focusing on the filter press. In the wastewater treatment plants of Garmerwolde and Heerenveen this technique is used for sludge dewatering.

2.6.1 Theory

Filtration can be described by the standard filtration theory based on Darcy's law. This law describes the laminar flow through a porous medium with increase of the filter cake. The rate of filtration depends on different parameters such as: the pressure drop, the area of filtering surface, the viscosity of the filtrate, the resistance of the filter cake and the resistance of the filter medium (W.Gosele & C.Alt, 2009). There are two different methods of operating a batch filter. One way is to keep the pressure constant and let the rate of flow progressively diminish. Another way is to keep the flow rate constant and let the pressure gradually increase. In Garmerwolde and Heerenveen a mix system is used where first the flow rate is constant but after a period of time the pressure is held constant and the flow progressively diminishes. The flow rate of the filtrate may be represented by the following equation (Harker, 2002).

$$u = \frac{1}{A}\frac{dV}{dt} = \frac{1}{5}\frac{e^3}{(1-e)^2}\frac{-\Delta P}{\mu l S^2} \quad (1)$$

With:
V = volume of filtrate (m^3)
A = total cross-sectional area of filter cake (m^2)
u = velocity of the filtrate (m/s)
l = cake thickness (m)
S = specific surface of the particles (m^2/m^3)
e = voidage
μ = viscosity of the filtrate (Pa.s)
ΔP = pressure difference (Pa)

Filter cakes can be divided into two classes, incompressible and compressible cakes (D.L.Forbes, 2009) . Sludge from the WWTP is compressible. The specific resistance r (m^{-2}), for compressible cakes, is shown below in the basic filtration equation.

$$\frac{1}{A}\frac{dV}{dt} = \frac{-\Delta P}{\mu l r} \quad (2)$$

$$r = = \frac{5(1-e)^2 S^2}{e^3} \quad (3)$$

The resistance r consists of the resistance of the filter cake and the resistance of the filter medium. When sludge has been conditioned with a coagulant and/or flocculent the resistance of the filter medium is negligible. This is due the lowered change of clogging of the filter by particles. There is a linear relation between t/V and V when the filtration is done at a constant pressure difference.

$$\frac{t}{V} = \frac{r\mu v}{2A^2(-\Delta P)} V \quad (4)$$

In practice the pressure difference is gradually built up to its ultimate value. Mechanical filtration consists of two phases, the filtration and the expression phase. In the filtration phase the water flows freely through the cake. The cake thickness increases and the filter resistance is low. In the second phase the cake is pressed such that the thickness decreases. Due to this, the filter resistance increases and the dewatering capacity decreases. Eventually the flow through the cake is zero. The two phases can be seen in figure 10.

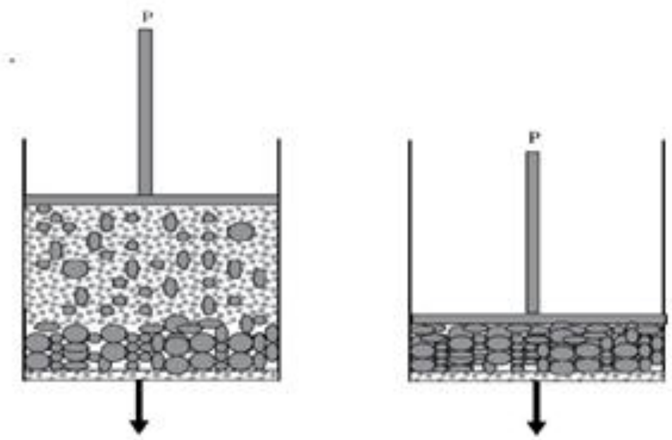


Figure 10: Filtration process

In the industry difficulties are encountered in the mechanical handling of larger quantities of suspension and solids. During filtration a thicker layer of solids exists and to achieve a high rate of passage higher pressures are needed. However, filtration is a mechanical operation and less demanding in energy than drying.

2.6.2 Filtration history

The earliest records of purifying water generate back to 2000 B.C.. Different methods where used like boiling or filtering water through crude sand or charcoal to clean water. After 1500 BC the Egyptians first discovered the principle of coagulation. They used the chemical alum for the destabilization and settlement of particles. Centuries later, Hippocrates invented the sieving of water; later known as the 'Hippocratic sleeve'. This filter was a cloth bag through which water could be poured after being boiled. The cloth would trap any sentiments in the water that caused bad taste or smell. During the Middle Ages water purification was rare and there was a lack of scientific innovations. A great discovery in the water filtration history was the invention of the microscope by Anton van Leeuwenhoek. Scientists were now able to view tiny material particles present in water that had been presumed to be clean. In 1804 the first municipal water treatment plan was installed in Paisly, Scotland (Outwater, 1996). The water purification was done by a slow sand filter which was later replaced by a rapid sand filter due to the need for higher capacity and efficiency. Later chlorine was added for disinfections purposes. In 1972 there was a great development in the water filtration history with the passage of the Clean Water Act. From now on every person had the right to have safe drinking water. New methods for water treatment were developed such as aeration, flocculation, and active carbon adsorption to fulfil this law (Baker & Taras, 1981). Therefore also new techniques for sludge dewatering were developed. For example, membrane presses and chamber filter presses were implemented in the wastewater treatment plant in the late seventies (Shirato, 2010).

2.6.3 Filtration techniques

Chamber filter press

In both Heerenveen and Garmerwolde sludge is mechanically dewatered by a filter press. A filter press is composed of a series of hollow vertical frames with filter cloths stretched on both sides. A chamber is formed between each pair of successive plates. The sludge slurry is pumped through a feed channel in the centre of each of the plates. The plates are nowadays frequently made of polypropylene whereas in the past stainless steel was used. A figure of plates with filter cloths is given in figure 11. A schematic figure of a plate is given in appendix F.

Figure 11: Plates with filter cloth

Filter clothes are arranged on the plates, which retains the solid particles. Water flows through the clothes and is therefore separated. Dewatering is done by a batch process, which is described next. First the press is closed by pressing the plates together with a pressure of 500 bar. Then the sludge is pumped through a feed channel in the chambers. Filling time depends on the flow of the feed pump and dry solid content of the sludge. For sludge having good filterability it is the best way to fill the filter press very quickly to avoid the formation of a cake in the first chamber before the last ones have been filled. A rise of pressure occurs due to the formation of an increasingly thick layer of filter sludge on the filter cloths when the chambers are filled. In addition to the filter plate filtration medium, the growing filter cake enhances removal of fine particles in the slurry. In most cases the pressure is build up by a low pressure pump to a pressure of 8 bar and then a high pressure pump brings the pressure to 15 bar. After some time the end of the filtration rate has been reached. The filter plates are opened automatically by a moving head that pulls out the plates one for one. The resulting filter cake falls due to its weight and is collected in a container. The filtration cycle time lies around two hours (Harker, 2002). A schematic picture of a chamber filter press process is shown in figure 12.

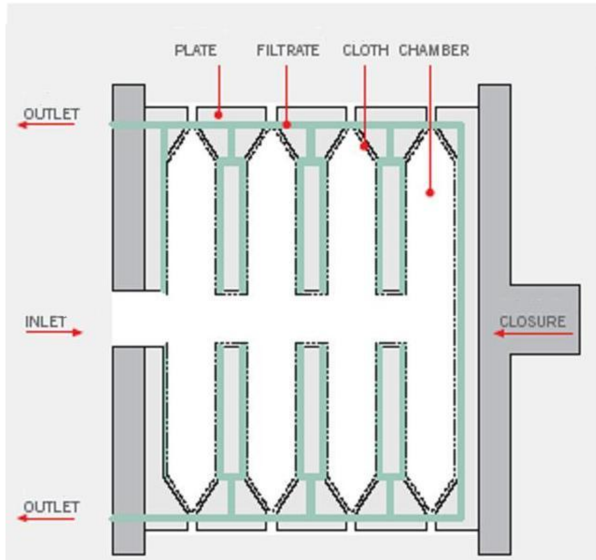


Figure 12: Filter press chambers

Membrane filter press

In a membrane filter press a membrane is arranged in the filter chamber. The membrane exerts pressure on the sludge in the chamber due to the pumping of the sludge into the press. The operation cycle of the membrane filter press is almost the same for the chamber filter press, however now two phases can be distinguished. First the dewatering is done by pumping the sludge into the press and pressure is built up. Secondly, dewatering is enhanced by bringing the membranes on pressure so that the filter cake is pressed. A membrane filtration cycle time is a bit shorter and lies around 1.5 hours (W.Gosele & C.Alt, 2009). In WWTP Heerenveen two of the four filter presses where membrane filter presses. However, in 2004 there were converted into chamber filter presses.

Air press

An air press system has been developed for improved dewatering of paper webs (Hermans, Hada, & Y.D.Lindsay, 2003). In the paper industry cakes are made with a dry solid content of 50-60 %. In principle, such high dry solid contents for sludge are not possible, however an air press implemented in the current filter press system could improve dewatering. In general, the air press applies gas pressure in a central pressurized plenum to a web between two moving fabrics. Water is displaced and the dry solid content of the paper increases. In the current filter press system, a lot of water accumulates in the feed channel. A filter press consisting of 100 plates (width 75 mm) and a feed channel diameter of 150 mm results in an accumulation of 0.53 m^3 wet sludge. The air press should be able to press the remaining sludge out of the feed channel. There are two options possible for implementing the air press in the current system. In the first scenario, air is pressed through the feed channel. Water in the sludge is either moved or dissolved in the air, where a mix drain of water and air exists. In the other scenario the air is pressed through the drains and water in the sludge is pressed into the feed channel, where it can leave the filter press. Both options require adjustments to the current design. A company in the United States, DryVac, designed a chamber filter press where pressured air is introduced in the chamber to squeeze the cake (Technology, 2010).

Centrifuges

Another method of separating sludge and water is centrifugation, where sludge is separated based on a centrifugal force. The Stokes law can be applied for this process (Man, 1998):

$$v = \frac{\rho_s - \rho_L \;\; d^2 (\frac{\pi n}{30})^2 r}{18\mu} \tag{5}$$

With:
v = sedimentation speed of solid (m/s)
ρ_S = density of solid (kg/m^3)
ρ_L = density of liquid (kg/m^3)
d = diameter of the particles (m)
n= rotational speed (rpm)
r = distance to the rotational centre (m)
μ = viscosity of the liquid (Pa.s)

In most cases the decanter centrifuge (figure 13) is applied for the dewatering of sludge. A centrifuge consists of a rotating mantle and screw. The mantle and screw both rotates in the same direction, where the screw rotation is a bit slower (1-15 rpm). The sludge is added centrally, where the solid particles are deposited on the mantle. The screw transports the sludge cake to the end. Most centrifuges operate with a counter current flow principle.

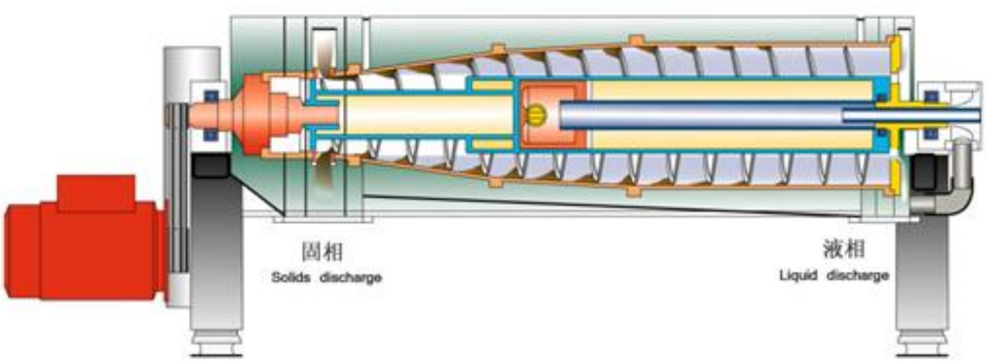


Figure 13: Centrifuge

Belt filters

In the horizontal belt filter, shown in figure 14, an endless belt is arranged in the horizontal plane. The sludge particles are separated from the water under gravity forces via a filter cloth. Water seeps through the filter cloth and is collected and transported to the wastewater treatment. Often the belt filter is used prior to the filter presses to increase the dry solid content and the dewatering ability of the sludge. The sludge on the belt filter is agitated to improve the thickening results. In Garmerwolde two belt thickeners are used to increase the DSC of the secondary sludge stream.

Figure 14: Belt filter

3. Process description

3.1 WWTP Garmerwolde

3.1.1 Introduction

In the following chapter the processes of the wastewater treatment plant in Garmerwolde are described. An overall block diagram (OBD) is given below where the in and out going flows are defined.

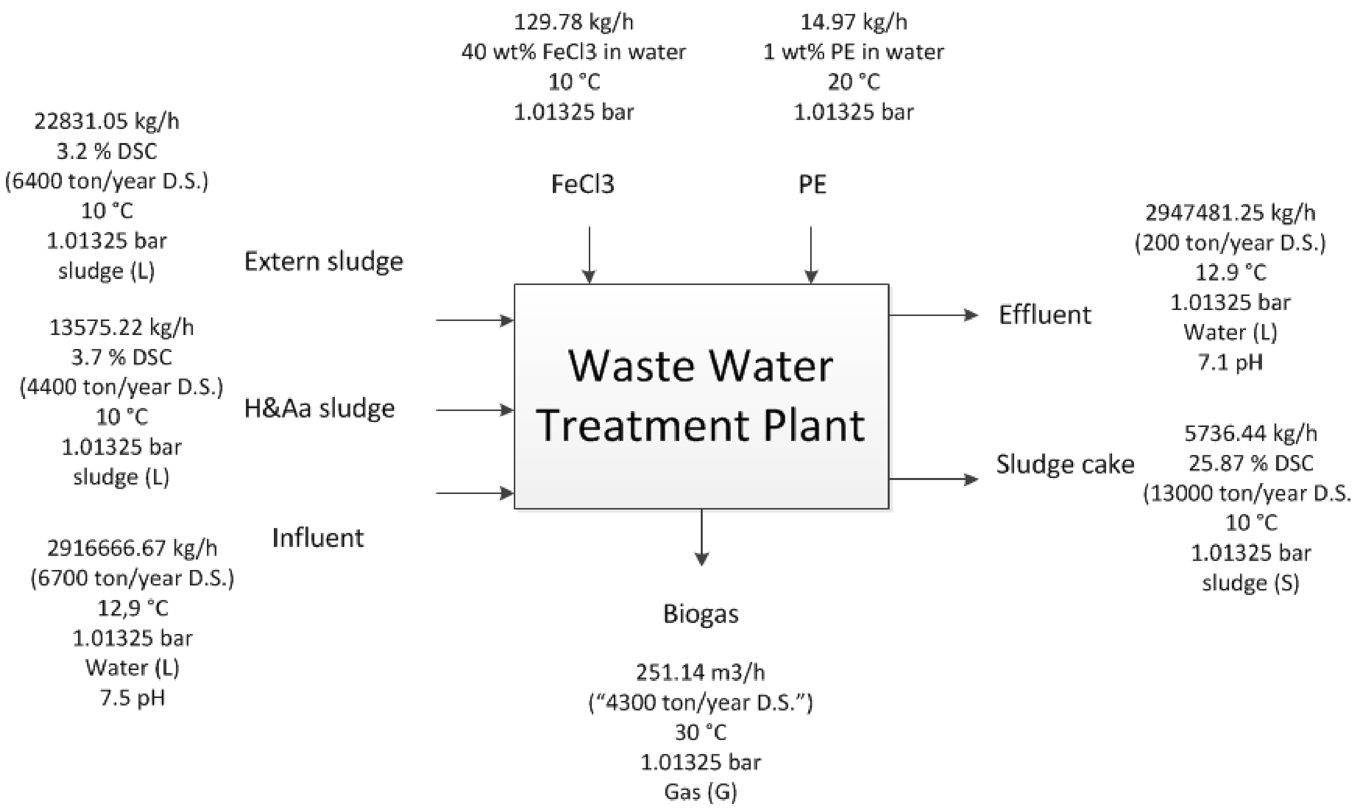


Figure 15: Overall block diagram

3.1.2 Hardware

The wastewater treatment plant can be divided into two parts, water and sludge treatment. Sludge helps to clean the sewage water but afterwards it contains a lot of bacteria, metals and high concentrations of nitrate and phosphate. Therefore the sludge is dewatered and finally transported to Swiss Combi. A process block diagram of WWTP Garmerwolde is shown below. Each step will be explained and conditions will be given.

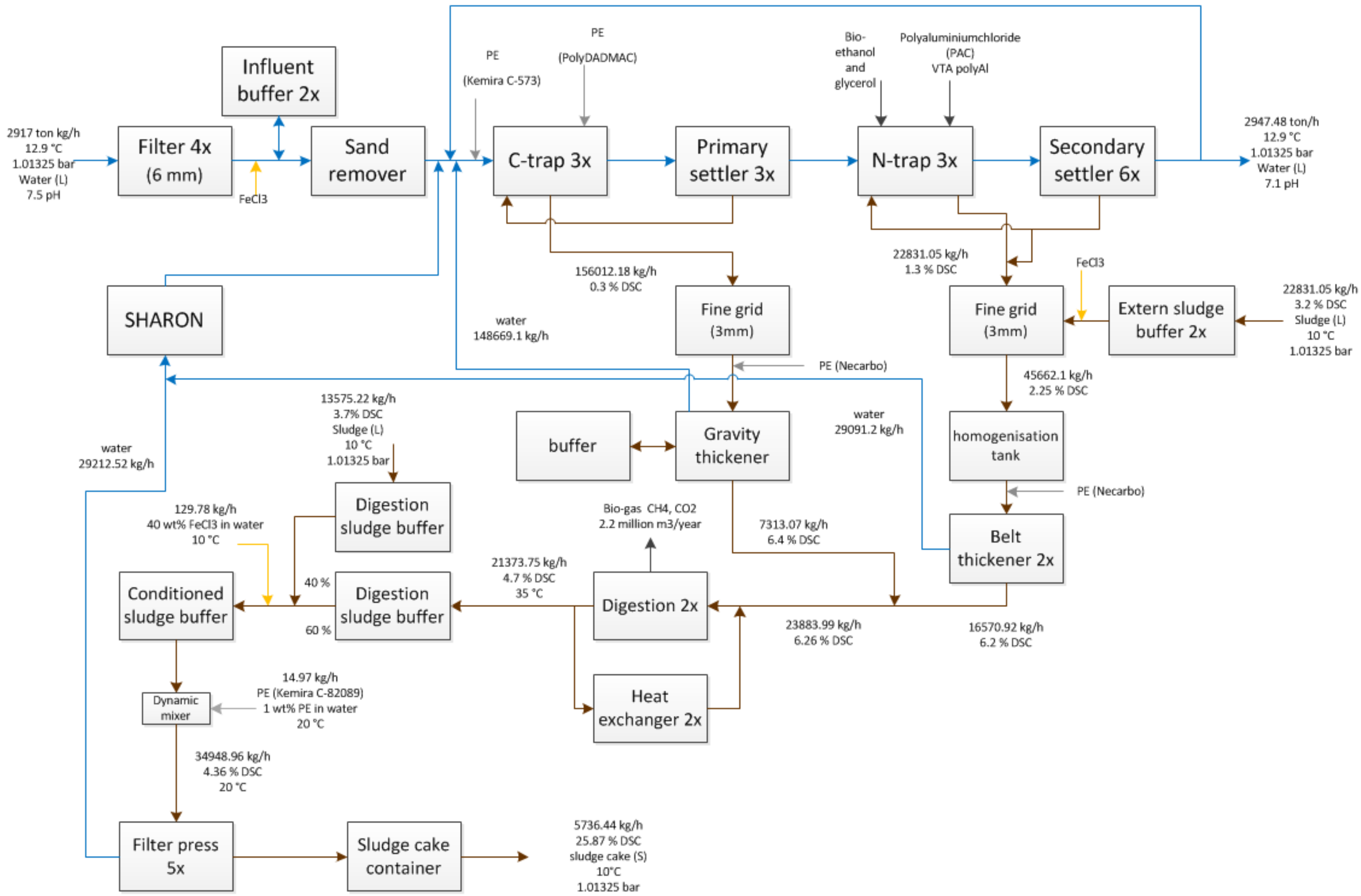


Figure 16: Process Block Diagram Garmerwolde

Water treatment

Sewage water comes from three different discharge pipes: one from the city Groningen (Damsterdiep), one from the district Lewenborg and one from Loppersum/Ten Boer. The influent has a pH of 7.5 and a temperature comparable with the ambient temperature. Around 2917 m^3/h sewage water flows in and 2948 m^3/h flows out of the wastewater treatment plant. The out flow is higher due to water in external sludge, which is separated by a filter press and then returned to the water treatment.

First the influent passes four rotary filters with a mesh of 6 mm. Here the larger parts are removed such as paper, plastic and wood. The dirt is collected, washed, pressed and then taken away to the dump. After the filters $FeCl_3$ is added to enhance particle formation, phosphorus removal and reducing H_2S to prevent a nasty odour. The influent can be stored at two large storage basins when the capacity of the purification is limited.

The influent still contains a lot of sand. This is removed by decreasing the velocity of the wastewater. Therefore the small sand particles will sink to the bottom, where it can be collected by a scraper and a rake and put in a container (see figure 17). Sometimes sand can be re-used for the construction of new roads. Sand is primarily removed to reduce the wear off of the pumps and the pipes. Also sand will accumulate in the bottom of digestion tanks without removal. This will reduce the capacity after a few years.

Figure 17: Sand removed and collected

The wastewater is now divided in three 'streets'. Water is purified in the same way for every 'street'. The first biological purification step is called the C-trap. First polyelectrolyte (PE) is dosed by a so called FAST dosage. It consists of a double PE dosage, one just before the C-trap and one during the C-trap. The first PE dosage consists of Superfloc C-573, produced by Kemira, and is a cationic polyamine. The second PE dosage is done with polyDADMAC which is a cationic polymer. The dosage set is based on the amount of influent, concentration hazardous components and dry solid content. The chemical structures of the polymers are shown below.

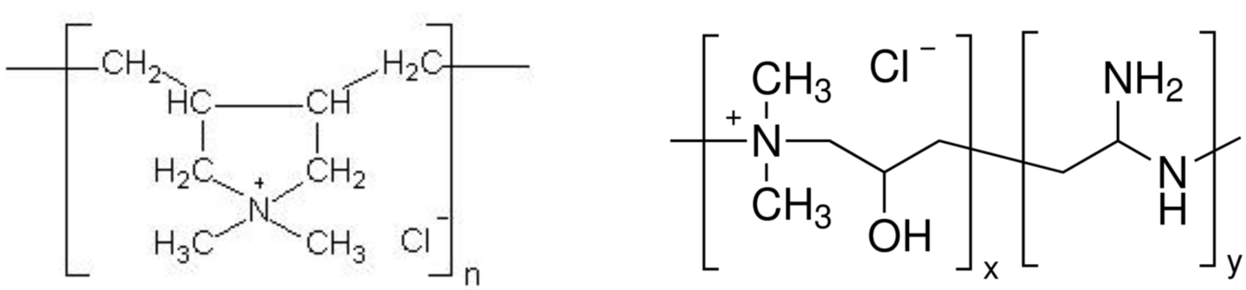


Figure 18: Left Superfloc C-573 and right polyDADMAC

The PE is added to enhance particle formation and sedimentation of these particles in the sedimentation tank. The C-trap consists of a big round basin in which active sludge is present in the inner ring consisting of bacteria that live from the organic content in the wastewater. These bacteria cannot live without oxygen. Therefore big compressors are used to bring oxygen in the water. The sludge content in the first trap is around 2.5 g D.S./L. The aeration is controlled centrally and based on the influent. It is therefore not possible to adjust the aeration for every street. The residence time lies around 12 hours.

After the C-trap the sewage water is transported to a sedimentation tank where sludge sinks to the bottom. An arm rotates above the basin and moves the sludge to the centre of the basin. Most of the sludge is pumped back to the C-trap where it can purify the water again. The rest is pumped to a gravity thickener. The water overflow of the primary settler flows to the second biological purification step, also called the N-trap. Other bacteria are used to remove the hazardous contents in the water. This time the water flows relatively slowly through two long tanks. The residence time varies between 5 days in the summer and 10-20 days in the winter. Every tank consists of multiple spaces, where in some oxygen is added and some not. In the first space water is mixed with active sludge consisting of bacteria, unicellular and multicellular organism. In the oxygen rich spaces nitrification takes place, whereas in the oxygen poor space denitrification takes place. During the N-trap a C-source (bio-ethanol and glycerol) for the bacteria and $AlCl_3$ for coagulation are added. $AlCl_3$ also enhances the phosphorus removal. In order to keep the volume of the influent flow rate constant, the influent is supplemented with effluent before the C-trap at an average of 1 at 1.

The last step is the sedimentation of the sludge in the second sedimentation tank. Every 'street' has two large tanks. The sludge sinks to the bottom and is re-used in the N-trap. The excess sludge or surplus sludge is transported to the thickeners. The overflow of the sedimentation sank flows to an effluent ditch around the WWTP. Finally water from the ditch is pumped into the Eemskanaal.

Sludge treatment

The sludge treatment process is controlled by four operators whereas the water treatment process is controlled by two operators. The overall process can be visualised by a process flow diagram (PFD). The diagram is used to indicate the general flow of plant processes and the equipment used. The PFD of the sludge treatment for WWTP Garmerwolde is shown in figure 19. The sludge treatment is divided into six different sections: primary sludge and (1), secondary sludge (2) treatment, digestion (3), $FeCl_3$ (4) and PE (5) supply and mechanically dewatering (6).

Sludge from WWTP Garmerwolde can be distinguished between primary and secondary sludge. Primary sludge (0.3% DSC) is obtained from the first sedimentation tank and secondary sludge (1.3 % DSC) from the second sedimentation tank. Both sludge forms are transported to a fine dirt sieve of 3 mm (F-1201/F-1101) to remove remaining large particles. Primary sludge is then transported to a gravity settler (C-1101). A flocculent from the fabricant Necarbo is added during transport. The resulting flakes will sink in the settler and any water overflow is transported back to the water line before the C-trap. The gravity settler has also a buffer for storage of the thickened sludge (C-1102). Sludge has a dry solid content of 6.4 % after the gravity thickener.

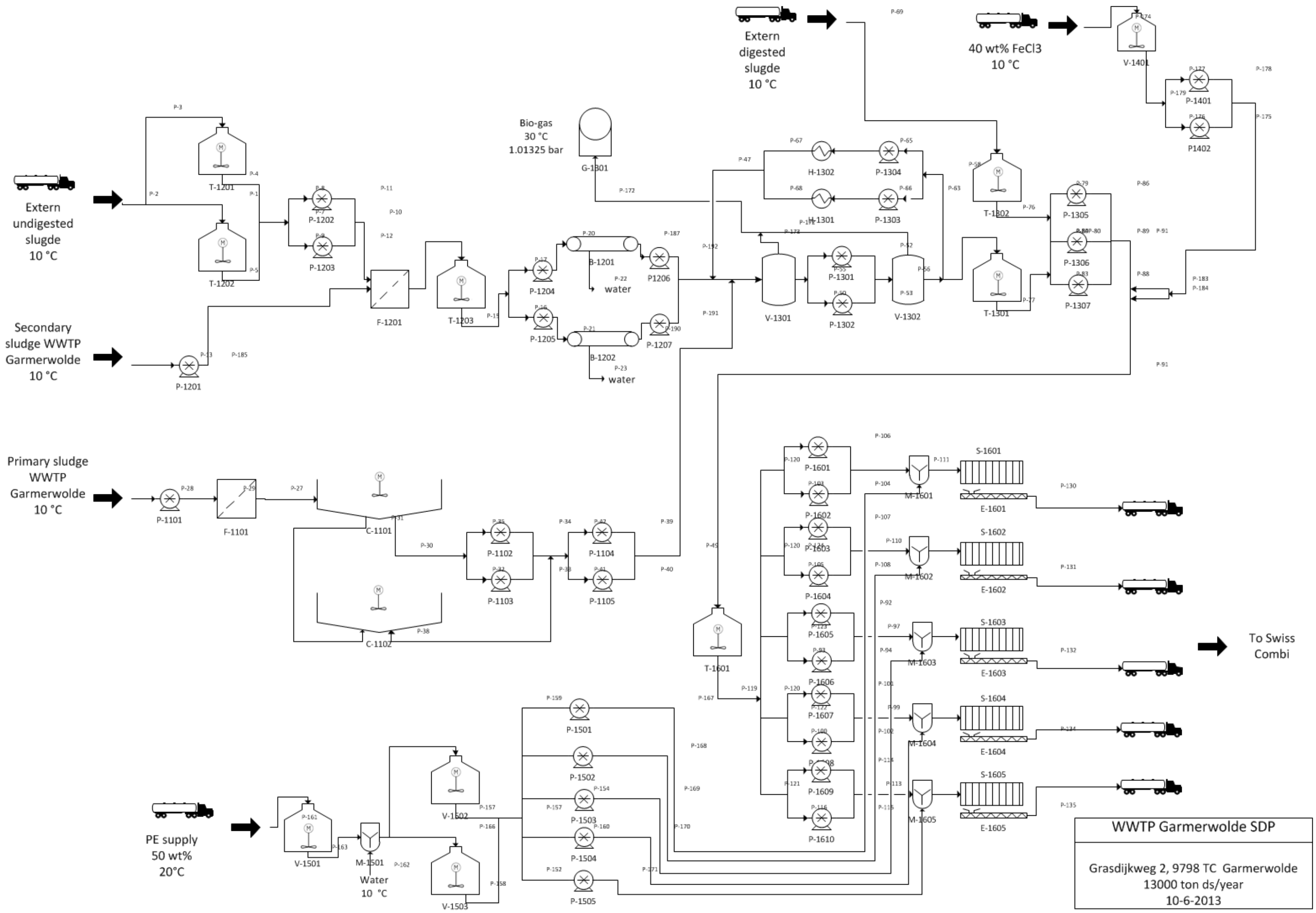


Figure 19: Process Flow Diagram Garmerwolde (PFD)

Also extern undigested sludge (3.2 % DSC) from other wastewater treatment plants of Noorderzijlvest is dewatered in Garmerwolde. The sludge can be stored in two buffer tanks of 1000 m^3 (T-1201/T-1202). It then flows through a fine dirt sieve (3mm) together with secondary sludge from WWTP Garmerwolde. The mixture of secondary and extern sludge is transported and mixed in a homogenisation buffer tank (T-1203). After the tank a polyelectrolyte (PE) from fabricant Necarbo is added for flocculation. Then the sludge is thickened by two belt thickeners (see figure 20). Water is removed using a stainless steel mesh-belt. After the belt thickeners, sludge has a dry solid content of 6.2 %. The gravity and the belt thickeners are necessary to increase the DSC of the sludge. It is also useful for reducing the volume of the digestion tanks, where more water in the sludge results in larger tanks.

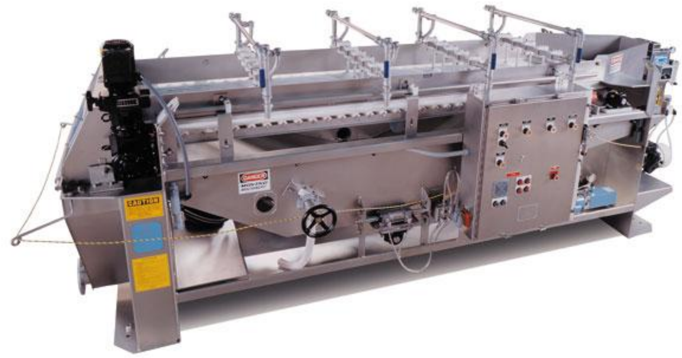


Figure 20: Belt thickener

The sludge stream from the gravity settler and the sludge stream from the belt thickeners are combined and are transported to two large digestion tanks of 4600 m^3 each (V-1301/V-1302). The incoming sludge is heated by a return flow of digested sludge with a temperature of 43 °C. The temperature in the digestion tanks is around 38 °C, which is the optimal temperature where bacteria can digest most of the hazardous compounds. The pH is circa 7.5. The residence time of the sludge is approximately 20 days. The formed biogas is washed and then discharged to a gas holder (G-1301) in the shape of a sphere. After digestion an amount of digested sludge is heated by two heat exchangers (H-1301/H-1302) and is returned to heat the incoming sludge. The heat exchangers are operated parallel and only one is operational. This is done for cleaning purposes. The utility stream is water with a temperature of 76.4 °C. The sludge stream has a pressure drop in the heat exchanger from 2.5 to 1.8 bar (ΔP 0.72 bar). After digestion, sludge is transported to a digestion sludge buffer (T-1301) of 1300 m^3. The digested sludge has a dry solid content of 4.7 %

Digested sludge (3.7 % DSC) from other wastewater treatment plants of Noorderzijlvest and Hunze and Aa's is also stored in a digestion sludge buffer (T-1302) of 1300 m^3. The streams of the two digestion sludge buffers are combined with a ratio of 40/60 extern/intern sludge. Then 65 gram $FeCl_3$/kg sludge D.S. is dosed with a 40 wt% $FeCl_3$ solution in water. This is done by two injection points of around 18 meters before the conditioned sludge tank (T-1601). The $FeCl_3$ has been stored in a 55 m^3 buffer (V-1401). The pipes of the main sludge stream are made from polypropylene with a diameter of 160 mm. The sludge is stored and mixed (4 rpm) in a conditioned sludge buffer tank (30 m^3). The pH of the sludge mixture is 6.8. The final step is the mechanical dewatering of sludge using filtration. WWTP Garmerwolde uses five multiple chamber filter presses (S-1601-..-S-1605). Three are from the brand Ritterhaus & Blecher and have 92 frames each. The other two filter presses are from the brand Passavant and have 105 frames each. The dewatering of sludge by Passavant is less efficient (≈1% DSC) and these filter presses are only used when capacity is needed. A figure of a filter press in Garmerwolde is shown in figure 21.

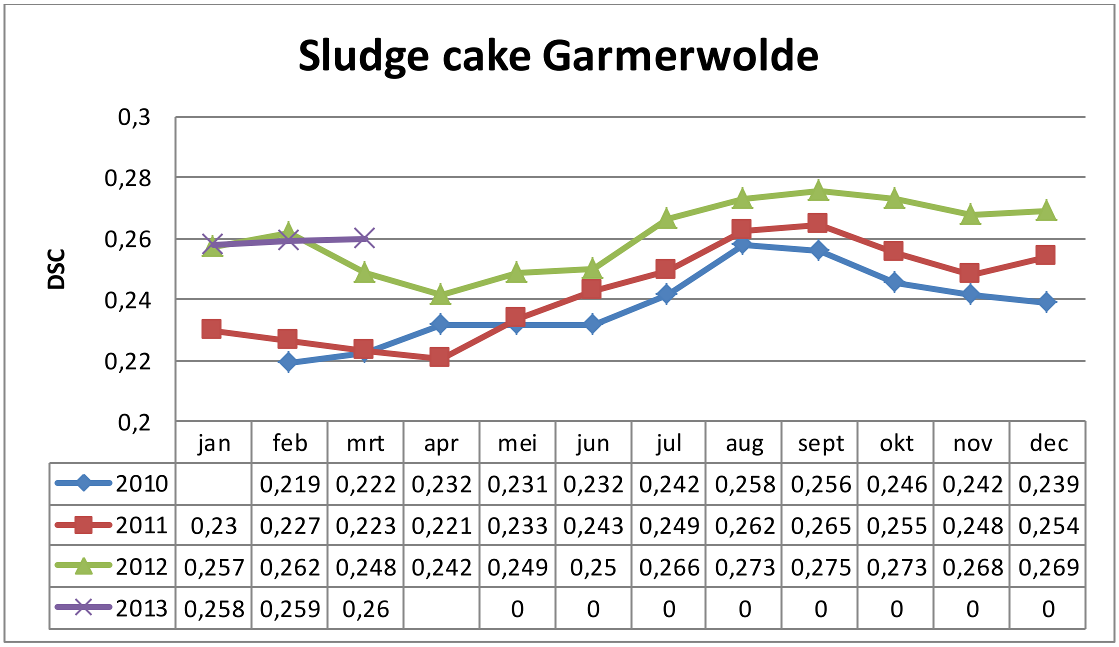
Figure 21: Chamber filter press (Ritterhaus & Blecher)

Just before the sludge enters the chamber filter press, a flocculent 1 wt% polyelectrolyte solution in water (Kemira C-82089) is added at a dosage of 7.5 gram PE/kg sludge D.S.. The PE is mixed by a dynamic mixer (1400-1500 rpm) fabricated by Knauer. In the current process PE is added 1 meter before the filter press. The dynamic mixer (M-1601/M-1605) is shown in figure 22. The PE is bought from Kemira and stored in a 30 m^3 buffer tank (V-1501) as a 50 wt% solution in water. The PE is mixed with water by a Polymix system to a 1 wt% solution and stored in two 7 m^3 buffers (V-1502/V-1503).

Figure 22: Dynamic mixer

The filter cloths used in the filter presses are from the fabricants Finsa and NEDfilter. Normally the lifespan of a filter cloth is 4 years but due to wear and lower efficiency the cloths are only used for 1.5 years. The cost of a filter cloth is 80-120 euro each. The cloths are washed once a month to ensure constant quality

Every batch cycle the chamber filter presses are filled with a volume between 35 and 40 m^3. First the pressure is build up to 8 bar by the low pressure pomp. Then the high pressure pump takes over and finishes at 15 bar. The press/fill time is 110 minutes and discharging is done in 13 minutes. After a batch cycle sludge falls down and is transported by a screw to containers. The container is weighted and transported fifteen times a day to Swiss Combi. The sludge cake has an average dry solid content of 25.87 %. However the DSC differs during the year. This is mainly due to weather conditions. See figure 23 for the DSC of the past three years.



	jan	feb	mrt	apr	mei	jun	jul	aug	sept	okt	nov	dec
2010		0,219	0,222	0,232	0,231	0,232	0,242	0,258	0,256	0,246	0,242	0,239
2011	0,23	0,227	0,223	0,221	0,233	0,243	0,249	0,262	0,265	0,255	0,248	0,254
2012	0,257	0,262	0,248	0,242	0,249	0,25	0,266	0,273	0,275	0,273	0,268	0,269
2013	0,258	0,259	0,26		0	0	0	0	0	0	0	0

Figure 23: DSC sludge cake

The filtrate water flows to a SHARON reactor. SHARON (Single reactor system for High activity Ammonium Removal Over Nitrite) is a sewage treatment process where nitrogen is removed by combining two separate treatment steps: a partial nitrification process (Sharon) followed by an anaerobic ammonium oxidation process (Anammox). After removal of the contaminants the water stream is returned to the main sewage stream before the C-trap.

3.1.3 P&ID

In the previous chapters an OBD, PBD and a PFD were already shown. In the process industry also a piping and instrumentation diagram is displayed, which shows more detailed information such as the installed equipment and instrumentation. Three P&ID will be shown with the first displaying the primary and secondary sludge treatment (see figure 24). The second shows the digestion of the mixed sludge (see figure 25). The third shows the $FeCl_3$ and PE supply and the mechanically dewatering of sludge (see figure 26). See appendix I for more information about the equipment that is used.

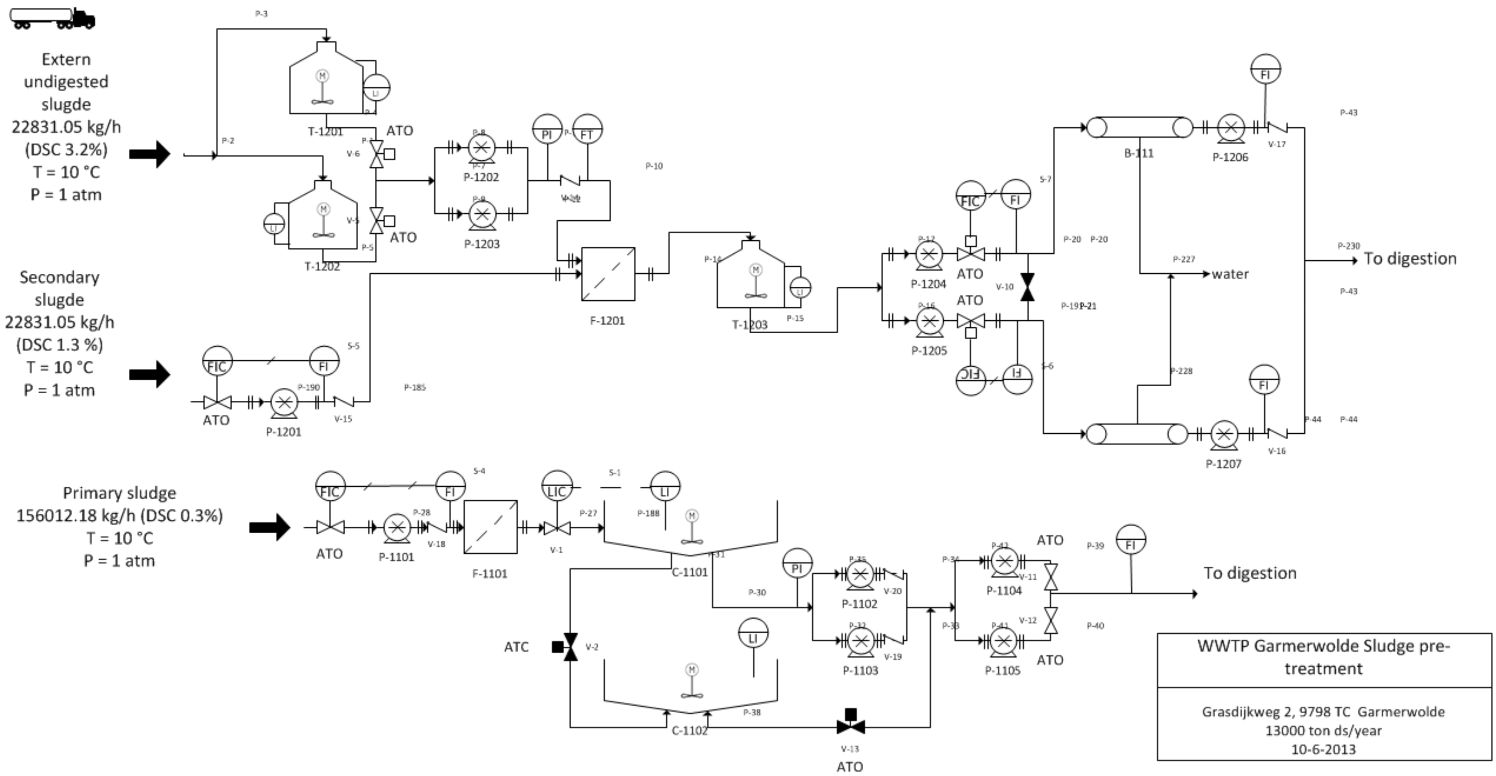


Figure 24: P&ID sludge pre-treatment

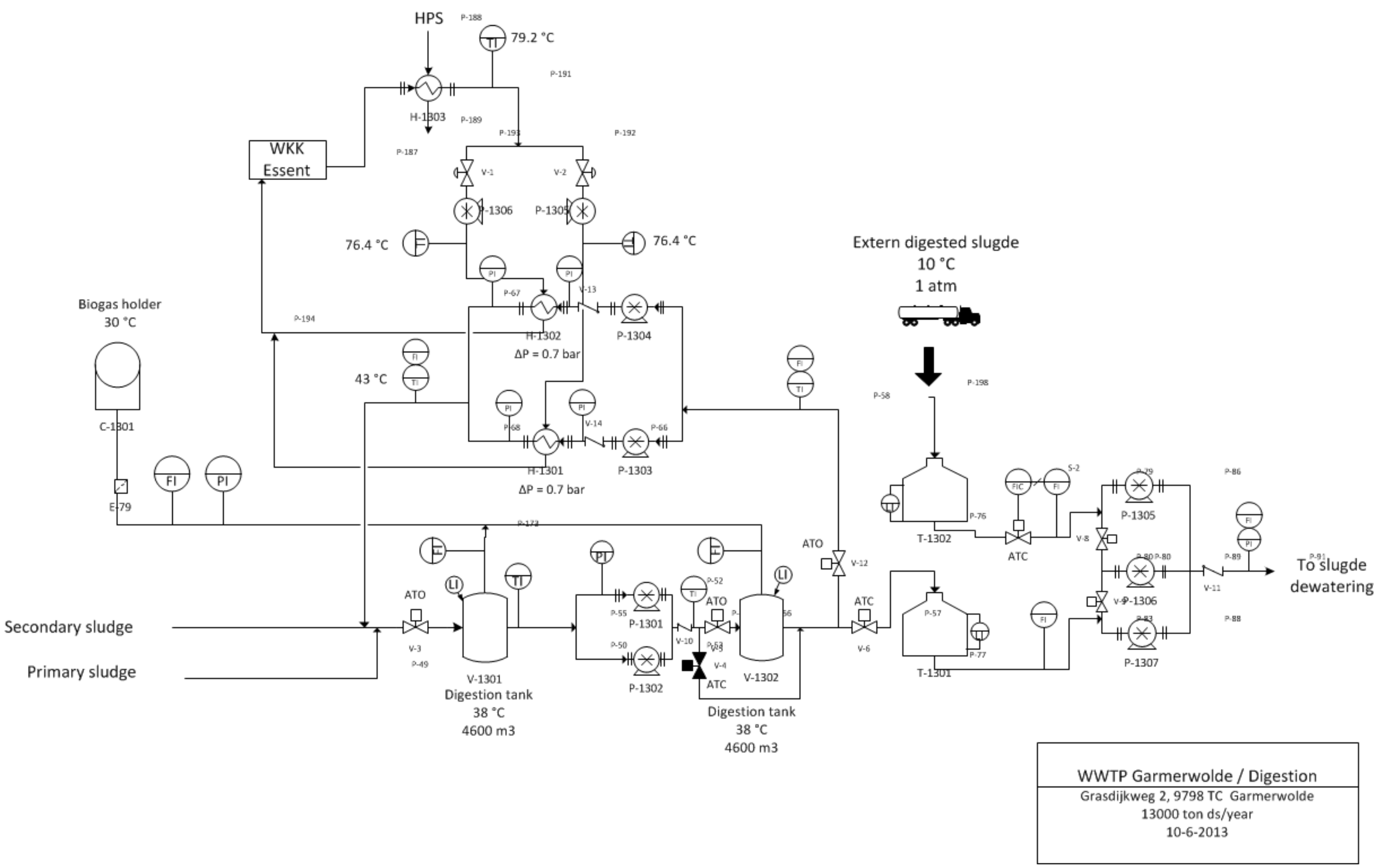


Figure 25: P&ID sludge digestion

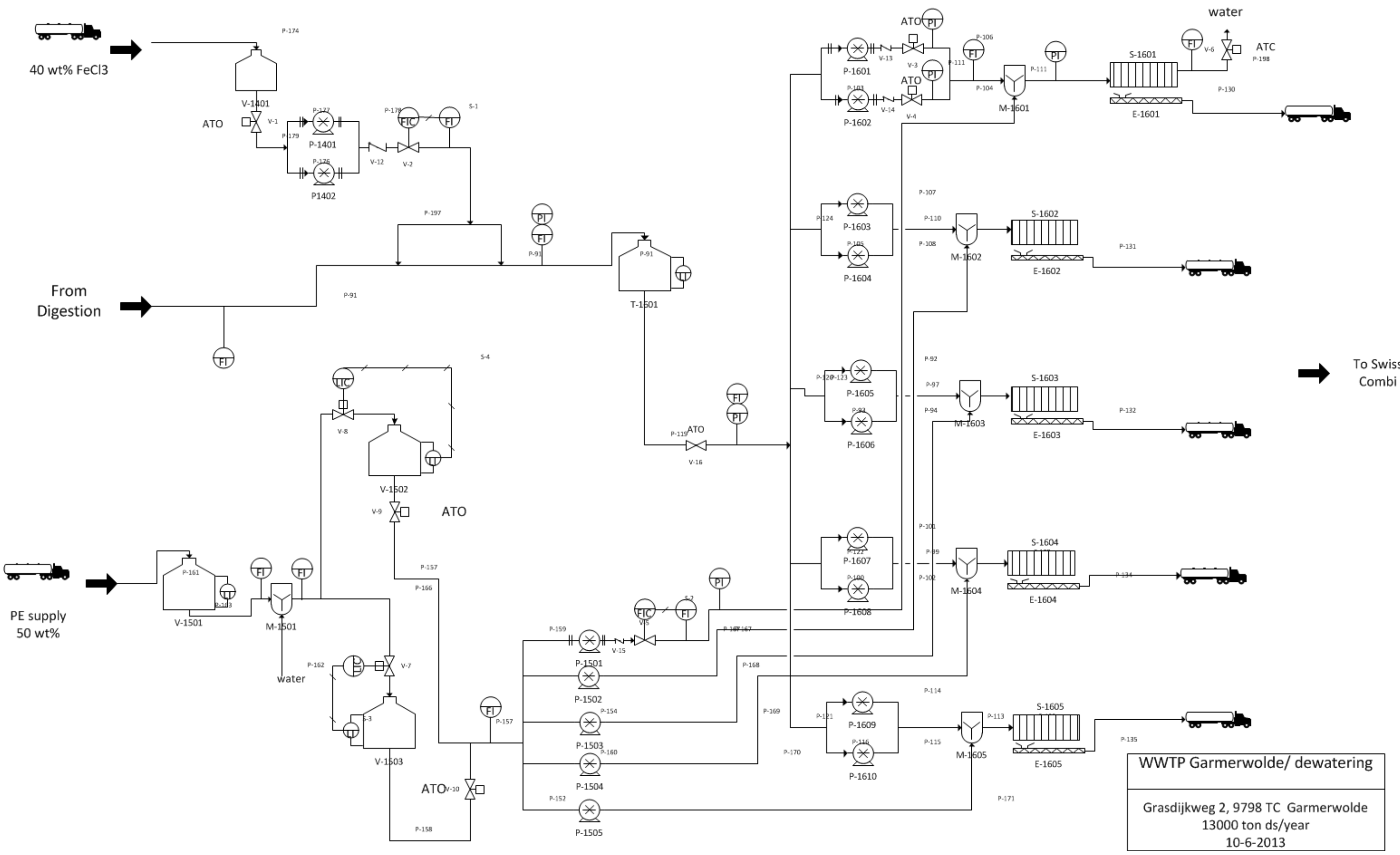


Figure 26: P&ID sludge dewatering

3.1.4 Key numbers

The processes at the WWTP can be simplified by key numbers such as kg sludge D.S./m^3 purified water, kg sludge D.S./h residence time, kg PE/kg $FeCl_3$, kg PE/kg sludge D.S., kg $FeCl_3$/ kg sludge D.S., kg PE/ kg wet sludge, kg $FeCl_3$/ kg wet sludge kg and kg wet sludge/kg sludge cake. For the calculation of these numbers it is assumed that the density of sludge is 1000 kg/m^3 if the sludge has a dry solid content less than 30 %. First the kg sludge D.S./h residence time is calculated for each process in the sludge treatment.

	D.S. in tank (kg)	residence time (hours)	kg sludge D.S./h residence time
gravity thickener (C-1101/C-1102)	4500	9.61	468
extern undigested sludge buffer (T-1201/T1202)	64000	32	2000
homogenization tank (T-1203)	2250	2.19	1027
digestion tanks (V-1301/V-1302)	575920	385	1496
digestion sludge buffer (T-1301)	61100	61	1002
extern digestion sludge buffer (T-1302)	48100	96	501
conditioned sludge buffer (T-1601)	1293	0.51	2535
filter press (S-1601)	1744	1.83	953

Table 1: Key number residence time

Sludge conditioning			
kg PE	14.97	kg PE/kg $FeCl_3$	0.12
kg $FeCl_3$	129.78	kg PE/kg D.S.	0.010
kg sludge D.S.	1523.77	kg Fe/kg D.S.	0.098
purified water m^3	2947.48	kg D.S./m^3 purified water	0.52
kg wet sludge	34948.96	kg PE/kg wet sludge	0.00043
kg sludge cake	5756.47	kg $FeCl_3$/kg wet sludge	0.0037
		kg wet sludge/kg sludge	6.07

Table 2: Key numbers sludge conditioning

Also the wastewater treatment plant has some key numbers. The calculated numbers are shown below.

Data water treatment		
Sludge content retour sludge	gram D.S./l	12
Sludge content C-trap	gram D.S./l	2.5
Retour sludge factor	-	0.26
Retour sludge capacity per TBT	m^3/h	965
Sludge volume index	ml/g	100
primary settler aeration	(m^3/m^2h)	2.4
C-trap (COD)	kg/(kg*d)	5
C-trap (BOD)	kg/(kg*d)	1.85
sludge supply to SDP	ton/year	1566655.67
sludge supply to SDP	ton D.S./year	6700
DSC % sludge supply	%	0.3 - 1.3
specific sludge production	kg D.S./removed i.e. TOD-150	14.36
sludge load	kg BOD/(kg D.S.*d)	0.045

Table 3: Key numbers water treatment

It is interesting to calculate the specific energy consumption for some processes such as sludge dewatering, water transport and purifying. The key numbers are shown below.

Specific energy consumption		
Sludge dewatering	kWh/ton D.S.	80
Water transport	kWh/m^3km	0.0118
Water purifying	kWh/i.e. TOD removed	23.8
Aeration	kWh/i.e. TOD removed	13.7
costs per charged i.e.	€	43.97

Table 4: Key number specific energy

Sludge dewatering is achieved by a chamber filter press. Some key numbers based on the geometry are calculated to judge the performance. The numbers are shown below.

Garmerwolde	filter press
kg wet sludge/operation	42000
kg dry solid/operation	1831.20
kg dry solid/chamber	18.50
kg dry solid /m^3 chamber	274.03
kg dry solid/min operation	16.65
kg dry solid/mm sludge cake	0.55
DSC increase/min	0.20
DSC increase/chamber	0.22

Table 5: Filter press key numbers

3.2 WWTP Heerenveen

3.2.1 Introduction

In the following paragraph the hardware of the wastewater treatment plant in Heerenveen is described. The WWTP can be divided into two main processes: the purification of the influent and the treatment of the resulting sludge. The purification is done by the WWTP and the treatment is done by the sludge dewatering plant (SDP). Both processes are done at the same location and excess sludge from the WWTP Heerenveen is treated at the SDP. However the largest amount of sludge comes from the other WWTPs supervised by Wetterskip Fryslan. The sludge dewatering plant can be divided into two sections: SDP-1 and SDP-2. This was mainly done for controlling purposes. An overall block diagram is given below where the in and out going flows are defined.

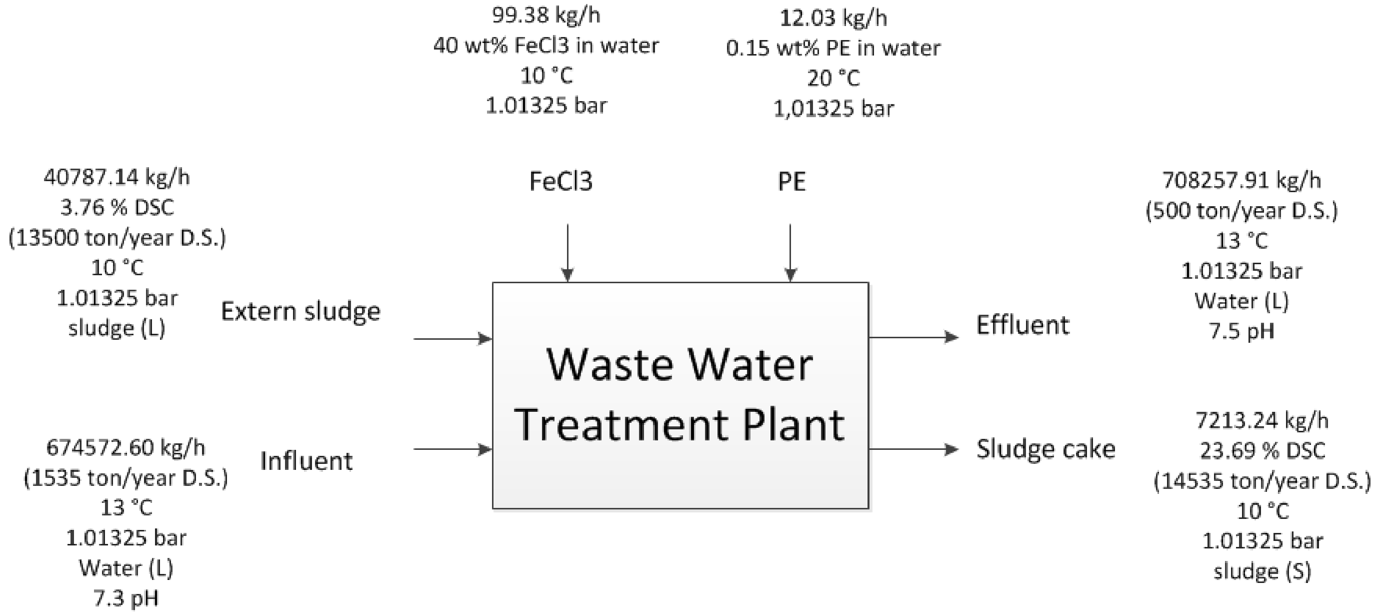


Figure 27: Overall block diagram WWTP Heerenveen

3.2.2 Hardware

In the following chapter the hardware of the wastewater treatment plant in Heerenveen is described. A process block diagram (PBD) is given in the figure below:

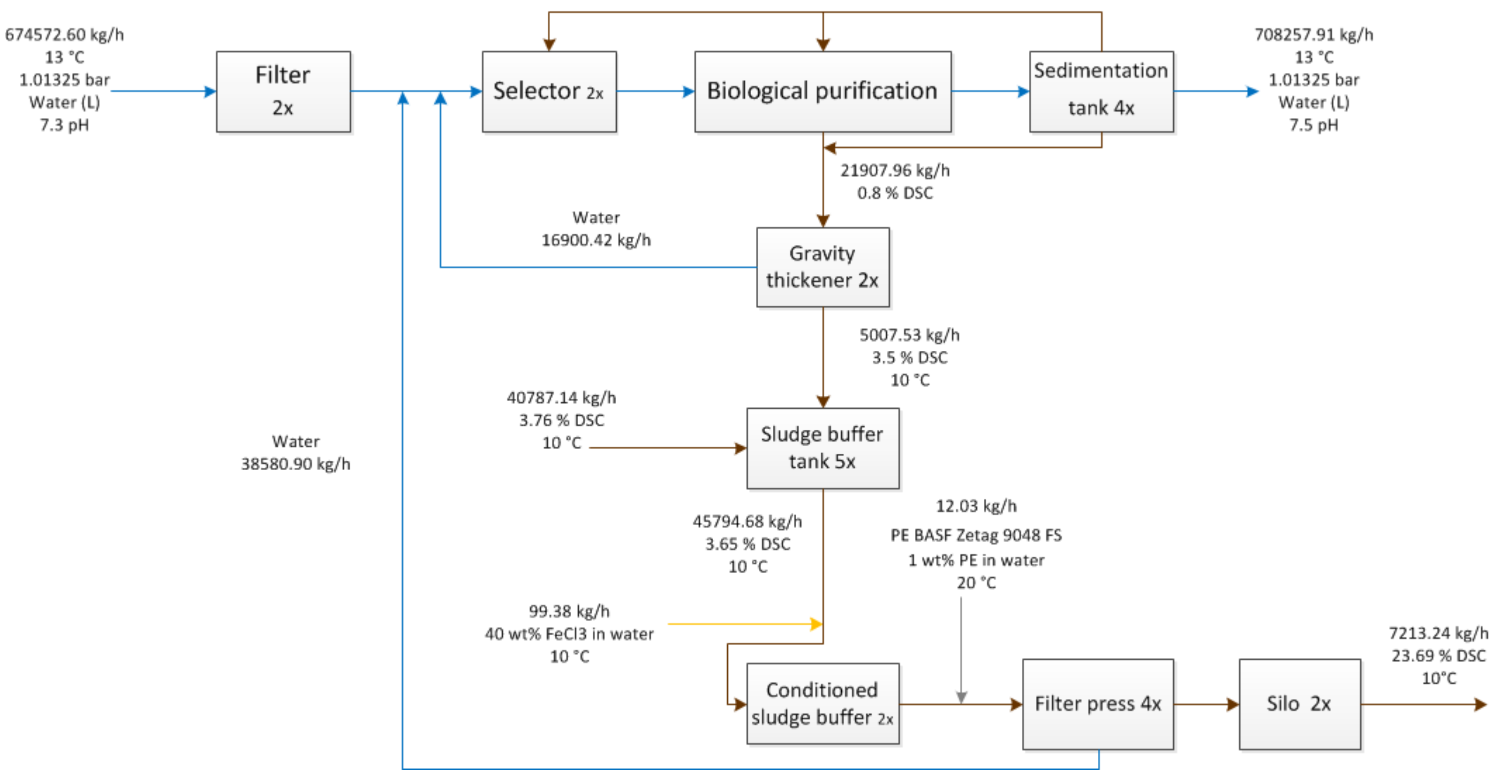


Figure 28: Process block diagram WWTP Heerenveen

Water treatment

The influent is transported by ten discharge pipes to the WWTP with a maximum of 4700 m^3/h sewage water. The pipes are made of PVC and differ in diameter between 110and355 mm. The goal of the WWTP is to remove hazardous content ammonium, nitrogen and phosphate. The influent and effluent specifications for WWTP Heerenveen are shown below:

		Influent						Effluent											Verwijderingsrendementen				
rwzi te	type	CZV	BZV	Kj.N	NH_4-N	PO_4-P	Cl^-	CZV	BZV	Kj.N	NH_4-N	NO_2-N	NO_3-N	Tot-N	PO_4-P	Cl^-	zw.st	CZV	BZV	Kj.N	Tot-N	PO_4-P
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	%	%	%	%	%
Heerenveen	AS ZLB	558	222	66,1	54,6	6,7	280	58	2,0	4,1	1,5	0,1	3,6	7,8	0,5	248	4,1	90	99	94	88	93

Figure 29: influent and effluent numbers

After arrival, the influent passes two screens with a mesh of 5 mm. As the water flows through the fine grid, the coarse particles are left behind, such as paper and plastic. When the fine grid threatens to clog the dirt is removed by means of an automatic rake. The bulky waste is transported to a hydraulic press, where it is mechanically dewatered. After passing the fine grid, the sewage water is divided into two “streets” (every “street” has a selector, an activated sludge space and two secondary settlers).

In the two selectors (645 and 880 m^3) the sewage water is intensively mixed with return sludge of the sedimentation tank. The organic compounds from the sewage can therefore be better absorbed in the sludge flakes. By choosing the correct ratio of wastewater and sludge, only bacteria will grow that settle very well. The selector provides therefore good settling properties of the sludge. A figure of a selector is shown below.

Figure 30: Selector

The mixture of wastewater and sludge is now fed to one of the two the aeration chambers (8750 and 11750 m^3). One chamber has 2 aerators (à 110 kW) and 2 propulsors. The other chamber has 3 aerators (à 110 kW) and also 2 propulsors. The five aerators and the four propulsors are controlled individually by multiple oxygen meters. By adding oxygen the contaminations are removed by bacteria. Nitrogen removal is enhanced by recycling aerated nitrate rich sludge and mixing this in the selectors with fresh sewage water. The nitrogen is also removed by nitrification, where in an aerobe environment the organic nitrogen is converted to nitrate. The nitrates are broken down in an anaerobe environment into nitrogen gas (denitrification). This is enhanced by adding methanol. Almost 90 % of the phosphate is removed from the sewage water. The residence time of the water in the active sludge spaces is two days. A figure of an aeration chamber is shown below:

Figure 31: Aeration chambers

The purified sludge- water mixture is transported to one of the four sedimentation tanks (1735, 1035, 1735 and 1990 m^2). In the funnel-shaped tanks the settable sludge is separated from the water, while the water flows via an overflow edge. The purified water, effluent, is discharged through an effluent pipe in the Nieuw Heerenveense Kanaal. The settled sludge is largely returned to the selectors and the aeration chambers. A small amount is transported to the thickeners. A figure of a sedimentation tank is shown below.

Figure 32: Sedimentation tank

The surplus sludge is transported to the two gravity settlers with a volume of 201 and 725 m^3. The sludge is stirred where the water and air bubbles will rise and the sludge settles at the bottom. The sludge is pushed to the middle of the tank by a wide, after which it is pumped to the sludge buffer basins. In the gravity thickeners the sludge is thickened from a DSC of 0.8 % to a DSC of 3.5%. The sludge has an age of 31 days.

Sludge treatment

As already noted the WWTP plant could be divided into wastewater treatment and sludge treatment. At this point, from an organizational point of view, the sludge treatment begins (SDP). The overall process can be visualised by a process flow diagram (PFD), which is shown in figure 33.The PFD is divided into two plants SDP-1 and 2, with both four sections: sludge pre-treatment (1), $FeCl_3$ (2) and PE(3) supply and sludge dewatering.

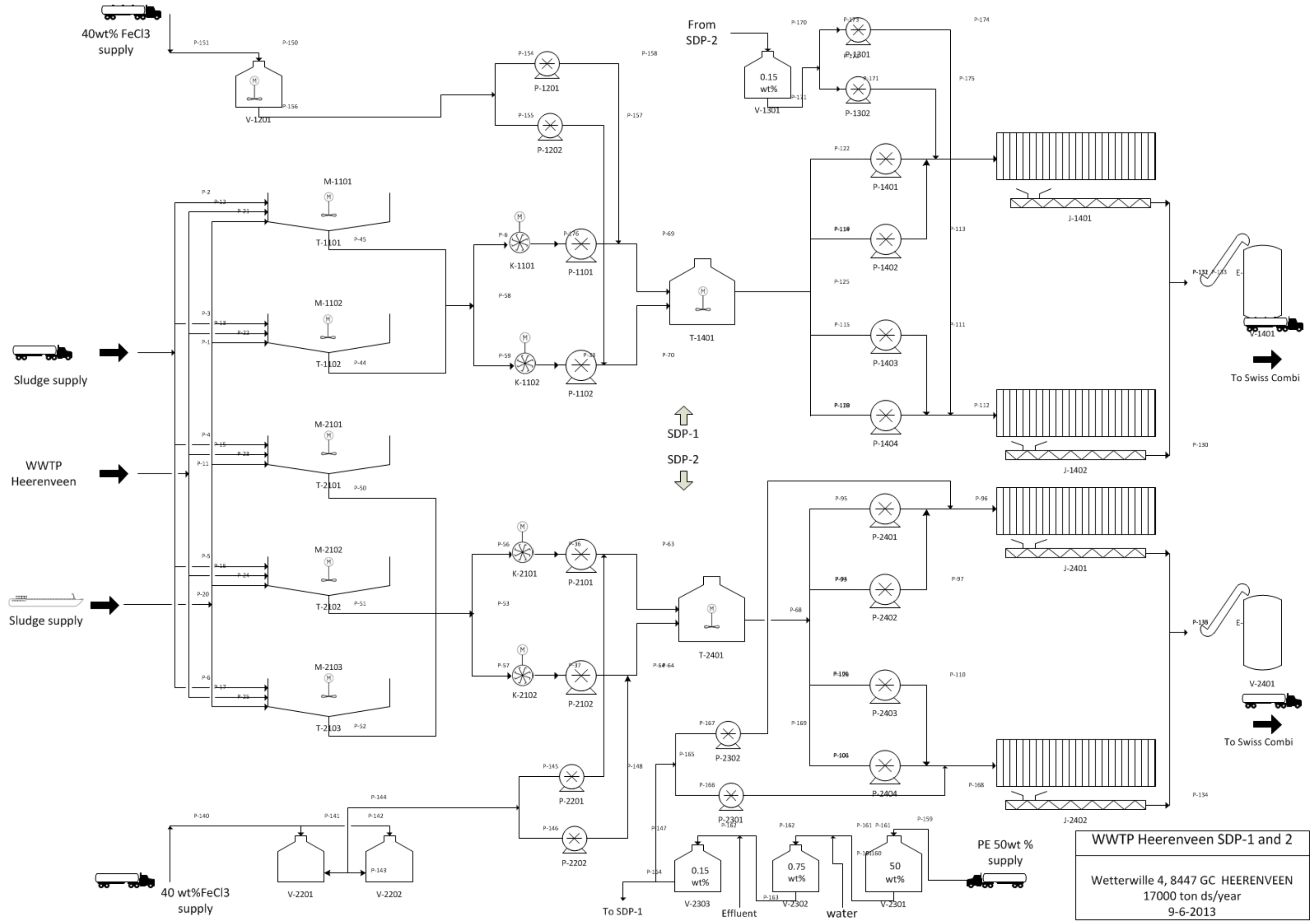


Figure 33: Process flow diagram Heerenveen (PFD)

Sludge of WWTP Heerenveen (43866 ton/year) and sludge from other WWTPs (357295.38 ton/year) are stored in five sludge buffer tanks (T-1101/1201 and T-2101/T-2102/T-2103) of 1000 m^3. The buffers are covered to prevent a nasty odour. The sludge in every tank is mixed to obtain a homogenous mixture. The average DSC is 3.65 %. Sludge is divided into four streams, where two belong to SDP-1 and two to SDP-2. The sludge then flows through a slicer (K-1101/K-1102/K-2101/K-2102) to remove remained large particles. The slicer consists of a stationary drum surrounded by rotating blades. After the slicer 55 gram $FeCl_3$/kg sludge D.S. is dosed with a 40 wt% $FeCl_3$ solution in water. The main pipes are from stainless steel type 316 with a diameter of 150 mm. The pipes used for $FeCl_3$ dosage are made from polypropylene. $FeCl_3$ is transported by tank car to the wastewater treatment plant and stored in two tanks (V-2201/V-2202) of 16 m^3. It is a 40 wt % solution in water with a pH lower than 1. The freezing point lies around -12 °C and with low temperatures the $FeCl_3$ crystallizes. Therefore the chemicals must be diluted or $FeCl_3$ tanks and pipes should have tracing. In both SDP-1 and 2 the sludge is pumped to a sludge buffer tank (T-1401/T-2401) of 40 m^3. Next the conditioned sludge is pumped into the filter press. SDP-1 has two filter presses (S-1401/S1402) with 126 chambers each. SDP-2 has two filter presses (S-2401/S2402) with 154 chambers each. A filter press from Heerenveen is shown below:

Figure 34: chamber filter press

The filter presses from SDP-1 were built in November 1988. In 1992 the two filter presses from SDP-2 were added to increase capacity. First they were membrane filter presses however in 2004 the presses were converted to chamber presses. All the filter presses are from the supplier Rittershaus & Blecher. The SDP-1 presses types are DSEH 1500, where the 1500 means the plate size. The SDP-2 presses types are AEHIS 1500. The plates in the presses are made of polypropylene. The difference between the filter presses from SDP-1 and SDP-2, besides the number of chambers, is the way of releasing the filter cake. At SDP-1 the plates are moved by a moving head that pulls out the plates one by one. At SDP-2 the plates are moved by a rotating chain, which increases the speed dramatically. Discharging of the filter cake at SDP-1 takes 18 minutes where discharging at SDP-2 takes 8 minutes. The filter cloth on the presses is from NEDfilter. The material used in the filter cloths is a polyamide called Rilsan® 11. It is a high-performance technical polymer developed by Arkema in 1942. The chemical structure is given in figure 35. The filter cloths are washed once a month. The average lifetime is around 5000-6000 charges. Every day around 9 - 10 charges per press are done, therefore the lifetime lies around 1.5 years.

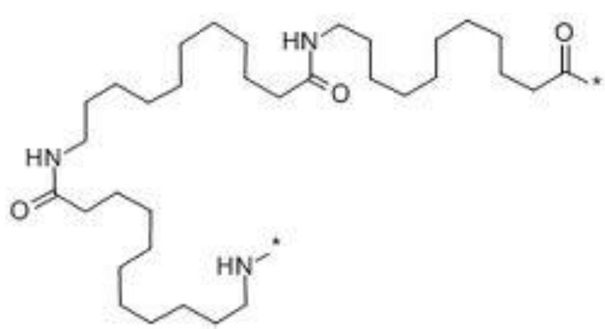


Figure 35: Rilsan® 11

Before the filter press, a 0.15 wt % PE solution in water is added at a dosage of 7 gram PE/kg sludge D.S.. The PE is from the fabricant BASF; type Zetag 9048 FS. However, soon PE from supplier VTA, type LC 76883, will be used. The MSDS of the flocculants of Garmerwolde and Heerenveen can be found in appendix C and D, respectively. The PE has a temperature of 20 °C and is initially a 48 wt% active solution. The concentration is lowered to 0.15 wt% by first adding fresh water to a concentration of 0.75 wt%. Secondly, effluent water is added to obtain the desired concentration of 0.15 wt%. The mixing of PE and sludge is done by three static mixers i.e. three valves where one is controlled manually and two automatic. By adjusting the valves a venturi effect is created that enhances mixing. A figure of the static mixers is shown below.

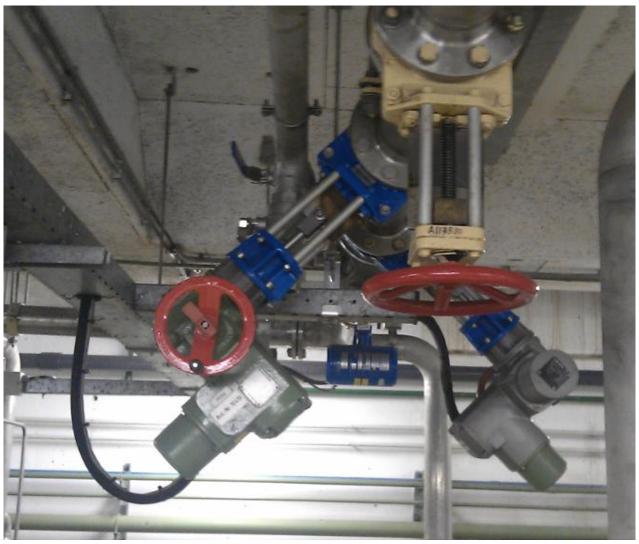


Figure 36: static PE mixer

Every batch cycle, the chamber filter presses are filled with a volume between 40 and 65 m^3. This varies due to the dry solid content and cycle time. First the pressure is build up to 8 bar by the low pressure pomp. Then the high pressure pump takes over and finishes at 15 bar. The thickness of the filter cake is 30 mm. The filtrate is drained through four exits with a diameter of 80 mm. The average pump/process time lies around 1.5 hours. The resulting sludge cake is transported by a screw to two silos with a volume of 100 and 125 m^3. The processes for sludge treatment are controlled in two control rooms, for each SDP one. There are seven operators that work in two shifts of eight hours. The process for wastewater treatment is controlled in another control room where only two operators work. The control system for the SDP is called Polykon. It was designed by the company Ciba, which is now under control of BASF. The pumps used in Garmerwolde and Heerenveen are of the same type; a progressive cavity pump. It is a positive displacement pump and transfers the fluid by a sequence of small, fixed shape, discrete cavities, as its rotor is turned. The advantage is the low amount of shearing being applied to the pumped liquid. The progressive cavity pump, used in Garmerwolde, is shown in figure 37.

Figure 37: progressive cavity pump

3.2.3 P&ID

In the previous chapters already an OBD, BDP and a PFD were shown. In the process industry also a piping and instrumentation diagram is displayed, which shows more detailed information such as the installed equipment and instrumentation. The P&ID of the sludge treatment for Heerenveen is shown below. See appendix H for more information about the equipment that is used.

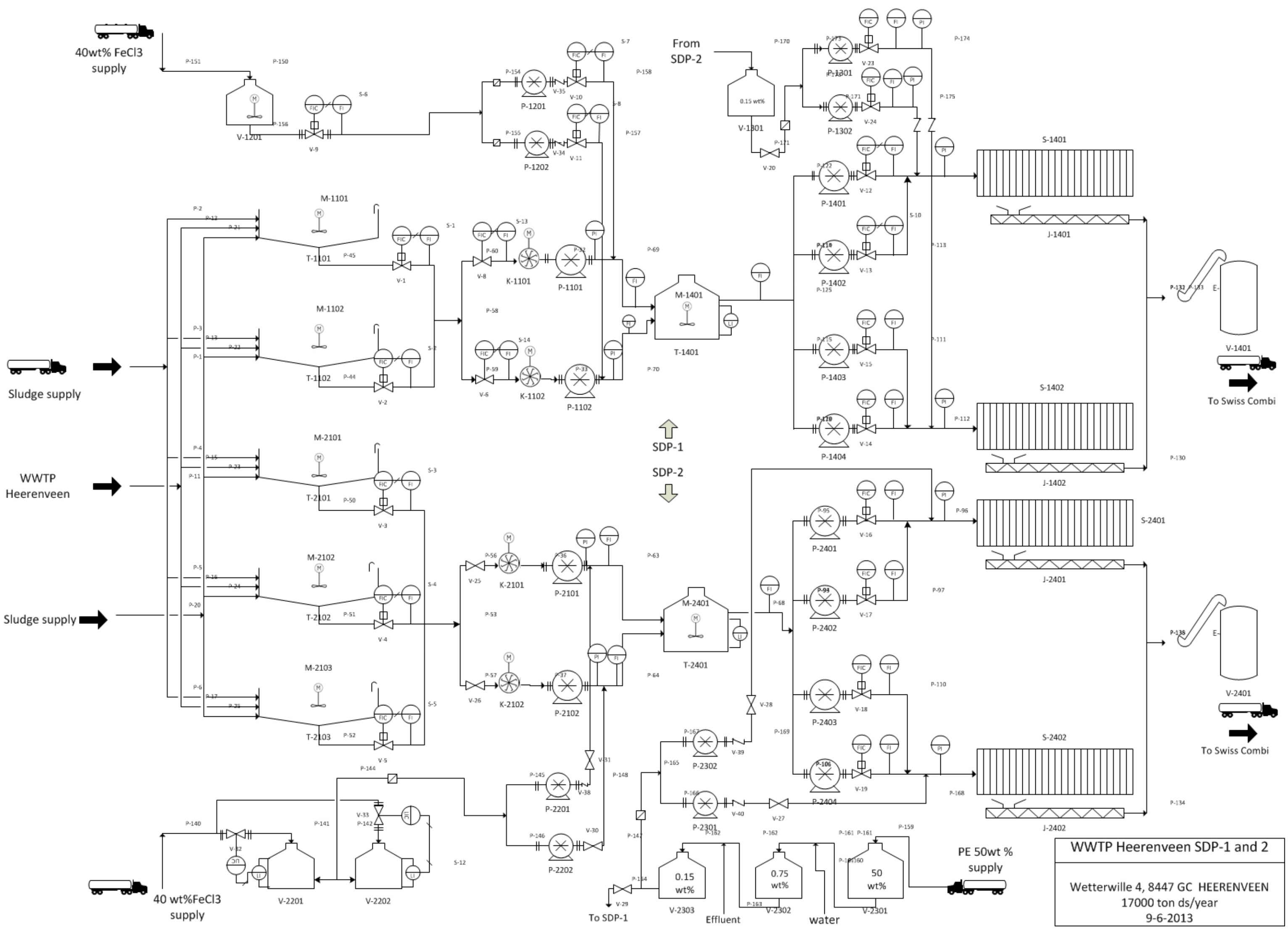


Figure 38: P&ID WWTP Heerenveen

3.2.4 Key numbers

The processes at the WWTP can be simplified by key numbers. First the kg D.S./h residence time is calculated for each process in the sludge treatment. The resulting value consists of two numbers while the residence time is variable, due to variations in input of extern sludge and sewage water.

	D.S. in tank (kg)	residence time (hours)	kg D.S./h residence time
gravity thickener	7408	42	176
sludge buffer tank	36500	24-48	760 - 1520
conditioned sludge buffer	1460	0.2 – 0.7	2086 - 1920
filter press	1460 - 2372.5	1.5	973 - 1582
silo	53302.5	24-36	1481 - 2220

Table 6: Key number kg D.S./h residence time

Key numbers considering sludge conditioning are also important. Different numbers are shown below. The amounts of PE, $FeCl_3$, D.S., wet sludge are taken between the conditioned sludge buffer tank and the filter press.

Sludge conditioning			
kg PE	12.03	**kg PE/kg $FeCl_3$**	0.12
kg FeCl3	99.38	**kg PE/kg D.S.**	0.0072
kg D.S.	1671.51	**kg Fe/kg D.S.**	0.059
purified water m^3	708.26	**kg DS/m^3 purified water**	2.36
kg wet sludge	45794.68	**kg PE/kg wet sludge**	0.00026
kg sludge cake	7213.24	**kg $FeCl_3$ /kg wet sludge**	0.0022
		kg wet sludge/kg sludge cake	6.35

Table 7: Key numbers sludge conditioning

There are also key numbers for the cost and energy used for purification of sewage water. The costs can be divided in three subjects: transport, water purification and sludge treatment. The energy used for sewage water purification is mainly used for aeration. See table 8 and 9 for the numbers.

transport sewage water (€)	5996166
Purification sewage water (€)	24908764
sludge treatment(€)	10129099
total (€)	41034029
costs removed per TOD i.e. 150	43.98
costs per charged i.e.	46.11

Table 8: Key numbers costs

Total energy consumption	kWh	2465597
aeration consumption	kWh	1971383
part aeration consumption	%	80
energy consumption other than aeration	Wh/m^3	84
specific consumption purifying	kWh/i.e. TOD removed	28.6
specific consumption aeration	kWh/i.e. TOD removed	22.8

Table 9: Key numbers energy consumption

There is also energy used for the sludge treatment. The key numbers calculated are shown below.

Total energy consumption	kWh	610892
specific consumption sludge	kWh/m^3 sludge	1.50
	kWh/ton sludge D.S.	40.8

Table 10: Key numbers

Sludge from the wastewater treatment plant Heerenveen has different properties and key numbers than the total sludge that is dewatered. The key numbers for Heerenveen and total sludge are given below.

sludge data Heerenveen		
sludge load	kg COD/kg D.S. * d	0.080
sludge load	kg BOD/kg D.S. * d	0.032
sludge load	kg KjN/kg D.S. * d	0.009
sludge content	g/l	5.3
sludge index	ml/g	84
sludge age	d	31
sludge supply to SDP	kg/year	43866000
sludge supply to SDP	kg D.S./year	1535310
DSC sludge supply	%	3.5
specific sludge production	kg D.S./removed i.e. TOD-150	14.6

Table 11: Key numbers sludge Heerenveen

production sludge	
sludge dewatering (kg)	401161380
in kg D.S.	14642390.37
dry solid lost via effluent ton D.S.	503
production kg sludge/i.e. removed	16.1

Table 12: Key numbers sludge before filter press

There are also a few key numbers of the filters based on the geometry. The numbers are calculated for both SDP-1 and SDP-2, because the filter press geometry and capacity differ.

	SDP-1	SDP-2
kg wet sludge/operation	45000	60000
kg dry solid/operation	1642.50	2190
kg dry solid/chamber	13.04	14.22
kg dry solid /m^3 chamber	193.12	210.68
kg dry solid/min operation	18.25	24.33
kg dry solid/mm sludge cake	0.43	0.47
DSC increase/min	0.22	0.22
DSC increase/chamber	0.16	0.13

Table 13: Key numbers filter press

4. Experimental

4.1 Introduction

Last year the student T. Stoffelsma did a bachelor research to develop a flocculation methodology. He made test equipment where flocculation was made visible. My goal was to use this equipment to see if the process conditions for sludge conditioning in the wastewater treatment plants are the optimum conditions. The operational conditions at the plants for adding coagulant and flocculent are as follows:

Garmerwolde

- Coagulant: 40 wt% $FeCl_3$ in water with a dosage of 65 gram/kg sludge D.S.
- Flocculent: 1 wt% PE in water with a dosage 7.5 gram/kg sludge D.S.

Heerenveen

- Coagulant: 40 wt% $FeCl_3$ in water with a dosage of 55 gram/kg sludge D.S.
- Flocculent: 0.15 wt% PE in water with a dosage 7.0 gram/kg sludge D.S.

In the flocculation equipment the dosage of coagulant and flocculent can be varied. Therefore the optimum conditions can be found.

4.2 Preparations

4.2.1 Equipment

- Prototype flocculation rack (see figure 39)
- beaker glasses
- Magnet stirrer

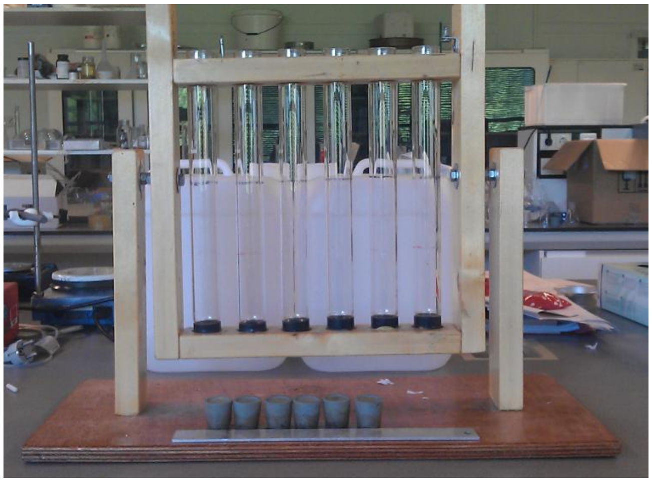


Figure 39: Flocculation set-up

4.2.2 Chemicals

- Sludge from Heerenveen and Garmerwolde (see for MSDS appendix E)
- 1 wt% PE in water (Kemira Superfloc C-82089)
- 40 wt% $FeCl_3$ in water
- Water

4.2.3 Assumptions

Before the experiments could take place some assumptions were made. In both WWTPs a 40 wt% $FeCl_3$ solution is added to the sludge stream. In the experiments the amount of sludge is very low and therefore also the amount of $FeCl_3$ that has to be added. Accuracy in these experiments is very important and that is why the 40 wt% $FeCl_3$ solution is diluted to a 4 wt% $FeCl_3$ solution. The same is done for the PE solution. The 1 wt% PE solution is diluted to a 0.1 wt% solution.

The amount of sludge added in each cylinder is around 100 ml. In preliminary experiments it was clear that the visibility of coagulation and flocculation was very low. The resulting flakes where nearly invisible. Therefore some experiments were done to obtain the right dilution of sludge where flakes could be seen well after adding $FeCl_3$ and PE. It was chosen to dilute the sludge to a 10 wt% solution in water. This is the same result that T. Stoffelsma recommended in his thesis (Stoffelsma, 2012).

The flocculation rack consists of six glass tubes where sludge is added. After addition of an amount of coagulant and flocculent flakes become visible. It is very hard to make an objective choice between six tubes, where the flakes are nearly the same. Therefore a methodology for flake observation was made. Four parameters that are important for mechanically dewatering sludge are flake size, amount of flakes, water separation and flake stability. In the optimum case there are a few large flakes with a good water separation and a high stability. The first three parameters can be seen visually. The flake stability is determined after fierce revolutions. The four parameters are assessed according to the mathematical symbols plus and minus. Four options are therefore available for each parameter. The options are specified below.

	flake size	amount of flakes	water separation	flake stability
++	large	few	excellent	excellent
+	medium	several	good	good
-	small	many	moderate	moderate
--	none	a lot	none	poor

Table 14: Flocculation parameters

4.2.4 Experimental method

Prepare a 10 wt% sludge solution by mixing 60 ml sludge with 540 ml water. Stir the solution on a magnetic stirrer to get an uniform distribution of sludge. Put in each tube 100 ml sludge solution. Add the desired amount of coagulant to all tubes. The coagulant and flocculent calculations for dosage can be found in appendix A. Close the tubes with plugs and close the test equipment by turning the butterfly nut. Turn the test equipment upside down 8 times, which are 4 revelations. Coagulation should cause some flocculation already and this should be visible. Be careful when opening the tubes, while pressure may build up and sludge may spray out. Wait for 3 minutes for all the CO_2 to disappear. Next add the desired amount of flocculent to all tubes. Again close the tubes with plugs and the butterfly nut. Turn the test equipment upside down for two times. This results in 1 revelation. Let the flakes settle for 5 minutes and visually inspect the flake size, amount of flakes and the water separation for each tube. Next close the tubes again and turn the test equipment upside down for 14 times, which results in 7 revelations. Visually inspect the flake size and report the stability.

5. Results and Discussion

5.1 Introduction

In this chapter the results of the described experiments are presented. The results are analysed and discussed for possible explanations. In addition the results of the process overview are discussed. The processes are compared and the main differences will be summarized.

5.2 Coagulation and flocculation experiments

5.2.1 Garmerwolde

As stated in section 4.2.4 the coagulation and flocculation dosage was varied. The coagulant dosage was varied between 15 and 215 gram $FeCl_3$/kg sludge D.S.. In each experiment the process condition was situated in one tube for comparison. The flocculent dosage was varied between 5.5 and 14.5 gram PE/kg sludge D.S.. In each experiment a different dosage of coagulant and a constant dosage of flocculent were added to each tube. The first batch sludge used from Garmerwolde had a DSC of 3.72%, but the second batch had a DSC of 4.43 %.

After addition of six different dosages of $FeCl_3$ and a number of revelations the coagulation was examined. The coagulation for the dosage of 15-215 $FeCl_3$/kg sludge D.S. can be seen in figures below.

Figure 41: 15-65 $FeCl_3$ /kg D.S.

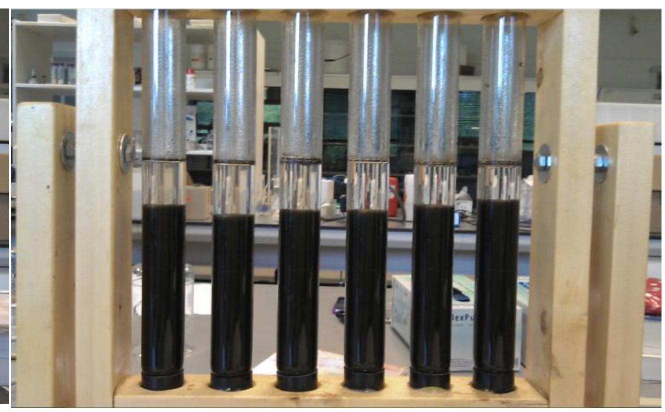


Figure 40: 65, 75-115 $FeCl_3$/kg D.S.

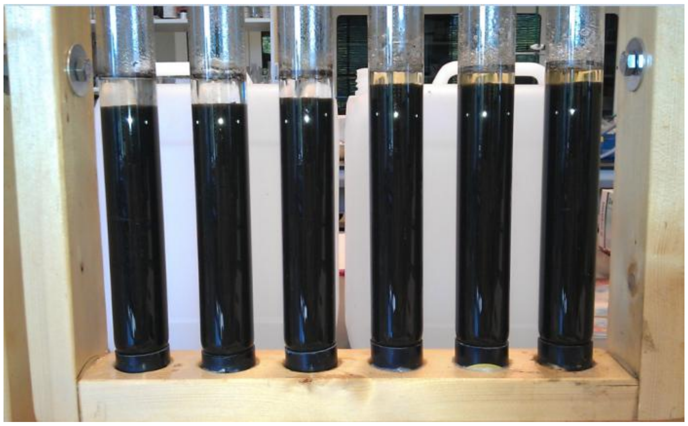


Figure 43: 65, 125-165 $FeCl_3$/kg D.S.

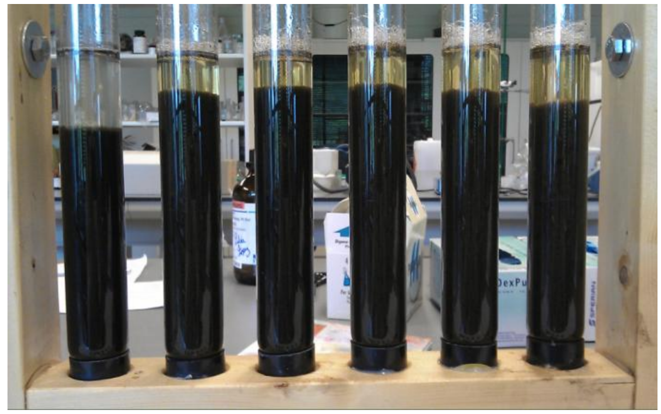


Figure 42: 65, 175-215 $FeCl_3$/kg D.S.

It can be seen that at a very low dosage (15-35 $FeCl_3$/kg sludge D.S.) the negative colloidal particles are not destabilized enough and a lot of suspended particles are present. Enough $FeCl_3$ addition causes the destabilized particles to settle down. At a point of 145 $FeCl_3$/kg sludge D.S. the water colour turned yellow, which became brighter with increasing dosage.

To the four coagulant batches above the same amount of PE was added in each tube. With the visual model, explained in section 4.2.3 the resulting flakes were examined and compared. For every dosage PE an optimum with a dosage $FeCl_3$ was obtained. The optimums are given below.

Optimum	$FeCl_3$ (g/kg sludge D.S.)	PE (g/kg sludge D.S.)
1	75	5.5
2	75	6.5
3	85	7.5
4	85	8.5
5	75	9.5
6	75	10.5
7	75	11.5
8	145	12.5
9	175	13.5
10	135	14.5

Table 15: Optimums for each PE dosage

These optimums generated the best flakes, based on flake size, amount of flakes, water separation and flake stability. However there are large differences between the optimums. For example the optimums with 5.5, 6.5 and 14.5 PE generated the best results for their experiments however flakes were nearly present.

To determine the best dosage, the above dosages were compared in a final experiment. The resulting flocculation in the tubes is shown in figure 44.

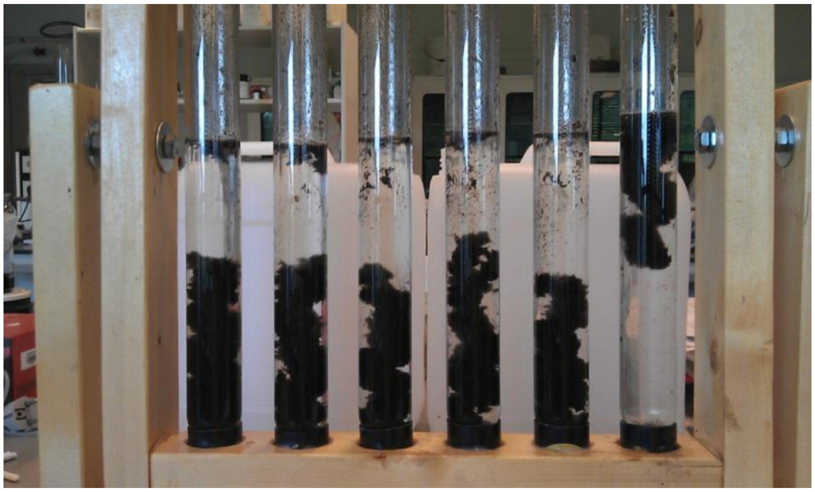


Figure 44: optimums 3-9

It can be seen that in each tube the water separation is quite high. In the most right tube the flakes moved above due to gas bubbles, however after some time the flakes settled. After close examination tube six had the best flakes according to the four parameters. Therefore, for the sludge in Garmerwolde addition of $FeCl_3$ with a dosage of 145 gram $FeCl_3$/kg sludge D.S. and addition of PE with a dosage of 12.5 gram PE/kg sludge D.S. resulted in the optimum flocculation.

5.2.2 Heerenveen

Also for sludge from Heerenveen the optimum flocculation was determined by varying the dosage of coagulant and flocculent. The coagulant dosage was varied between 15 and 125 gram $FeCl_3$/kg sludge D.S.. The flocculent dosage was varied between 5 and 12 gram PE/kg sludge D.S.. In each experiment a different dosage of coagulant and a constant dosage of flocculent were added to each tube. The batch sludge used from Heerenveen had a DSC of 3.47 %.

The coagulation for the dosage of 15-125 $FeCl_3$/kg sludge D.S. can be seen in figures below.

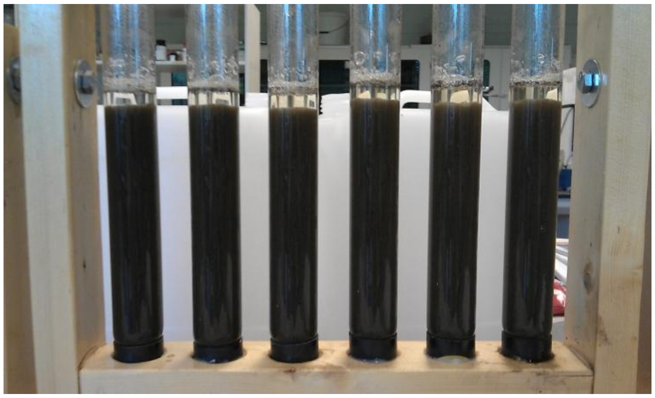


Figure 45: 15-65 $FeCl_3$/kg D.S.

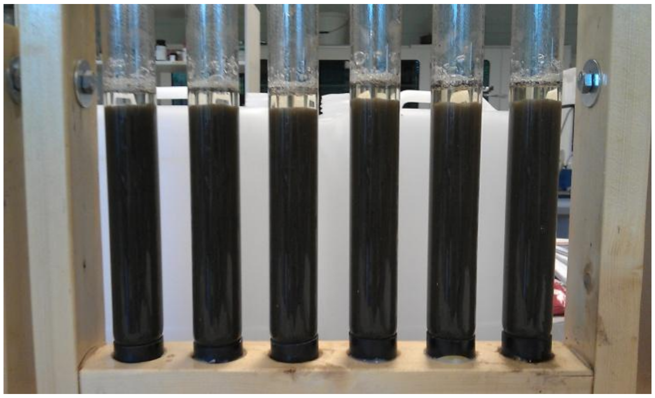


Figure 46: 75-125 $FeCl_3$/kg D.S.

The $FeCl_3$ dosage was less varied due to seemingly strong influence of $FeCl_3$ with Heerenveen sludge. After a dosage of more than 105 gram $FeCl_3$/kg sludge D.S. no flakes were formed no matter the amount of PE added.

To the two batches above the same amount of PE was added in each tube. With the visual model, explained in section 4.2.3 the resulting flakes were examined and compared. For every dosage PE an optimum with a dosage $FeCl_3$ was obtained. The optimums are given below.

Optimum	$FeCl_3$ (g/kg sludge D.S.)	PE (g/kg sludge D.S.)
1	65	5
2	65	6
3	65	7
4	65	8
5	65	9
6	65	10
7	65	11
8	65	12

Table 16: Optimums for PE dosage

It is notable to see that a dosage of 65 gram $FeCl_3$/kg sludge D.S. is the optimum dosage of $FeCl_3$ for each optimum. To determine the best dosage, the above dosages were compared. The resulting flocculation in the tubes is shown in figure 47.

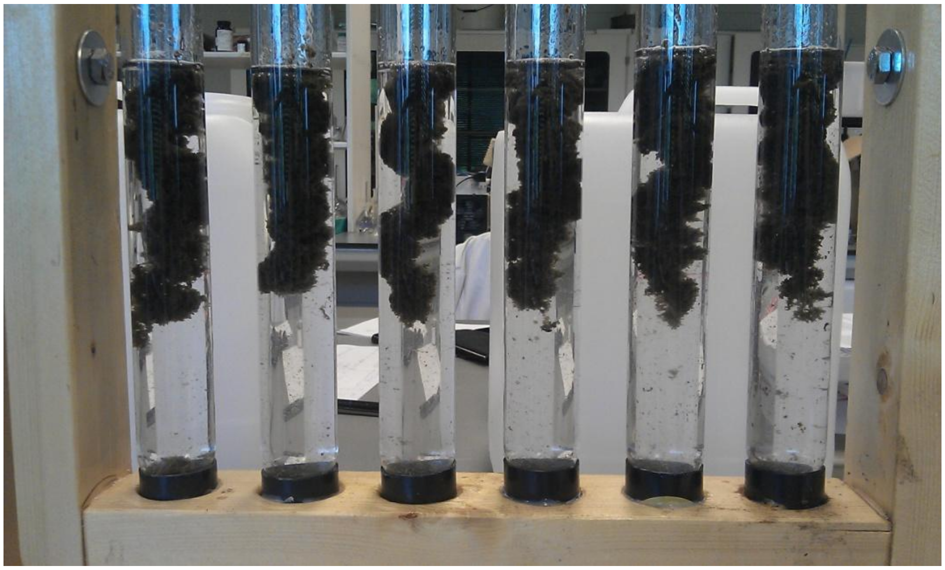


Figure 47: Optimums 2-7

The resulting flakes in the tubes all moved up, but again after some time they settled. After examination, tube 2 was the ultimate optimum. For sludge from Heerenveen addition of $FeCl_3$ with a dosage of 75 gram $FeCl_3$/kg sludge D.S. and addition of PE with a dosage of 7 gram PE/kg sludge D.S. resulted in the optimum flocculation.

There were also quite some differences in sludge properties between Garmerwolde and Heerenveen. Sludge from Heerenveen smelled more and had a brown colour, where sludge from Garmerwolde had a deep black colour. In contrast to sludge from Garmerwolde, sludge from Heerenveen settled (water separation was visible) after a period of time. Also sludge from Heerenveen was very sensible for overdosing of $FeCl_3$.

5.2.3 Discussion

For the sludge in Garmerwolde an optimum for coagulant and flocculent addition (145 gram $FeCl_3$/kg sludge D.S.; 12.5 gram PE/kg sludge D.S.) was found with the flocculation rack. However the process conditions (65 gram $FeCl_3$/kg sludge D.S.; 7.5 gram PE/kg sludge D.S.) are quite different. First it should be noted that sludge, $FeCl_3$ and PE were diluted to ensure accuracy and visibility. However it is not known what influences this has for flocculation. Now a lot more water is present and resulting flakes have less interaction, which can cause smaller flakes. It should also be noted that the reproducibility for Garmerwolde sludge was low. When experiments were done duplo, results were quite different sometimes. There are many variables that may influences flocculation such as sludge age, dilution, temperature, DSC and sludge origin. However the resulting optimum is based on multiple experiments, but the usefulness is uncertain.

For the sludge in Heerenveen an optimum for coagulant and flocculent addition (75 gram $FeCl_3$/kg sludge D.S.; 7 gram PE/kg sludge D.S.) was found with the flocculation rack. This is quite similar to the process conditions (55 gram $FeCl_3$/kg sludge D.S.; 7 gram PE/kg sludge D.S.). The reproducibility was very high; each duplo experiment had the same results. These results could be implemented in the WWTP process to obtain higher dry solid contents of the sludge cake after dewatering.

Conclusions of experiments with the flocculation rack are based on visual determinations of the resulting flakes. In these experiments only small variations of the concentrations of $FeCl_3$ and PE were used. Therefore it was hard to conclude the best flocculation without quantitative results. In a WWTP, flocculation and the filter press are used to obtain the highest dry solid content of the sludge as possible. When flocculation should be measured, the dry solid content after filtration is a quantitative result and therefore a parameter for flocculation. However it might be difficult to know in which dosage region of $FeCl_3$ and PE flocculation occurs. In that case, the flocculation rack is a very convenient and useful tool to determine this region.

5.3 Main differences between the WWTPs

5.3.1 Water treatment

The systems used for the purification of sewage water are quite different between Heerenveen and Garmerwolde. WWTP Heerenveen uses a circulation system called carrousel, where the sewage water/active sludge mixture goes many times around in the aeration space. A schematic figure of a carousel process is given below.

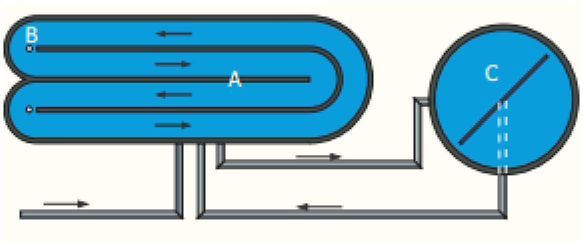


Figure 48: Carrousel system

The system used in Garmerwolde is a two stage activated sludge system (AB system). It consists of a highly loaded first stage with a primary settler and a low loaded second stage with secondary settler (Delft, 2012). Due to the AB system, there are two sludge surplus streams with different dewatering properties. A figure is shown below.

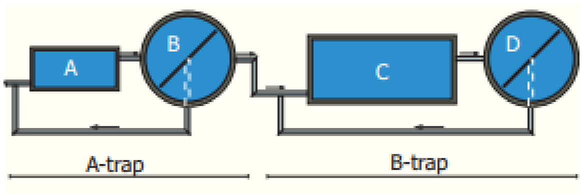


Figure 49: AB system

The most important properties of both wastewater treatment plants are shown in the table 17. WWTP Garmerwolde processes 4.3 times more sewage water than Heerenveen and has clearly a higher capacity.

	Garmerwolde	**Heerenveen**
average sewage water (m^3/day)	70000	16190
type	AB system	carrousel
Biological capacity (136 gr.TOD/day)	375161	143000
Max. RWD (m^3/h)	13500	4700

Table 17: Water treatment

Both Garmerwolde and Heerenveen processes own and extern sludge. An overview is given below.

	Garmerwolde	Heerenveen
WWTP primary sludge (kg/h)	156012.18	-
WWTP primary sludge (ton D.S./year)	4100	-
DSC (%)	0.3	-
WWTP secondary sludge (kg/h)	22831.05	5007.53
WWTP secondary sludge (ton D.S./year)	2600	1535
DSC (%)	1.3	3.5
extern undigested (kg/h)	22831.05	31978.27
extern undigested (ton D.S./year)	6400	9000
DSC (%)	3.2	3.76
extern digested (kg/h)	13575.22	13816.41
extern digested (ton D.S./year)	4400	4500
DSC (%)	3.7	4.51
total before filter press (kg/h)	34948.96	45794.68
Total before filter press (ton D.S./year)	13200	15035
DSC (%)	4.36	3.65
total after filter press (kg/h)	5736.44	7213.24
total after filter press (ton D.S./year)	13000	14535
DSC (%)	25.87	23.69

Table 18: Sludge streams

5.3.2 Sludge pre-treatment

Primary and secondary sludge from WWTP Garmerwolde are thickened by a gravity settler and a belt thickener, respectively. Undigested sludge from other wastewater treatment plants is mixed with secondary sludge and therefore also thickened by a belt thickener. In Heerenveen only one sludge stream exists, which is thickened by a gravity settler. The main difference is after these steps. In Garmerwolde, primary and secondary sludge are digested in two large digestion tanks. This results in a uniform sludge stream with a relative constant dry solid content. At WWTP Heerenveen, own sludge isn't digested but mixed with sludge from other plants. The WWTP at Franeker, Leeuwarden, Drachten and Burgum only digest their sludge. The sludge from Leeuwarden and Burgum is treated complete separately and isn't mixed with other sludge, due to the very low dewatering ability. The sludge content of sludge in Heerenveen varies due to different delivery times of the sludge from other WWTP. Therefore also the dry solid content in the sludge stream to the filter press is not constant. The coagulant and flocculent dosage is based on the dry solid content and therefore have to be adjusted constantly. Therefore the optimal flocculation is probably not achieved. A more mixed and constant stream is favourable. The important properties are shown in table 19.

	Garmerwolde	Heerenveen
gravity thickeners	2	2
belt thickeners	2	0
Digestion tanks	2	0
DSC	4.7 %	3.5 %

Table 19: sludge pre-treatment

5.3.3 Sludge Conditioning

Before sludge is mechanically dewatered by a filter press, it is conditioned with a coagulant and a flocculent. The process conditions are shown in table 20.

	$FeCl_3$	gram/kg sludge D.S.	PE	gram/kg sludge D.S.
Garmerwolde	40 wt%	65	1 wt%	7.5
Heerenveen	40 wt%	55	0.15 wt%	7

Table 20: sludge conditioning

The coagulant is mixed in a sludge conditioning tank. The residence times are quite similar for Garmerwolde (0.8 hours) and Heerenveen (0.5 - 0.7 hours). The mixing (4 rpm - 6 rpm) is done by a rotary two-sided blade. The coagulant must be dispersed by high-energy mixing to promote particle collisions and achieve good coagulation. Over-mixing does not affect coagulation, but insufficient mixing will leave this step incomplete (MWRA, 2008). The Reynolds number can give an indication of the mixing efficiency. The Reynolds number in the conditioned sludge tank can be calculated with formula 6 (Akker & Mudde, 2008). The system is fully turbulent for values of Re above 10000.

$$Re = \frac{\rho * N * D^2}{\mu} \qquad (6)$$

With:
ρ = density of liquid (kg/m^3)
D = diameter of agitator (m)
N = rotational speed (rad/s)
μ = viscosity (Pa.s)

The Reynolds number for both Heerenveen and Garmerwolde is calculated with the following data.

	Heerenveen	Garmerwolde
density (kg/m^3)	1000	1000
diameter propeller (m)	0.95	0.95
viscosity (Pa.s)	0.0013 (10 °C)	0.0010 (20 °C)
speed (rpm)	6	4
Rotational speed (rad/s)	0.63	0.42
Reynolds number	**433532**	**377285**

Table 21: coagulation Reynolds number

Probably the most important difference is the mixing of poly electrolyte. In Garmerwolde this is done by a dynamic mixer, where PE is intensively added to the sludge flow by a rotating arm with a speed of 1400-1500 rpm. In Heerenveen addition is done by a static mixer, where three valves are positioned in series. Mixing is achieved, due to venturi effects. Flocculation requires careful attention to the mixing velocity and amount of mixing energy. When two fluids have to mix, the Reynolds number should be above 4000, because then the flow is turbulent. The Reynolds number for a flow in a pipe can be calculated with the formula below (Akker & Mudde, 2008).

$$Re = \frac{\rho * d * v}{\mu} \qquad (7)$$

With:
ρ = density of liquid (kg/m^3)
d = diameter of pipe (m)
v = flow speed liquid (m/s)
μ = viscosity (Pa.s)

The Reynolds number before and after the mixing process will be calculated. The viscosity changes due to the resulting flakes. Therefore after addition of PE it is assumed that the viscosity has the same value as glycerine. The data and resulting Reynolds numbers are shown below.

	Heerenveen	Garmerwolde
density (kg/m^3)	1000	1000
diameter pipe (m)	0.15	0.16
viscosity (Pa.s)	0.0013 (10 °C)	0.0010 (20 °C)
flow speed (m/s)	6	4
Rotational speed (rad/s)	0.86	0.55
Reynolds number (before)	99145.11	88242.93
viscosity (Pa.s)	0.0045	0.0045
Reynolds number (after)	28818.18	19648.76

Table 22: flocculation Reynolds number

Both the sludge streams of Heerenveen and Garmerwolde have a turbulent flow before and after mixing. It can be seen that the Reynolds number of Heerenveen after mixing is quite higher than Garmerwolde. However the turbulence created by the static or dynamic mixer is not included in the calculation. The dynamic mixer in Garmerwolde probably increases the turbulence significantly due to a rotating arm (1400-1500 rpm), which adds polyelectrolyte. Anyway the sludge flow is turbulent and therefore mixing occurs. However sludge flakes are very sensitive to shear forces and therefore the turbulence should not be too high. (S.J.Langer & R.Klute, 2010)

How much influence the distance between the PE addition and filter press has, is difficult to say. The time for mixing is increased, however the resulting flakes are very sensible to shear forces and flake size can be decreased. Also the temperature of sludge, PE and $FeCl_3$ may have influence on the flocculation (Stamperius, J.P.Kruissink, & P.J.Roeleveld, 2000). In Garmerwolde the temperature of the sludge will be around 25 °C due to the remaining heat of the digestion. In Heerenveen the temperature will be similar to the ambient temperature.

An overview of the mixing is given in table 23.

	Garmerwolde	Heerenveen
PE	Kemira, C-82089	BASF, zetag 9048 FS
mixing	dynamic	static
distance before press (m)	1	13
pipe diameter (mm)	160	150
MOC pipe	polypropylene	stainless steel type 316

Table 23: properties of PE mixing

5.3.4 Filter press

The filter press is used to mechanically dewater the sludge. The SDP in Heerenveen processes 1.3 times more sludge than Garmerwolde. The properties of the filter press for Heerenveen are shown in table 24 and for Garmerwolde in table 25. The dry solid content of the sludge cake is higher for Garmerwolde (Δ 2.18 %); however dry solid content of the incoming sludge is also higher (Δ 0.71 %). The filter press operation for both plants is the same. The pressure is first increased by the low pressure pump to 8 bar and then by the high pressure pump to 15 bar. The pressure curves are shown in appendix G.

Heerenveen	SDP-1	SDP-2
supplier	Rittershaus & Blecher	Rittershaus & Blecher
number	2	2
type	DESH-1500	AEHIS-1500
number of plates	127	155
plate material	polypropylene	polypropylene
plate size (mm)	1500x1500	1500x1500
Filtration pressure (bar)	15	15

power total (kW)	10.3	9.2
filter cloth	NEDfilter	NEDfilter
cake thickness (mm)	30	30
capacity (m^3/h)	40-65	40-65
operation time (min)	90	90
discharge time (min)	18	8
total sludge before filter press (kg/h)	45794.68	
DSC (%)	3.65	
total sludge after filter press (kg/h)	7213.24	
DSC (%)	23.69	

Table 24: Filter press properties Heerenveen

Garmerwolde		
supplier	Rittershaus & Blecher	Passavant
number	3	2
number of plates	92	105
plate material	polypropylene	polypropylene
plate size (mm)	1500x1500	1500x1500
Filtration pressure (bar)	15	15
filter cloth	NEDfilter/Finsa	NEDfilter/Finsa
cake thickness (mm)	30	30
capacity (m^3/h)	35-45	35-45
operation time (min)	110	110
discharge time (min)	13	14
total sludge before filter press (kg/h)	34948.96	
DSC (%)	4.36	
total after filter press (kg/h)	5736.44	
DSC (%)	25.87	

Table 25: Filter press properties Garmerwolde

5.3.5 Key numbers

For a good comparison of flocculation and filtration different key numbers are calculated for both wastewater treatment plants. WWTP Garmerwolde uses a lot more processes for sludge treatment than Heerenveen, therefore a comparison is difficult. The key numbers given for the flocculation and filtration in the process descriptions of both wastewater treatment plants are now compared.

Flocculation

The key numbers for flocculation are given in the table below.

	Heerenveen	Garmerwolde
kg PE/kg $FeCl_3$	0.12	0.12
kg PE/kg D.S.	0.0072	0.010
kg $FeCl_3$/kg D.S.	0.059	0.098
kg D.S./m^3 purified water	2.36	0.52
kg PE/kg wet sludge	0.00026	0.00043
kg $FeCl_3$/kg wet sludge	0.0022	0.0037
kg wet sludge/kg sludge cake	6.35	6.07

Table 26: comparison flocculation

It can be seen that Garmerwolde uses a lot more coagulant and flocculent than Heerenveen. In a year, the amount of cost for sludge conditioning is higher. However if this results in a reduction of further processing costs of sludge, the costs may balance. The key numbers also show that ratio between wet sludge/sludge cake is almost the same for Heerenveen and Garmerwolde. This was not expected while Heerenveen processes 1.3 times more sludge. However the sludge cake from Garmerwolde has a higher dry solid content.

Filtration

The key numbers for filtration are given in the table below.

	Garmerwolde	Heerenveen
kg wet sludge/operation	42000	52500
kg dry solid/operation	1831.20	1916.25
kg dry solid/chamber	18.50	13.63
kg dry solid /m3 chamber	274.03	201.90
kg dry solid/min operation	16.65	21.29
kg dry solid/mm sludge cake	0.55	0.45
DSC increase/min	0.20	0.22
DSC increase/chamber	0.22	0.14

Table 27: comparison filtration

It can be seen that the filter press in Garmerwolde has the highest increase of DSC/chamber. However the DSC/min is lower than in Heerenveen. Still, it can be concluded that the filter presses in Garmerwolde have a higher efficiency.

6. Plant design

6.1 Introduction

Sludge conditioning (coagulation and flocculation) is done by adding $FeCl_3$ and PE based on the dry solid content of the sludge flow. In Garmerwolde the dry solid content of the sludge is relatively constant due to fact that all sludge is digested. However in Heerenveen the dry solid content varies due to the different origins of the sludge and no uniform mixing process. Therefore dosage based on dry solid content isn't accurate enough. A different method based on the turbidity could be an option (M.Boesten). In this chapter a design proposal is given of an on-line measurement and control system for coagulation and flocculation based on a measurement of turbidity in a parallel measurement. First the Basis of Design (BoD) will be completed with information of the on-line turbidity measurement system. Then the system will be explained and schematically given in a process flow diagram. The design will be based on the WWTP in Heerenveen.

6.2 Basis of Design (BoD)

DESIGN BASIS FOR	INFORMATION **DESIGN BASIS**
Turbidity measurement system	BA turbidity meter **Conceptual Engineering**
PROJECT: **0001**	
Approved: Process Eng. Dept.: RUG Client : Wetterskip Fryslan	Date of issue: 24-6-2013 Page 61 of 34

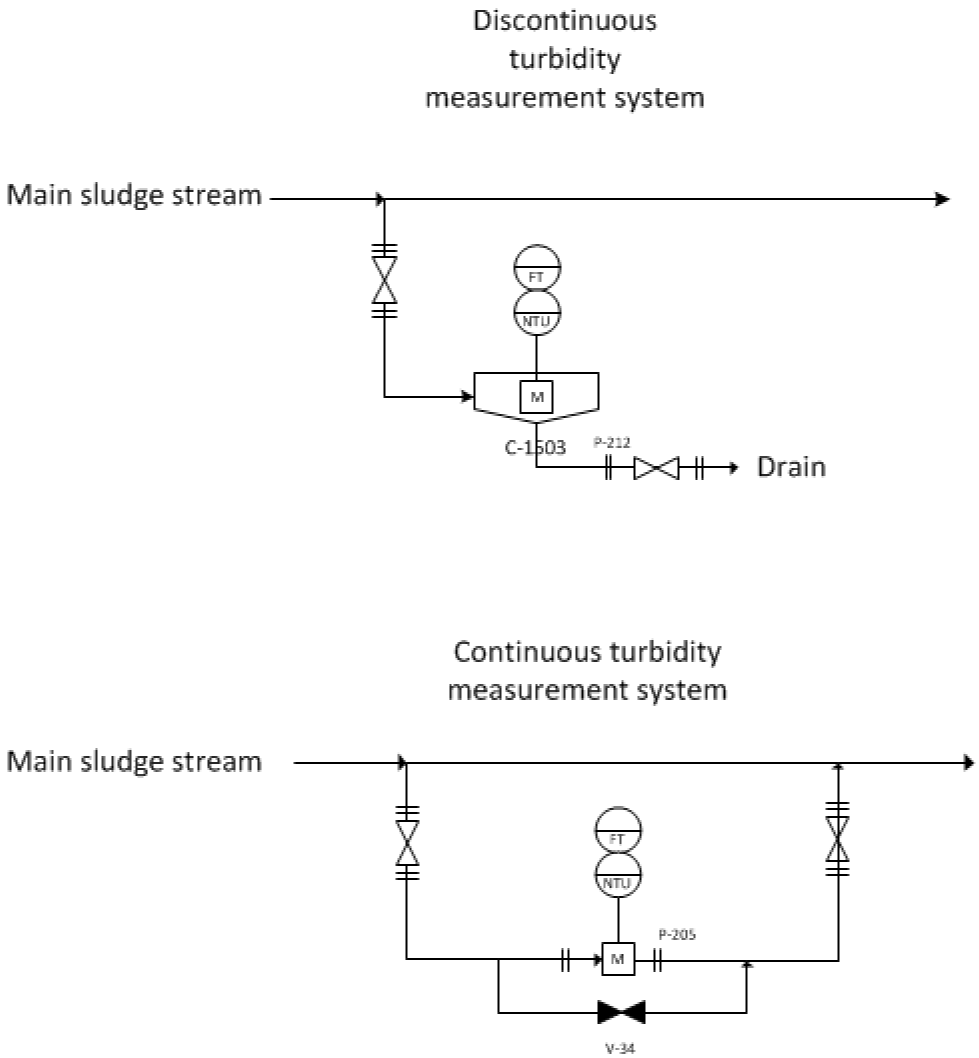


Figure 50: turbidity measurement system

3.1. Units of measurement

3.2. Meteorological data *(Leeuwarden)*

4. *ATTACHMENTS*

Appendix 1: Process Flow Diagrams (PFD's)

Appendix 2: Equipment list

Appendix 3: Process Description

Appendix 4: Preliminary lay-out and Plot plan

Appendix 5: Duty Specs/datasheets special equipment

Appendix 6: Batch time sequence

Appendix 7: Process Safety Analysis

0. INTRODUCTION

The purpose of this document is to give general guidelines during the conceptual/basic engineering of the so-called *Turbidity measurement system*. All numbers and values as well as descriptions have been agreed upon between the client and Engineering-company. Therefore this document will form the solid basis for the conceptual/basic engineering to be started. It is the intention of *Wetterskip Fryslan* to investigate *the feasibility of turbidity measurements for coagulation and flocculation in the sludge dewatering plant* and to prepare all required documents to support the feasibility study. *ETC*

1. SCOPE

1.1. Function of the facilities

1.1.1. The function of the facilities designated as *the turbidity measurement system in the sludge dewatering plant is to produce 625 kt/a of sludge cake from sludge, PE and* $FeCl_3$ *as a feedstock*.

1.1.2. *The Turbidity Measurement System is close to the existing Sludge Dewatering Plant at Heerenveen, location: Wetterwille 4, 8447 GC HEERENVEEN. Feed will be made available from the Sludge Dewatering plant. Products will be send to Swiss Combi for further thermal dewatering. By products, such as filtrate water will be sent to the Wastewater Treatment plant for removing excess ammonia and phosphate.*

1.1.3. A warehouse will be constructed for the storage of the products. *The capacity of this warehouse will be for 32 hours production.*

1.1.4. Wastewater will be send to the process sewer system and from there to the biological pond wastewater treatment plant (wwtp). All waste streams (gas, liquid or solid) should be dealt with in agreement with governmental laws, permit requirement, and corporate requirements and guidelines.

Vent gasses will be routed through a vent gas scrubber. A stack will be installed from which the gasses are sent to atmosphere.

1.1.5. The utilities will be available at battery limits, see also stream summary 1.1.9.

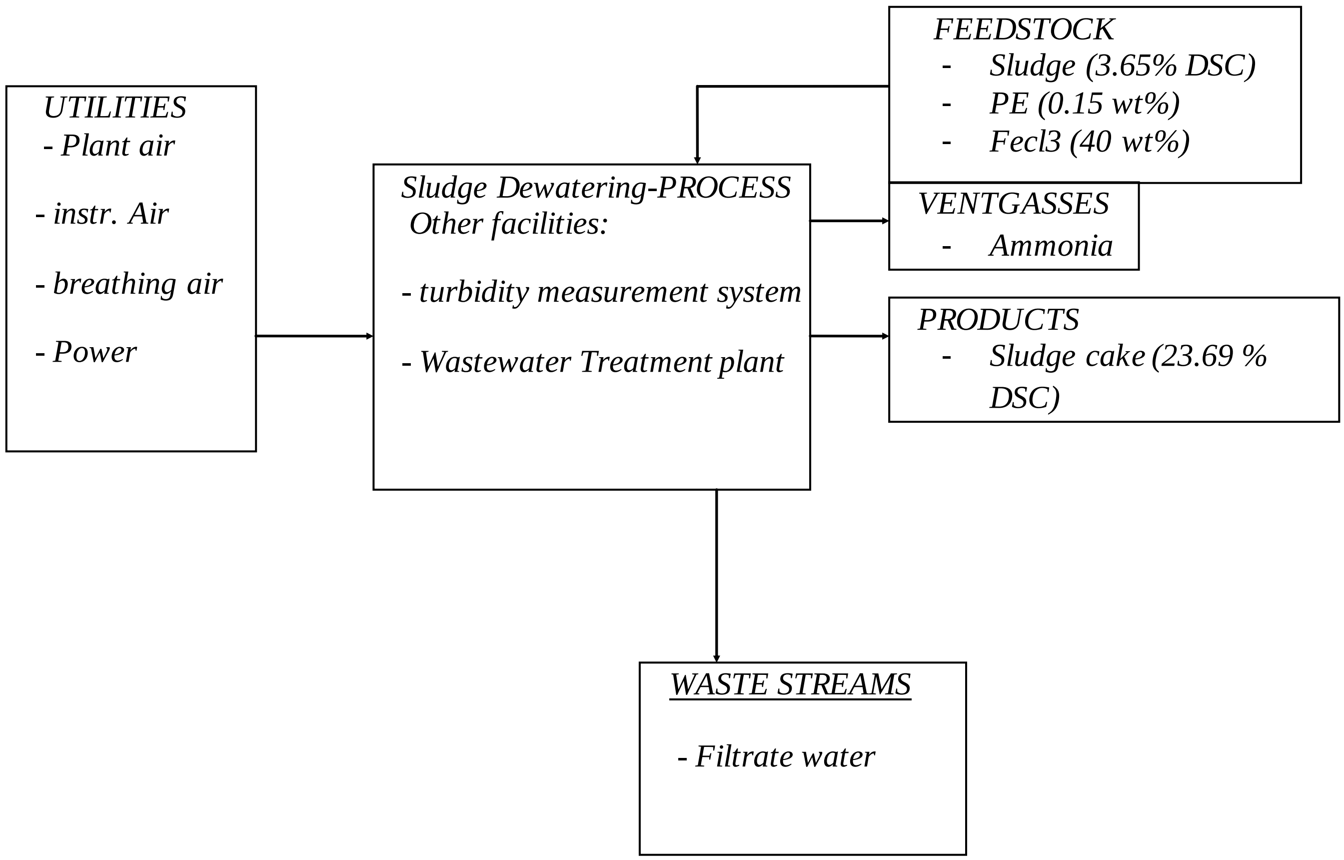
1.1.6. *On stream time basis 5840 hours/year. This leads to a sludge cake production of 7.2 t/h.*

1.1.7. **All pressures referred to in this design basis are absolute pressures**.

1.1.8. *The facilities of the Turbidity Measurement System will be designed with a life time expectancy of 20 years, where possible.*

1.1.9 Stream Summary

This will show a sketch (block flow diagram) of all in and outgoing streams). An example of such a sketch is given below.



1.2. Description of the facilities

The plant includes the following sections:

(See also PFD's in Attachment 3.1 and Process Description in Attachment 3.4.)

1.2.1. Tag coding of equipment

Equipment will be tag coded as laid down in appendix G

1.2.2. Production and Utility Facilities

The plant will include the following production sections; this section numbering will form the basis of the PFD's:

SDP-1

Section 1100	*Sludge pre-treatment*
Section 1200	*$FeCl_3$ supply*

Section 1300	*PE supply*
Section 1400	*sludge dewatering*
Section 1500	*Turbidity Measurement system*
SDP-2	
Section 2100	*Sludge pre-treatment*
Section 2200	*$FeCl_3$ supply*
Section 2300	*PE supply*
Section 2400	*Sludge dewatering*
Section 2500	*Turbidity Measurement system*

The utilities available at battery limit are specified in Chapter 1.8.

A detailed survey of the utility tie-ins is indicated in the project specifications of the mechanical department.

1.2.3. General facilities

1.2.3.1. Water treating and sewerage

Surface water which can reasonably be expected not to be contaminated shall be collected in a clean water sewer system, which has to be connected to the existing main sewer. (Domestic sewage shall first be treated in a biological pond prior to drainage into the clean water sewer system.) Process water and contaminated surface water shall drain to a process sewer system. And then (via an API-separator) to the biological pond. The maximum allowable temperature of wastewater in sewage systems is 30 °C.

1.2.3.2. Bleed, relief and disposal systems

- The relief system has to protect equipment and piping against overpressure, and shall be designed in such a way that the maximum credible relief quantity can be handled, regardless of mode of operation. The system shall be designed in such a way that a release cannot upset the operation of other sections in the plant or adjacent installations.

- Gases containing combustible components which are blown off by safety valves shall be relieved to a flare system or to 'safe location'. Dispersion calculations might be required to determine ‘safe location’. A risk assessment study and evaluation will have to be made before the start of the basic engineering. Gases containing non-combustible, non-poisonous or non-odorous components, may be relieved to local vents. The design of these vents must prevent dangerous ground level concentrations of suffocating components (N_2, NH_3, CO_2 etc.) and liquid entrainment. Venting should always be to a safe location.

Waste gases produced continuously during normal operation and containing significant amounts of combustible, poisonous or odorous components shall be incinerated*, or sent to a Biofilter.*

- For draining of liquids containing combustible, poisonous or odorous components a closed piping system and/or a slop tank shall be installed. Organic liquids not miscible with water are separated and recovered.

1.2.3.3. Control room, social rooms, offices, workshop

The existing facilities of the *Sludge Dewatering plant* will be used as much as possible. It is assumed that the plant will have a mixed crew of operators

The erection or expansion of operator- and social rooms, an office, workshop and additive storage is excluded from the project scope of work. This project will only cover the control room.

1.2.4. Outside battery limit (OSBL)

OSBL connections are detailed in the stream summary 1.1.9.

1.2.5. Safety measures and facilities

All *Wetterskip Fryslan* and government standards are to be adhered to, see also 2.6.

<u>1.3. Plant site information</u>

The plant will be located in Heerenveen (The Netherlands) on the Wetterskip Fryslan, Wetterwille 4.

The plant will be as indicated in the preliminary lay-out, see Attachment 4.

The following details are shown:

- Battery limits of the plant

- Access and internal roads

- Areas designated for construction facilities

A preliminary plot plan is shown in Attachment 4.

The site will be flat and free of obstacles and underground cables.

With regard to earthquakes is referred to Government Building Regulations.

A preliminary report of geotechnical survey will be included in the Project specification of the civil department.

It will be assumed that the soil at the site is not polluted, and that a so called 'Clean soil statement' will be given ('schone grond verklaring'). However this is just a term and the soil always contains too high doses of some contaminations. Therefore a 'geschikheidsverklaring'' (suitability statement) is given according to a soil research based on the Dutch norm NEN 5740.

1.4. Plant capacity and flexibility

The Sludge Dewatering plant will have a production capacity of 625 kt/a, with a composition as given in Paragraph 1.5. See also 1.1.1.

The production of 1000 kg of sludge cake will not require more than 6348.70 kg feedstock, based on the normal feedstock specification as per Section 1.6 and not more than 14 kg $FeCl_3$ and 1.68 kg PE.

When operating *at 80 % of design capacity* (turn down ratio), the plant shall still be able to produce products which meet their specification as given in Section 1.5 and consumption figures of feedstock and/or utilities as agreed upon and listed above.

1.5. Product specifications

1.5.1. Product: *sludge cake*

Composition:water/nitrogen/ammonia/phosphorus/sodiumthiocyanate/phenol/chloride/organic material/ ferric salts

Battery limits conditions

Pressure in bar: *1.01325*

Temperature °C: *5; 12; 23*

Physical data: physical state and appearance: solid with a high percentage of water

pH: 6.8

Colour: brown

Density: 1279.3 kg/m^3

1.5.2. Co-product: *filtrate water*

Composition: water/ nitrogen/ammonia/chloride

Battery limits conditions

Pressure in bar: *1.01325*

Temperature °C: *5; 12; 23*

Physical data: physical state and appearance: light yellow liquid

pH: 6.5

Density: 998 kg/m^3

1.6. Feedstock specifications at battery limit

1.6.1. Feed: *sludge*

Composition: water/nitrogen/ammonia/phosphorus/sodium thiocyanate/phenol/organic material

Battery limits conditions

Pressure in bar: *1.01325*

Temperature °C: *5; 12; 23*

Physical data: physical state and appearance: suspension

pH: 7.1

Colour: brown

Density: 1000 kg/m^3

1.6.2. Feed: PE

Composition: 0.15 wt% polyelectrolyte in water

Battery limits conditions

Pressure in bar: *1.01325*

Temperature °C: *18; 20; 40*

Physical data: physical state and appearance: viscous fluid

pH: 3.6-4.1

Colour: white

Density: 1030 kg/m^3

Viscosity: 900 cPs

1.6.3. Feed: *$FeCl_3$*

Composition: 40 wt% $FeCl_3$ in water

Battery limits conditions

Pressure in bar: *1.01325*

Temperature °C: *5; 12; 23*

Physical data: physical state and appearance: yellow solution

pH: <1

Colour: yellow

Density: 1033 kg/m^3

1.7. Waste stream specifications

1.7.1. Air pollution

Ammonia

The maximum allowable emissions figures are: - *(NeR)*

The maximum allowable concentrations are: - *(NeR)*

The expected emissions are: *5 $\mu g/m^3$*

Remark: The maximum allowable emissions figures and concentrations mentioned here are the figures mentioned in the 'Wet Milieubeheer'.

The emissions include the total of:

- normal and continuous vent and purge losses
- normal leakage from flanges, pumps, valves
- the losses during cleaning and/or repair of equipment

Not included are:

- the expected losses due to blow-off of relief valves
- other losses which are not normal but can be expected (start-up and shut-down losses)

1.7.2. Water pollution

The water flow to the process sewer should be as minimal as feasible. The quantity of organic and inorganic components in the water should be known for normal operating conditions as well as special cases e.g. start-up, shut-down, blow-down and grade change. The temperature is typically 25 °C and shall not exceed 30 °C.

1.7.3. Soil pollution

The soil should be protected to prevent possible pollution. The maximum values of some components in sludge are given below:

Chloride 200 mg/l

Ammonium 2.5 mg/l

Sulphate 150 mg/l

1.8. Utility specifications at battery limits

The utility data as well as the statement that the total capacity will be available at Battery Limits will be confirmed and approved by *Wetterskip Fryslan* Utility department. All utility figures mentioned in this chapter shall be verified and adapted if necessary and have to be approved by the Utility Supplier and the client.

1.8.1. Electric power

Reference to be made to Project Specification PS 3.5-(project number) (see PEM 40.20.20

page 4). For preliminary Conceptual engineering, the following information can be used.

STANDARDIZED VOLTAGE

Alternating current: 50 Hz

1.8.1.1. 10,000 VOLT - 3 PHASE - 50 CYCLES

Derived from the utilities system outside battery limits. The system is or shall be neutral grounded by an 8 Ohm resistance. The maximum short circuit level may be 250 up to 500 MVA. For motors above 400 kW.

1.8.1.2. 690/400 VOLT - 3 PHASE + NEUTRAL - 50 CYCLES

This system shall be derived from the 10 kV system with delta-star (DYn) connected transformers. The secondary starpoint of the feeding transformers shall be solidly grounded in the low voltage main switchboard.

690 V main switchboard:

motors from 55 kW with a maximum power (in kW) equal to 17 % of the rated power of one transformer feeder (in kVA).

690 V MCC:

motors from 15 kW up to and including 90 kW.

1.8.1.3. 400/230 VOLT - 3 PH + NEUTRAL - 50 CYCLES

This system shall be derived from the 10 kV or 690 V system with DYn-connected transformers. The secondary starpoint of the feeding transformers shall be solidly grounded in the low voltage main switchboard.

400 V main switchboard:

motors from 55 kW with a maximum power (in kW) equal to 17 % of the rated power of one transformer feeder (in kVA).

To a combined main switchboard/MCC all motors up to the above mentioned maximum power may be connected.

400 V MCC:

Motors up to and including 55 kW.

In case of variable speed drives, different power ratings can apply for the connection to the switchboards. Proposals have to be discussed with owner.

The motor of a drive and the motor of the spare-drive, e.g. the A and B drive, shall be connected to different sides of the buscoupler or to different MCC's fed from different sides of the buscoupler. All motors which belong to a specific unit, for instance motors and the auxiliary motors of a compressor, shall be connected to one and the same side of the HV and/or LV buscoupler(s) and/or to one and the same MCC.

1.8.1.4. 230 VOLT - 2 WIRE - SINGLE PHASE - 50 CYCLES

This system is derived from a 400 Volt - 3 phase - 4 wire system having the neutral grounded.

1.8.1.5. 42 VOLT - 2 WIRE - SINGLE PHASE - 50 CYCLES

This system is normally derived from local installed 230/42 Volt 100 VA transformers.

1.8.2. Electric Power - Direct Current

1.8.2.1. 110 VOLT DC - non earthed system

This system shall be derived from the 400/230 V system by rectifier(s) and shall have a battery back-up.

1.8.2.2. 110 VOLT DC - earthed system

This system shall be derived from the 400/230 V system by rectifier(s) and shall have a battery back-up. The +pole of the system shall be earthed in the first 110 V DC switchboard.

1.8.2.3. 24 VOLT DC - non-earthed system

This system shall be derived from the 400/230 V system by rectifier(s) and shall have a battery back-up.

1.8.2.4. 24 VOLT DC - earthed system

This system shall be derived from the 400/230 V system by rectifier(s) and shall have a battery back-up. The -pole of the system shall be earthed in the first 24 V DC switchboard

1.8.2.5. Other voltage systems and networks

Other voltage systems and networks can be used for special instruments (e.g. computer systems). This will be subject to owners approval. These voltages shall always be derived from the 400/230 V system by means of transformers or -in case of DC- rectifier(s) with suitable battery back-up.

Equipment other than motors shall be connected to the different voltage systems as mentioned here-under:

- heater	: 400V or 690V 3 phases
- packaged units	: 400V or 690V 3 phases
- welding socket outlets	: 400V 3 pH
- heat tracing	: 230V
- lighting	: 230V
- socket outlets	: 230V
- computer systems	: 230V
- socket outlets or handlamps and portable tools in enclosed spaces	: 42V
- control of HV switchgear	: 110V DC non-earthed
- control of LV switchgear	: 110V DC earthed
- emergency lighting in control room and switch room	: 110V DC earthed

- network annunciator systems in switch room	: 110V DC earthed
- telephone system	: 60V DC
- process control equipment	: according to EP 5.6-2.1

1.8.4. Water

1.8.4.1. Canal water

The effluent from the Wastewater Treatment plant is discharged in the Nieuw Heerenveens Kanaal .

pressure (at ground level)	*average*	*: 7.5*	*bar*
	max. and design	*: 16*	*bar*
	minimum	*: 6*	*bar*
temperature	*average*	*: 10*	*°C*
	max. and design	*: 25*	*°C*
	minimum	*: 4*	*°C*

1.8.4.6. Fire fighting water

See canal water. In case of fire the pressure will be boosted up to 16 bar, which is the design pressure of the system.

1.8.5. Air

1.8.5.1. Instrument air

Pressure	min.	: 4.5 bar
	max. and design	: 8 bar (setpoint PSV)
	norm.	: 5.8 bar
Temperature	norm.	: ambient
	design	: 50 °C
	dew point : -30 °C OR -40 °C	
	quality	: free of oil and dust

A filter shall be installed ISBL.

1.8.5.2. Plant & Breathing air

Pressure	min.	: 5.5 bar for plant air
		: 4.5 bar for breathing air
	max. and design	: 8 bar (setpoint PSV)
	norm.	: 5.5 bar
Temperature	norm.	: ambient
	design	: 50 °C
	dew point	: ambient

An ISBL filter for breathing air will be installed.

1.8.7. Natural gas

1.8.7.1. Low caloric

type		: Low calorific without odorant	
temperature		: 15 °C	
pressure	typical	: 17 bar (reduced ISBL to approx. 2 bar)	
Composition		: typical	
saturated hydrocarbons		: vol. %	85
N_2		: vol. %	14
CO_2		: vol. %	0.9
UHV		: MJ/Nm^3	35
LHV		: MJ/Nm^3	32
Wobbe no.		: MJ/Nm^3	45
Wobbe no.		: MJ/kg	31
Total sulphur content		: mg/Nm^3	0.4
density at T=273 K		: kg/Nm^3	0.83

1.8.7.2. High caloric

type		: High calorific without odorant
temperature		: 15 °C
pressure	max.	: 3.4 bar
	min.	: 1 bar

Composition

Hydrocarbons (CH_4)	: vol. %	95
CO_2	: vol. %	1.5
N_2	: vol. %	3
Total S	: mg/Nm^3	0.4
UHV	: MJ/Nm^3	41
LHV	: MJ/Nm^3	37
density at T=273 K	: kg/Nm^3	0.8
Wobbe no.	: MJ/Nm^3	52
Wobbe no.	: MJ/Nm^3	36

Explosion limits	(at 0 °C and 1.013 bar)	5.8 - 15 vol.%
Stoichiometric air (m^3/m^3)		9.75 in dry air at 0 °C and 1.013 bar
		9.87 in wet air at 0 °C and 1.013 bar

2. DESIGN CRITERIA AND POLICIES

2.1. Design consideration

- The plant shall be designed as a commercial unit for the performance as listed in 1.1.1.
- Where possible inherently safe design shall be applied.
- Where possible the design shall have a minimum impact on the environment and shall be as energy efficient as possible.
- Establish project key criteria and objectives.
- Establish design life time of the total installations and/or individual pieces of equipment.
- Determine which process parameters should be defined, taken into account the limitations of the technologies selected.
- Asses the significance of the process parameters.
- Identify the basic design parameters (key process parameters).
- Assure that the requirements of all key parties (operation, maintenance, marketing, finance, management, safety, quality) are recognised and presented so as to facilitate priorisation and resolution of conflicts.
- Mention the design criteria references and assumptions (test results, R & D reports, licence package etc.).
- All relevant design criteria of each piece of equipment have to be motivated in a separate document (e.g. Design Condition Analysis).

2.1.1. State of the art of the technologies and process

- The plant and equipment design shall, where possible, incorporate only those modern (state of the art), available and proven technologies that are consistent with highly reliable, low SHE (safety, health, environmental) risk plant design and with the Corporate Requirements and Guidelines.
- The technologies shall be evaluated with 'state of the art' knowledge from inside and outside *Wetterskip Fryslan*. The benchmarking position shall be indicated with an approximate technical/economical evaluation of the considered process.
- Any contractor is expected to consider recent developments of the technologies during design and consult Engineering-Stamicarbon before these are incorporated or rejected.
- The implications of the technologies on equipment design and selection shall be assessed.

2.1.2. Operational requirements

- During process engineering the operating procedures are translated into process design. Operating philosophy must be defined before basic engineering to assure that the designed plant can be operated according to these instructions.
- The degree of atomisation and controlling of the plant is determined by the operating philosophy. Atomisation and control system choice should lead to minimum manning.
- Main and by-product logistics (storage, transport etc.), interference with other plants; off-spec routing shall be indicated.
- Indicate the auxiliary requirements (catalyst, inhibitors, etc.) including handling aspects.
- Operational flexibility shall be assessed in accordance with ideas of the client.
- The installation has to meet the highest performance criteria during transitions: for instance feed composition changes, throughput variations, start up and shut down.
- The design shall be based on maximum and minimum operating conditions including, start up, shut down and cleaning or maintenance procedures, unless otherwise is specified.
- Specify required regeneration equipment (catalyst, adsorbent regeneration etc).

2.1.3. Maintenance requirements

- The specific maintenance philosophy shall be determined by client and Engineering-Stamicarbon.
- The plant equipment and materials of construction shall be consistent with a high service factor and low maintenance cost.
- Preventive, predictive maintenance and regular revision and maintenance intervals should be taken into account.
- The plant design shall allow carrying out as much routine maintenance as possible during operation or during downtime inherently necessary for process reasons.

2.1.4. Allowances for future extension and/or product upgrading

- Allowances for future extension and installation of equipment for product upgrading and off spec routing have to be determined in consultance with client.
- In case of constructing an additional line, the plot-plan of the first line must be designed in such a way that operation of the lines gives synergistic effects.
- In production plants with expected future expansion the capacity of special equipment may be over-designed. This shall be mentioned in the Design Basis and determined by the client.

2.1.5. Project and Technological risks

- The following major technological and project risks and uncertainties are present during the conceptual engineering phase of this project: (kinetics, powder characteristics and thermodynamics partly unknown etc etc.)
- The investigation of risk reduction options and remedial actions are part of this project.
- Indicate with sensivity analysis the economics of the considered risk options.
- After approval of the owner, the contractor is allowed to use other technologies than mentioned in the design.
- Experiences of *Wetterskip Fryslan* with vendors are reflected in the preferred vendor-list.
- Appreciation's of client can also determine the choice between several alternatives.
- The choice between a commercially proven, pilot plant proven, and a recently developed technology is complex and shall be assessed and agreed by Engineering-Stamicarbon and client.

2.1.6. Equipment including package units

Package units are equipment and/or process systems, which are purchased from specialised vendors in order to obtain the necessary performance integrity.

Package units include:

- Pumps, compressors, blowers, centrifuges, mixers, extruders, granulators and other rotating equipment
- Cooling towers, refrigeration equipment, cooling belts
- All fired equipment, incinerators and flares, hot oil furnaces
- Solid handling equipment including storage, filters, sieves, pneumatic transport, dosing units
- Hoisting equipment, bagging, debagging and packing equipment

Design, manufacturing and erection of package units shall comply with:

- Dutch national and local codes
- International design standards and specifications
- Additional requirements as mentioned in owners dedicated project specifications
- Additional requirements according to owners standard specifications as mentioned in the dedicated project specifications

- The *Wetterskip Fryslan* Corporate Requirements and Guidelines and Operational Requirements.

Equipment, lines, valves etc. shall be designed according to ANSI/DIN specifications where possible.

The scope of supply shall at least include the design, manufacturing, delivery and, when applicable, erection of equipment and or parts, necessary to achieve the required duty and safe operations.

The contractor remains fully responsible for a good design and the fitness for successful operation of the equipment and package units. The contractor remains also fully responsible for delivery in time of documents, services and materials.

In principle, only equipment, components and constructions, which have been proven during at least two years successful operation in similar process conditions, are acceptable.

The contractor makes sure, that at least the following guarantees (by Vendor) are incorporated in the agreements with Vendors:

- The compliance of the units, the components and the performance of the installation with the applicable technical specifications.
- That the installation and its individual parts function properly in all respects and that they are free from defects and sound in terms of design, workmanship and fabrication.
- Specific performance guarantees with regard to consumptions, capacities and quality of products; these specific performance guarantees shall be described as detailed as possible in figures which are easily measurable in the installation while operating.

In principle the Owner will provide a 'Vendor list'. The contractor is allowed to add other vendors to the list, resulting in the 'proposed Vendor list'. The Owner has the right to make modifications to this list. After Owner's approval, the modified/approved Vendor list will be appointed as the 'project Vendor list'. In case no Vendor list is provided by the Owner, the contractor shall compose and provide a 'project Vendor list'. The Owner has the right to make modifications to this list.

2.2. Total Quality Management Aspects

The contractor shall demonstrate that its organisation is supported by a Quality System, which preferably meets the requirements mentioned in ISO9001, in order to achieve quality of engineering. The organisation and procedures of the contractor can be assessed by means of a quality audit. This audit gives information about the deviations between ISO9001 and the contractor’s activities. The contractor shall prepare a project quality plan to demonstrate that engineering is executed according to ISO9001. This plan is to be regarded as the translation of the quality system in working procedures during the project. The same applies in rough outlines for the construction phase.

The contractor shall demonstrate a SHE project plan according to *Wetterskip Fryslan* and government standards and requirements.

2.3. Design standards and codes

The facility shall be designed in accordance with:

- *Wetterskip Fryslan* -design specifications and Process Design Guides (if applicable) as defined in the Project specification have to be used.
- Recommended practices as laid down in API reports and bulletins shall be adhered to.
- For the design or rating of shell and tube heat exchangers, the design methods of HTRI, or on contractors request HTFS, are strongly recommended.
- For heat exchanger types different from shell and tube, the design methods of HTFS are recommended or the design methods of approved vendors.
- For the design of fractionators the design methods of FRI are strongly recommended or for specific types of packing or tray types, the design methods of approved vendors.
- For the earthing of equipment the LP3 or LP4 safety measures shall be taken, in compliance with NEN1014.

2.4. Plant availability and sparing policies

2.4.1. Availability

The plant shall be designed for an annual availability of 5840 hours (7 tons per h) on-stream time. Availability should be read as availability for starting, stopping, production and regular cleaning procedures (e.g. Cleaning in Place). *While the planned shut-down of the whole plant for maintenance and 'Stoomwezen' inspection might take place every 2 years for 1-2 weeks, the unexpected plant outages may add up to approximately 20 days per year*. Regular maintenance or inspection shall not entail the total shut-down of the plant. *It should be noted that the plant gets its feed directly from Wastewater Treatment plant, a shutdown of the latter will generate a shutdown of the subject plant*. This effect has been taken into account in the annual availability.

2.4.2. Sparing policy

2.4.2.1. Vital services

Vital services are those which in the event of failure could cause an unsafe condition of the installation, jeopardising life and/or equipment. Running equipment in vital service shall be 100 % spared with one of the power sources being electric drive whilst the other motive source should be steam, diesel or gas turbine. The spare equipment shall always be available for operation and therefore a third facility should be available to allow essential maintenance to be carried out while the plant remains onstream. Vital services will include:

- Safeguarding devices (XPV's) for S1 situations
- Pressure relief systems (two PSV's when must be cleaned after use)
- Instrument air supply (ring line)
- Firewater supply (ring line)
- Electrical supply to control room
- Electrical supply to instruments being part of S1 safety loop

Note: In general there will not be installed two pressure relieving devices, the second being a back-up for the first. However this is required when it is expected that the relief valve will not re-open easily after closure, this may be caused by a sticky product. A second relieving device may be dictated by risk analysis.

2.4.2.2. Essential services

The essential services are those which, in the event of their failure, would result in the plant not being available to operate at 100% capacity and make it impossible to obtain the required availability between planned shut-downs.

Normal running equipment in essential service shall be 100 % spared. The spare unit driver does not require an alternative power source. If more than one piece of equipment, say n units, are required to obtain 100% design capacity, n+1 units shall be installed.

- It may be agreed upon not to install a second pump, but have a complete spare pump and spare motor in stock. This can be done when it is guaranteed that the change can be made in a couple of hours.

Other equipment in essential service shall have adequate provision to ensure operation in accordance with the above definition.

- In some cases, however, i.e. sparing of expensive equipment, the economics may be overriding in sparing policy decisions. (e.g. extruders, compressors)

Essential services include:

- Boiler feed water treating and steam generation facilities
- Seal oil/Lube oil systems of major equipment
- Effluent treatment facilities

- All process unit feed, reflux and product pumps

- Fuel gas supply

- Cooling water supply

2.4.2.3. Non-essential services :

Non-essential services are those which, in the event of failure for a limited time, would not impair production. Rotating equipment in non-essential service need not be spared. Non-essential equipment shall not have provisions for performing essential services.

2.5. Legal requirements and company requirements

The complete list of legal requirements applicable to this project will be defined in the Project specification. It will include requirements derived from the following laws:

- 'Wet Milieubeheer' (Environmental Protection Law)
- 'Stoomwet' (Rules for Pressure Vessels)
- 'Arbeidsomstandighedenwet' (Occupation Safety and Hazard Act)
- 'Wet verontreiniging oppervlaktewateren' (Water pollution Act)
- 'Bouwvergunning' (Building Permit)

Policies of *Wetterskip Fryslan* management:

- Corporate Requirements and Guidelines and Operational Requirements
- 'Beleidsverklaring' (*Wetterskip Fryslan* Policy Statement)

2.6. Safety, health and environmental considerations

Careful consideration must be given to operability and safety under normal operation, turn down, start up, shutdown and emergency conditions.

2.6.1. Corporate Standards

Translate the Corporate Safety and Environmental policies into key design features. Anticipation of the likely Safety, Health and Environment (SHE) restrictions of the permit and *Wetterskip Fryslan* corporate standards is made in the process design. *Wetterskip Fryslan* requirements are among others the Corporate Requirements and Guidelines.

The major potential hazards will be identified using the following methods:

- Systematic process safety analysis (PSA: 'Process Safety Analysis') (Proces Veiligheids Analyse)).

- MCA analyses (Max. Credible Accident) to be based on plot plan, lay out and site.
- Risk analyses, effect calculations and damage calculations.
- Standard for dust prevention in the plastics industry NFPA 654-1975, NFPA-68.
- VDI directive for dust explosion.
- DOW F&E Index

The following design standards are to be met:

- Process Design Guide 3.1 "Pressure relieving devices" latest revision.
- For venting requirements, fire protection, evaporation losses, protection against ignitions (several sources), personal protection and design see relevant API-recommendations.

Designing for external fire condition shall be determined by mutual agreement between Engineering-Stamicarbon and owner. According to Corporate Requirements and Guidelines and API-reports all equipment shall be protected against overpressure i.e. also caused by external fire. However indiscriminately designing for external fire conditions has to be avoided by:

Thorough analysis of the cause and the source of the fire. Calculations must be made if the maximum pressure increase, due to external fire, may exceed the design pressure regarding the amount of burning component present.

The contractor shall establish the scope and standard in co-operation with *Wetterskip Fryslan* for:

* drain systems
* fire protection
* fire proofing, insulation and/or coating
* emergency showers, eye showers

2.6.2. Asbestos

Asbestos or composites containing asbestos will not be used in this plant.

2.6.3. Noise

The maximum allowable noise level of individual pieces of equipment shall be according to DIN 80 dB(A) at 1 meter distance, under all circumstances. However a noise level of less than 75 dB(A) at 1 meter is strongly preferred. The total noise level shall not exceed the so called site noise 'Contours'.

2.6.4. Energy conservation

- Energy and thermal integration aspects should be considered in relation with corporate philosophy and client standpoint of view.

- Pinch Analysis and Exergy Analysis might be applied to check the energy efficiency.

2.7. Process control philosophy

- For the key process parameters (only 5 to 10) 'Statistical Process Control' (SPC) must be applied when agreed upon with the client.

- DCS, model based process control, advanced process control systems should be assessed with regard to process optimisation, environmental pollution and product quality.

- Local panel, centralised or decentralised control of the plant must be considered.

- In an early design phase (feasibility/conceptual) the control philosophy should be regarded in respect with efficiency, quality and Safety, Health and Environmental requirements.

2.8. Overdesign factors

In the design of process-equipment, uncertainty factors in thermodynamic properties, design correlations and calculation methods are historically compensated for by 'overdesign factors'.

Overdesign should be used with caution, the use of indiscriminative arbitrary safety factors should be avoided.

The magnitude of the risk and consequences involved in a certain application will be reflected in the value of the appropriate safety factor. The justification of the overdesign of individual pieces of equipment will be made on the datasheets/duty-specifications.

For the following non critical equipment the overdesign has been agreed upon:

- pumps 10% *(ETC)*

- For several streams in the material balance more than one condition will be shown for ‘normal operation’, and for ‘design conditions’. In this latter balance overdesign factors have been applied on process uncertainties.

2.10. Corrosion allowance

Basically corrosion allowance shall be granted in case of general corrosion attack. For critical process equipment, Engineering-Stamicarbon has to be consulted on this subject. Generally the allowance shall not exceed 3 mm, for economic reasons. A more resistant construction material shall be selected when required, also considering the design lifetime. No corrosion allowance with respect to ambient (atmospheric) conditions shall be used.

All materials to be used for piping and equipment will be detailed in the Construction Material report, which is part of the Conceptual Process Design Package.

The corrosion allowance for utilities (equipment and piping):

instrument air, mat. CS	: 0 (zero) mm
breathing air, mat. galvanised CS	: 0 (zero) mm
plant air, mat. CS	: 0 (zero) mm
nitrogen, mat. CS	: 0 (zero) mm
steam, mat. CS/alloy steel	: 0 (zero) mm
condensate, mat. CS	: 0 (zero) mm
cooling water, mat. CS	: 0 (zero) mm
demineralized water, mat. SS	: 0 (zero) mm

2.11. Economic criteria for optimisation of sub-systems

- An estimate of the production cost and preliminary economic analysis (pay-out time) including sensitivity analysis should be made in co-operation with the client.

For feasibility studies during the design the following prices (in Dutch guilders) will be used:

- (see editions of 'variabele verrekenprijzen Utilities' in order to obtain the prices).

Power : 0.0438 €/kWh

2.12. Temperatures and pressures for mechanical design

Regarding temperatures and pressures for mechanical design of plant piping (excluding transmission lines outside battery limits) and equipment, reference is made to the latest revision of Process Design Guide 1.15: 'Determination of the design pressures and design temperatures'. The design conditions will be reported on the Equipment Design Condition Forms which are a part of the Conceptual Process Design Package.

3. GENERAL DESIGN DATA

3.1. Units of measurement

SI units shall be adhered to, and the use of the following specific units is preferred.

- pressure : bar (10^5 N/m^2) absolute pressure unless stated otherwise
- flow : kg/s, kg/h, m^3/s, m^3/h, Nm^3/s
- viscosity : mPa.s
- power and heat flow : Watt (W, kW)
- energy : Joule (J, kJ)
- Nm^3 are defined at 0 °C and 1.01325 bar

3.2. *Meteorological data (Leeuwarden)*

3.2.1. Wind conditions

Prevailing wind: South West

3.2.2. Wind speed

- For the design of structures, buildings etc. see the Project Specification.
- For the calculation of heat losses 10 m/s.
- For the calculation of gas dispersion in the atmosphere min. 2 m/s (Pasquill class F) for the MCA calculations.
- *max mean wind speed: 16 m/s*
- *average mean wind speed: 4,7 m/s*

3.2.3. Temperatures

In tanks, as caused by the radiation of the sun : 50 °C

In tanks surrounded by a wall at approximate 2 m : 60 °C

3.2.4. Air temperatures

Extreme max. dry bulb : 35 °C

Minimum dry bulb : -20 °C.

35 °C is exceeded during 10 minutes/year

30 °C is exceeded during 10 hours/year

3.2.5. Design air temperatures for equipment:

- Air compressor
  - dry bulb 25 °C
  - wet bulb 18 °C
- *Air coolers 27 °C (27 °C is exceeded 39 hours per year)*
- *Air cooled turbine condensers 14°C (14 °C is exceeded 2404 hours per year).*
- *Minimum air temperature -16 °C*
- *Maximum air temperature 32 °C*
- Air conditioning : according to HVAC specification.

3.2.6. Relative humidity

Average, summer		*79.5 %*
Design	*- summer*	*80 %*
	- winter	*100 %*

3.2.7. Barometric pressure

Maximum	*1045 mbar*
Minimum	*975 mbar*
Design	*1030 mbar*

3.2.8. Rain- and snowfall

Rain, maximum 18.7 mm/hour during 60 minutes

Run off: 90 % on paved roads and roofs, 50% on unpaved roads.

Average annual rainfall 735 mm/year.

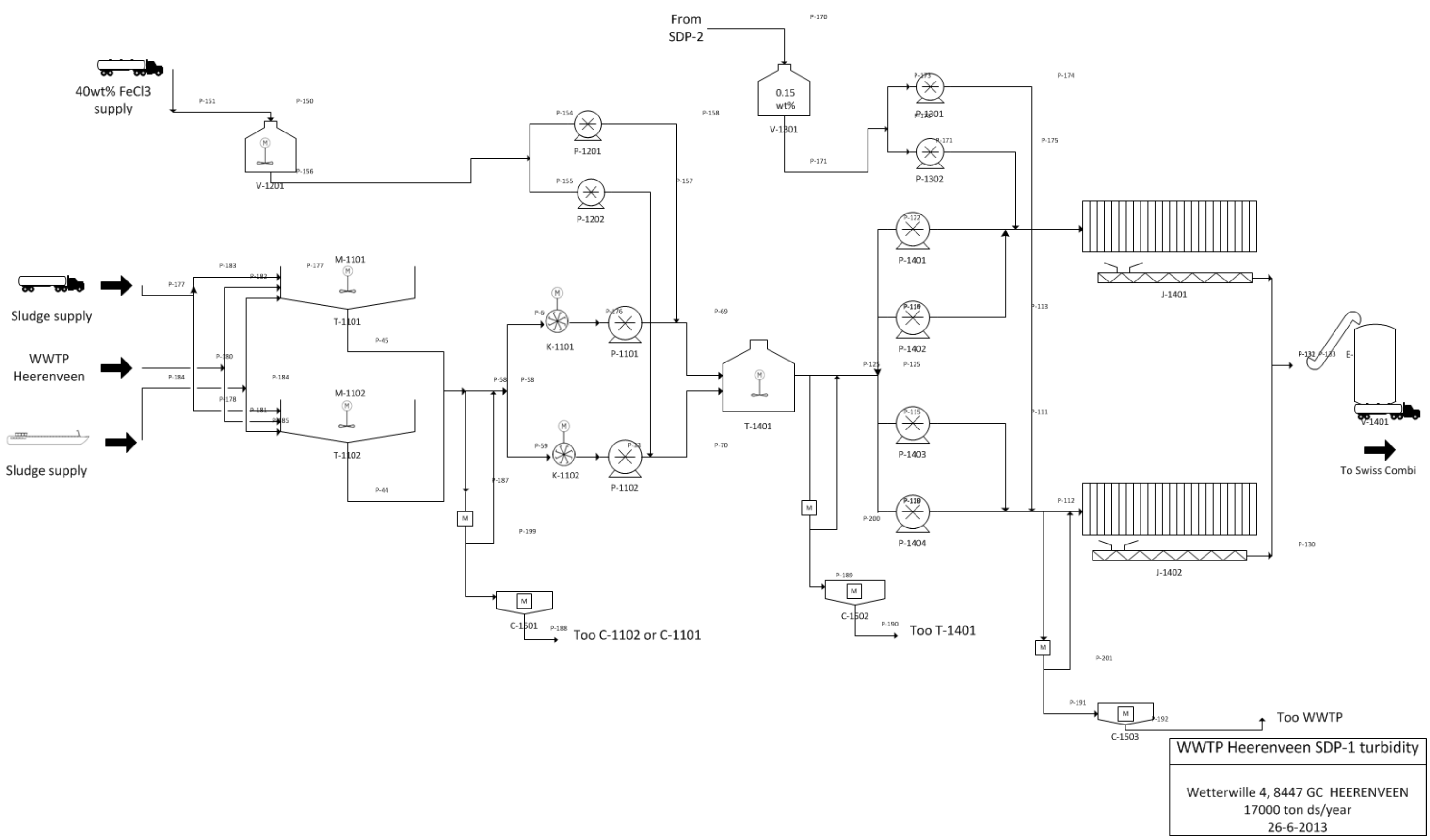
3.2.9. Environmental conditions

The installations will be erected on Wetterskip Fryslan site at Heerenveen, close to Sludge Dewatering and Sludge Treatment plants. The ambient air is polluted with NH_3 , SO_2 , CO_2, nitrate, nitrous vapours and industrial dust. Copper or its alloys shall not be used, unless stated otherwise.

4. Attachments

Appendix 1: Process Flow Diagrams (PFD's)

In the process flow diagram shown below, the turbidity measurement system is implemented in the PFD of SDP-1 Heerenveen. The turbidity can be measured continuous when sludge is branched from the main stream and later is returned. The turbidity can also be measured discontinue when the sludge is settled in the clarifiers C-1501/C-1502 and C-1503.



Appendix 2: Equipment list

Two different turbidity measurement systems can be implemented in the PFD, a continuous and a discontinuous system. To install the on-line continuous turbidity measurement system the following equipment is necessary.

- TMS 561 Turbidimeter (Wallace & Tiernan®) (see figure below)
- Instruction Manual
- Cuvette
- Shutt of clamp
- Back pressure valve
- Connecting tubing
- Drain vent screw

Figure 52: On line turbidity meter

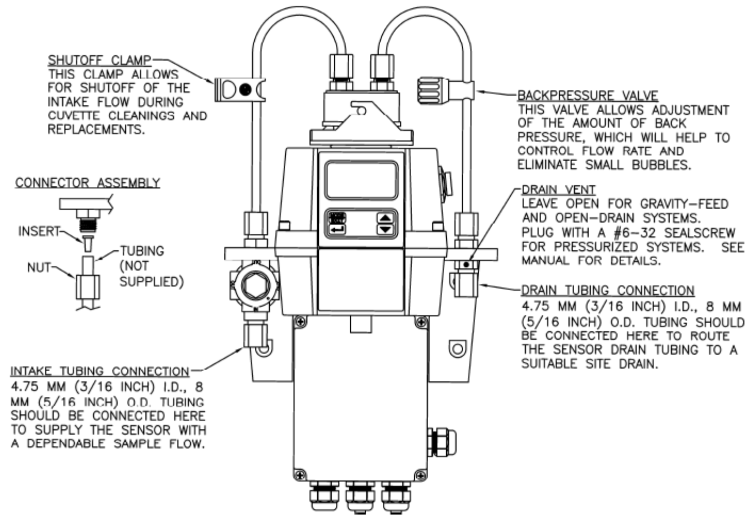


Figure 51: Schematic view

To install the discontinuous turbidity measurement system the following equipment is necessary.

- 5 litre clarifiers
- Neotek-Ponsel Turbidity Sensor: PONCIR-TU20-10 (see figure below)
- IR lamp

Figure 54: Discontinuous turbidity measurer

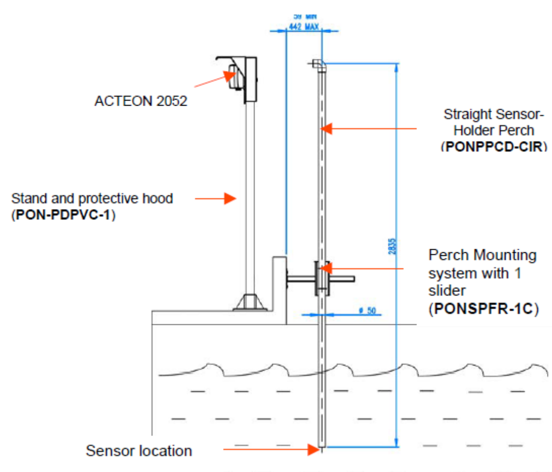


Figure 53: Set-up turbidity measurement system

Appendix 3: Process Description

The turbidity is measured at three different points with different contents of the measured substance: sludge, sludge with $FeCl_3$ and sludge with $FeCl_3$ and PE. Therefore the differences in turbidity are known before and after coagulation and flocculation. The dosage of $FeCl_3$ and PE is adjusted based on the turbidity measured after coagulation and flocculation. The turbidity of the water layer is the measured layer. This can be an indication for the completion of coagulation or flocculation. The results are used for controlling purposes, where if necessary a signal is send to the dosage system of $FeCl_3$ and PE when the turbidity is not the optimal value. The turbidity of the incoming sludge can also be a parameter for the dosage.

Turbidity is the cloudiness or haziness of a fluid caused by individual particles. The turbidity is measured in Nephelometric Turbidity Units. As shown in figure 55, modern turbidimeters use the technique of nephelometry, which measures the amount of light scattered at right angles to an incident light beam by particles present in a fluid sample.

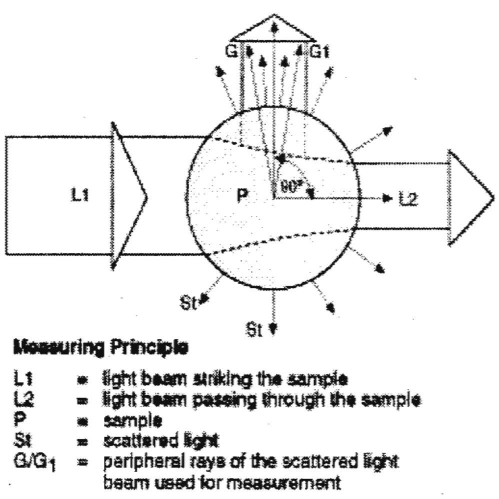


Figure 55: Measuring principle

For the turbidity measurement system a P&ID is made. This is shown in figure 56. It can be seen that a side stream is branched from the sludge stream at three different points. The turbidity can be measured continuously and discontinuously. Discontinuously has an advantage that the turbidity of the water layer can be measured when the sludge is settled in the clarifier. The continuous on-line turbidity meter works as follows. An amount of sludge passes the valve and flows into the turbidity meter. There the NTU is measured and feedback is given to the valves V-2 and V-15 for $FeCl_3$ and PE dosage, respectively. Then the sludge flows back to the main sludge stream. The discontinuous turbidity meter system works a bit different. The sludge flows in a clarifier, where the sludge settles after an amount of time. Then the turbidity is measured and feedback is given to the valves. The sludge is drained and transported back to previous tanks such as T-1101 or T-1401.

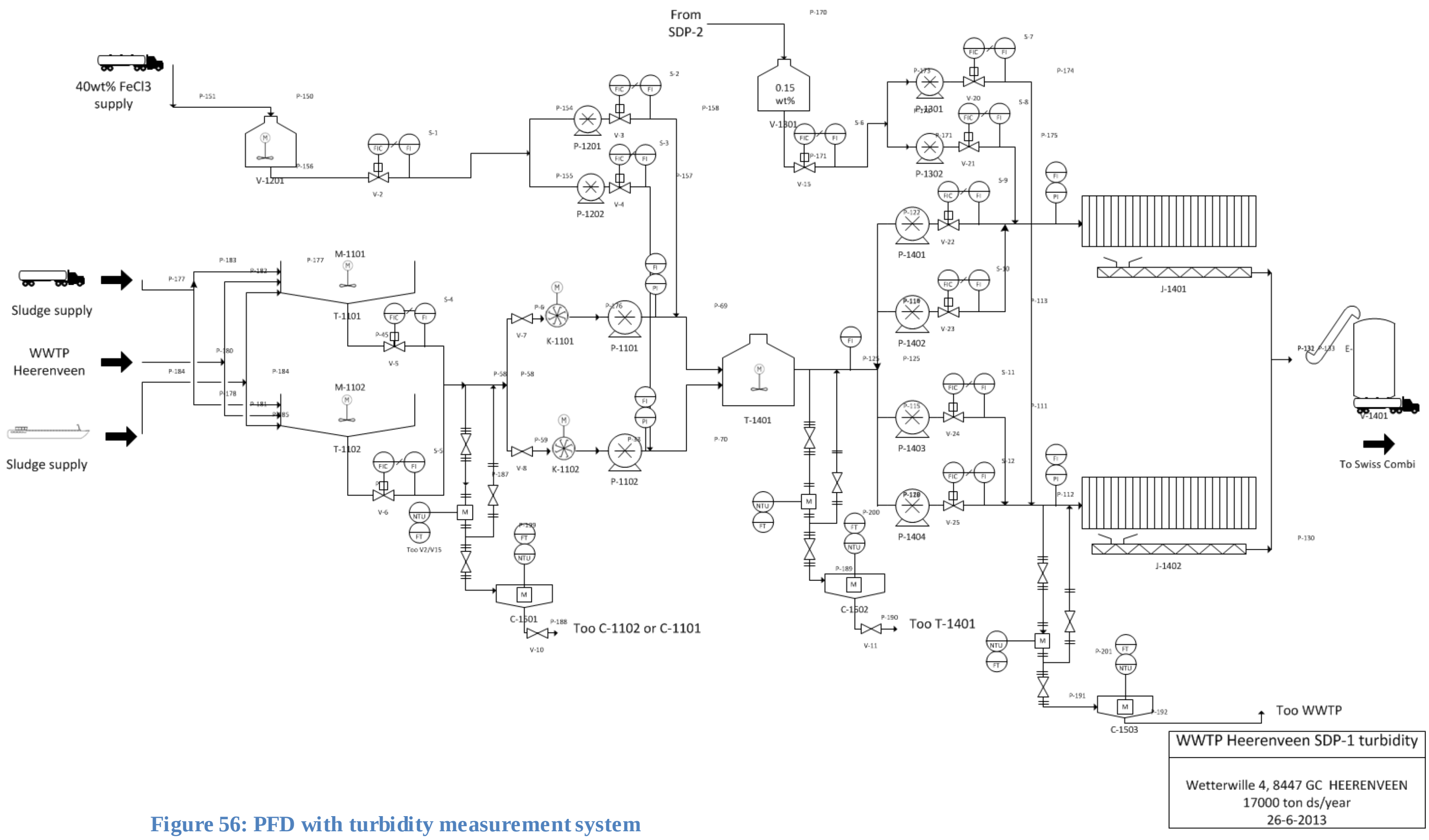


Figure 56: PFD with turbidity measurement system

Appendix 4: Preliminary lay-out and Plot plan

The preliminary lay-out consists of a satellite picture of the current WWTP and SDP in Heerenveen. The WWTP is indicated with a blue ellipse and the SDP with a brown ellipse. The satellite figure is shown below. The access and internal roads can be seen. Also the areas designated for construction facilities.

Figure 57: Preliminary lay-out

Appendix 5: Duty Specs/datasheets special equipment

The technical data for the discontinuous turbidity measurement system in the clarifiers is shown below.

Technical specifications

Measurement principle	IR absorption (880 nm)
Measurement ranges	0.0-200.0 or 0-2000 NTU0, 0-200,0 or 0-2000mg/L
Material	DELRIN, quartz
Weight	1kg
Waterproof rating	IP68
Cable	Polyurethane coated and shielded, 10m standard length (other lengths on request)
Pressure	5 bars
Operating temperature	-10 to +50°C

Figure 58: Technical specifications discontinuous turbidity meter

The technical data for the on-line turbidity meter is shown below.

Technical Data

Model Selection: All models provided fully calibrated and include 4-20 mA output, desiccant, spare measuring cuvette with light shield, power supply, and instruction manual. Also, an optional flow alarm is available to provide indication of a loss of sample flow.

Model No.	RS-485	Backlight Display	Ultrasonic Cleaning	Range NTU
TMS 561 BW (white light)	Standard	Standard	N/A	0-1000
TMS 561 BR (infrared light)	Standard	Standard	N/A	0-1000
TMS 561 CW (white light)	Standard	Standard	Standard	0-100
TMS 561 CR (infrared light)	Standard	Standard	Standard	0-100
TMS 561 DW (white light)	Standard	Standard	Standard	0-1000
TMS 561 DR (infrared light)	Standard	Standard	Standard	0-1000

Measurement Range: 0-1000 NTU (Models BW, BR, DW & DR) 0-100 NTU (Models CW & CR)

Accuracy: ±2% of reading or ±0.02 NTU below 40 NTU, whichever is greater ±5% of reading above 40 NTU

Resolution: 0.0001 NTU (below 10 NTU)

Response Time: Adjustable from 5 to 500 seconds

Display: Multi-line LCD back-lit display

Alarms: Two programmable high/low alarms, 120-240 VAC 2A Form C Relay

Analog Output: Powered 4-20 mA, 600 Ω drive, galvanically isolated

Communications Port: Bi-directional RS-485 with Modbus or W&T communication protocol

Light Source: White Light or Infrared (850nm)

Sample Flow Rate: 100 ml/min to 1 liter/min (0.026 to .26 gal/min)

Sample Pressure: 60 psi (4.1 bar) Maximum

Sample Connections: Intake and Drain tubing connections - 3/16"ID x 5/16"OD

Sample Flow Alarm: Optional, factory installed. Provides alarm indication in the event of a loss of sample flow.

Operating Temperature: 32°F to 122°F (0°C to 50°C)

Sample Temperature: 34°F to 122°F (1°C to 50°C)

Wetted Materials: Nylon, Borosilicate Glass, Silicon, Polypropylene, Stainless Steel

Power Requirements: 90-250 VAC, 47-63 Hz, 80VA

Enclosure Rating: NEMA 4X / IP 56

Environmental Conditions: Not recommended for outdoor use. Altitude up to 6560 ft. (2000 meters). Up to 95% RH (non-condensing)

Regulatory Compliance: White Light version compliant to U.S. EPA 180.1 Infrared version compliant to ISO 7027 Certifications: CE Approved, ETL listed to UL 3111-1. ETL Certified to CSA 22.2 No. 1010-1-92

Dimensions: 14" x 12" x 12" (35cm x 30cm x 30cm) See WT.050.610.101.UA.CN.

Typical Installation: See WT.050.610.200.UA,CN

Shipping Weight: 5.5 lbs (2.5 kg)

Figure 59: Technical specifications continuous turbidity meter

Appendix 6: Batch time sequence

The discontinuous turbidity meter has the following batch time. The measurement system has therefore a limited use. However the turbidity results are probably more accurate.

	time (min)
Filling	2
Settling	10
Measurement	5
Draining	2
Total	**19**

Table 28: Batch time

Appendix 7: Process safety analysis

In this appendix a process safety analysis is made of the turbidity measurement system. The used substances/chemicals are sludge, $FeCl_3$ and PE (see MSDS appendix C, D and E). For the discontinue turbidity system a clarifier (C-1501/C-1502/C-1503) has to be designed. The flow in and out the clarifier must be regulated. Therefore a flow meter and connected valve are implemented in the system. The pipes must be made of polypropylene, while the sludge stream may be corrosive. The corrosiveness will also decrease the lifetime of the turbidity measurement system. In addition, the possibility of fouling must be taken into account. The sludge stream consists of particles which can damage or clog the turbidity measurer. Therefore it is useful to have a double parallel measurement system for each measurement point. The measurements can continue even when one system is out of use due to fouling, clogging or cleaning purposes. The continuous measurement system should have a safety system because the side flow cannot be too high. Otherwise the turbidity measurer cannot handle the sludge flow and pressure might build up in the pipe. An option is to make a bifurcation before the turbidity measurer, with a flow that is just returned to the main sludge stream. The measurement systems should be constantly viewed by a process operator.

7. Conclusion

The goal of this report was to make an operational comparison between the wastewater treatment plant in Garmerwolde and in Heerenveen. Especially the sludge treatment of both plants was intensively examined. Sludge dewatering is depending mainly on flocculation and filtration. Flocculation experiments were done with a flocculation set-up in which the process conditions for flocculation were simulated and optimized. The optimum conditions for the WWTP in Garmerwolde were 145 gram $FeCl_3$/kg sludge D.S. and 12.5 gram PE/kg sludge D.S.. These results are quite different than the current flocculation conditions were 65 gram $FeCl_3$/kg sludge D.S. and 7.5 gram PE/kg sludge D.S. are added. The set-up was also used with sludge from Heerenveen, which resulted in the optimum flocculation conditions of 75 gram $FeCl_3$/kg sludge D.S. and 7 gram PE/kg sludge D.S.. These results were almost similar with the flocculation conditions used in Heerenveen (55 gram $FeCl_3$/kg sludge D.S.; 7 gram PE/kg sludge D.S.). However the flocculation set-up is not a quantitative method and therefore can only be used to find the flocculation region. The literature study focused on sludge treatment showed a few differences. First, the incoming sludge in Garmerwolde is digested, which results in a higher DSC (4.36% DSC) of the flow to the filter press than in Heerenveen (3.65% DSC). There only 30.22 % of the total incoming sludge has been digested. Digestion can improve the dewatering ability of the sludge. As already stated above also the flocculation conditions of the two plants are slightly different, however the main difference is the addition of a 1 wt% PE solution in Garmerwolde, where Heerenveen adds a 0.15 wt% PE solution. A 1 wt% solution has a much higher viscosity, which results in a more difficult distribution in the sludge. Also the way of mixing of the flocculent is quite different. Garmerwolde uses a relative modern mixing system where the PE is added and mixed 1 meter before the filter press by a rotating arm. Heerenveen adds the flocculent around 13 meters before the filter press. The mixing is done by three adjustable valves which causes a venturi effect. It is stated that a higher mixing efficiency, results in a higher dry solid content of the sludge cake. The filter presses are operated the same. However in Garmerwolde the dry solid content (25.87 % DSC) of the sludge cake is higher than in Heerenveen (23.69%). Also the filter presses of Garmerwolde operate more efficiently. In the recommendations advice is given for both plants to increase the dry solid content of the sludge cake.

8. Recommendations

Flocculation is necessary to obtain high dry solid contents of the sludge cake. However the addition of $FeCl_3$ results in high concentrations of chloride in the filtrate water and sludge cake. Also the raw material cost is quite high. Therefore different coagulants such as $MgCl_2$ and $Mg(OH)_2$ were examined by two fellow students (H.Heideman, 2013) (Sveistrup, 2013). Their report might give a good substitute for the current coagulant.

Flocculation and filtration are both complex processes with many variables. Efficient flocculation occurs in a specific range of coagulant and flocculent dosage. It is unknown how much influence the way of mixing of PE has for the dry solid content of the sludge cake. Also the distance between mixing and the filter press is a variable that has to be accounted for. Furthermore the influence of the temperature of the sludge/PE and $FeCl_3$ should be examined. It is known that the filtration efficiency is higher for higher temperatures. Also the polymer activity could increase and therefore the interaction with the sludge. In neither plant the temperature is measured during sludge conditioning and filtration. However, there may exist an optimum temperature for filtration. Also the addition of coagulant and flocculent based on the amount of dry solid in the sludge stream is not the optimum system. A different system such as a turbidity measurement system could be implemented to check coagulation and flocculation. The measured turbidity could be an indication for the dosage.

The filter press operation consists of pressing the sludge between filter plates, where water passes the filter cloth and is drained. When the pressure gradients of the operations are examined, it can be seen that already after half the operating time, the dry solid contents increases very slowly. An option to improve the dewatering is the addition of an air press system. After the set filter pressure is achieved, an air press could increase dewatering results by moving/absorbing the remaining liquid. This is already done in the paper industry. Further research should reveal whether this can be implemented in the current filter press.

Recommendations SDP Heerenveen

The mixing of PE with sludge by three adjustable valves is an outdated technology. Nowadays more efficient mixing systems are available. Also the digestion of sludge should be examined. The digestion can improve dewatering results and delivers enough gas to supply the wastewater treatment plant with electricity.

Recommendation SDP Garmerwolde

The results with the flocculation set-up are quite different than the current process conditions. The coagulant and flocculent concentrations should be examined for improved dewatering. Also the concentration of PE solution (1wt %) is quite high, which could decrease the interaction with the sludge, due to high viscosity.

9. Literature

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10. Appendices

Appendix A: Coagulant and PE calculations

Coagulant & Flocculant

Hoeveelheid slib:	a	ml.			
Gehalte droge stof:	b	%			
Hoeveelheid dr. stof:	a*(b/100)	gram			
Dosering polymeer:	x	g/kg dr. stof	**Dosering FeCl3:**	y	g/kg dr. stof
Oplossing polymeer:	d	%	**Oplossing FeCl3**	4,000	%
Gewicht polymeer:	(x*a*(b/100))/(1000)	gram	**Gewicht coagulant**	(y*a*(b/100))/(1000)	gram
polymeer:	(((x*a*(b/100))/(1000))/d)/10)	ml	**Gewicht polymeer:**	(y*a*(b/100))/(1000)*1.7482	ml

Figure 60: theoretic dosage calculation

The number 1.7482 is calculated below:

Molecuul:	$FeCl_3$					
S.m:	1,43	kg/m^3				
Oplossing:	40	%				
Atoomgewicht:	Fe: 56		Cl_3: 35,5			
	▼		▼			
Molecuulgewicht:	56	+	106,5	=	**162,5**	
Per liter:	1,43	x	0,40	=	**572**	gram $FeCl_3$
Per liter:	572	x	0,3446	=	**197,12**	gram Fe
1 kg $FeCl_3$:	1	/	572	=	**1,748**	liter $FeCl_3$ (40%)

Figure 61: measurement of specific number

An example of a flocculation experiment is given in the table below.

Experiment	75-125 gram $FeCl_3$/kg D.S.	7 gram PE/kg D.S.	DSC 3.47%
Tube	**$FeCl_3$ (ml)**	**PE (ml)**	
1	0.63	2.43	
2	0.71	2.43	
3	0.80	2.43	
4	0.88	2.43	
5	0.96	2.43	
6	1.05	2.43	

Table 29: flocculation experiment example

Appendix B: Flocculation experiments

The experiments, to visualize coagulation and flocculation, were done with a flocculation set-up. The coagulation of sludge from Garmerwolde and Heerenveen was already made clear in this report by figures 40-43 and 45 and 46, respectively. The optimum flocculation results are shown below. The flocculation of sludge in the tubes is shown in figures 62 and 64 where after the sludge flakes were separated and shown in figures 63 and 65.

<u>Garmerwolde</u>

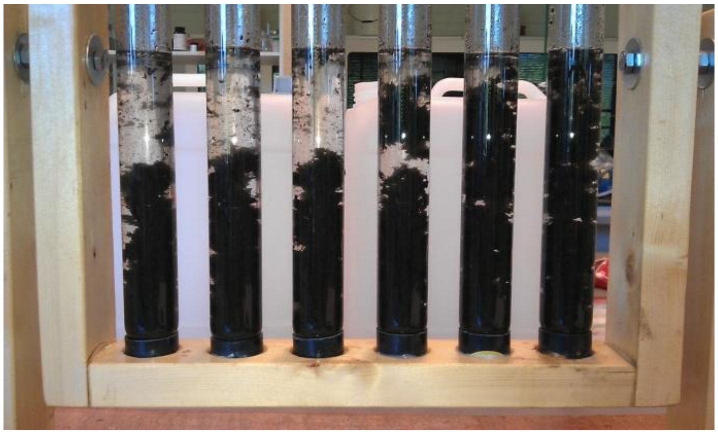


Figure 62: 125-175 $FeCl_3$/kg D.S. & 12.5 PE/kg D.S.

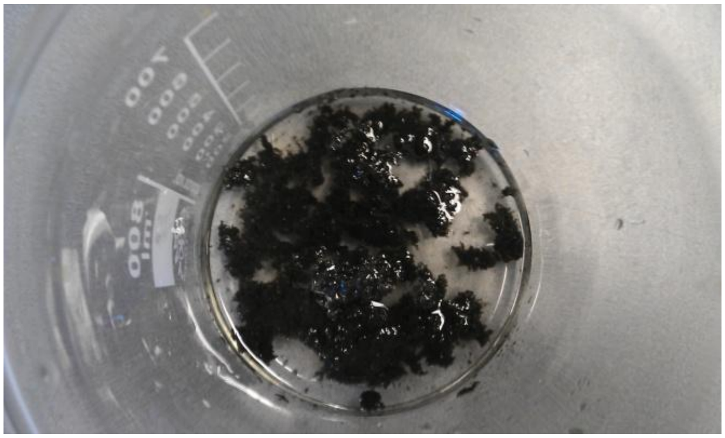


Figure 63: 145 gram $FeCl_3$/kg D.S. & 12.5 PE/kg D.S.

<u>Heerenveen</u>

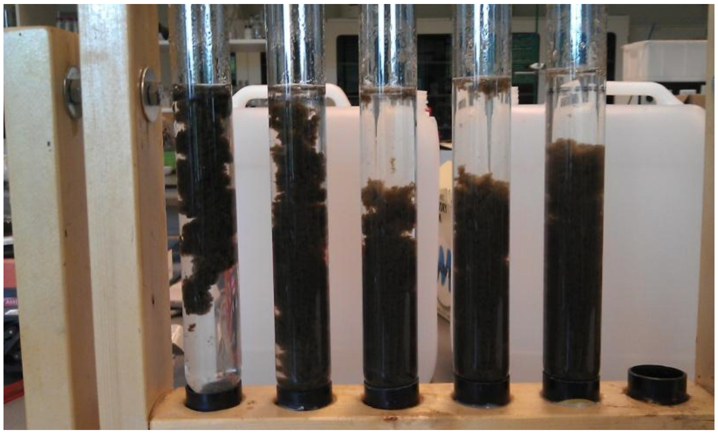


Figure 64: 65-105 $FeCl_3$/kg D.S. & 7 PE/kg D.S.

Figure 65: 65 gram $FeCl_3$/kg D.S. & 7 PE/kg D.S.

Appendix C: MSDS polymer Kemira, C-82089

Kemira

MSDS: 0099904
Drukdatum: 24-mrt-2009
Datum van herziening: 24-mrt-2009

VEILIGHEIDSINFORMATIEBLAD

1. IDENTIFICATIE VAN DE STOF OF HET PREPARAAT EN VAN DE VENNOOTSCHAP/ONDERNEMING

Productbenaming: **SUPERFLOC® C-82089**
PRODUKTOMSCHRIJVING: Vloeibaar Kationisch polyacrylamide

Kemira Kemi AB, P.O. Box 902, SE-25109, HELSINGBORG, Sweden - +46 42 17 10 00
ProductSafety.NL.Botlek@kemira.com
IN GEVAL VAN NOOD: IN NEDERLAND: 0181-295500; BUITEN NEDERLAND: 31-181-295500

® gedeponeerd handelsmerk in de U.S. Kan buiten de U.S. gedeponeerd zijn of is in afwachting ervan, danwel een handelsmerk. Het merk is of kan worden gebruikt onder licentie.

2. IDENTIFICATIE VAN DE GEVAREN

Gevaren voor mens en milieu
Irriterend voor de huid.

3. SAMENSTELLING EN INFORMATIE OVER DE BESTANDDELEN

GEVAARLIJKE BESTANDDELEN

COMPONENT / CAS. Nr.	% (w/w)	EG-Nr	Symbool / R-ZINNEN
Petroleumdestillaat, hydrotreated, lichte fractie 64742-47-8	24.0 - 28.0	265-149-8	Xn; R65
Citroenzuur 77-92-9	2.0 - 3.0	201-069-1	Xi; R:36
Alcoholen (ethoxylated C12-16), 68551-12-2	~ 2.7	-	Xn; N; R:22-38-41-50
C12-C14 ethoxylated alcohol 68439-50-9	0 - 3.5	-	Xn, N; R:22-38-41-50
Alcoholen (ethoxylated C10-16), 68002-97-1	~ 2.7	-	Xn; N; R:22-38-41-50

Zie sectie 16 voor de risico-zinnen van de ingredienten.

4. EERSTEHULPMAATREGELEN

Inname:
Alleen laten braken op instructie van een arts. Nooit een bewusteloos persoon laten drinken (of eten). Bij inname onmiddellijk een arts raadplegen.

Contact met de huid:
Met het produkt in aanraking gekomen kleding wassen alvorens opnieuw te gebruiken. Was onmiddellijk met veel water. Verwijder direkt gecontamineerde kleding en schoenen. Vraag aandacht van een arts wanneer pijn of irritatie blijft na wassen, of bij tekenen of symptomen van overmatige blootstelling.

Contact met de ogen:
Onmiddellijk met overvloedig water spoelen gedurende tenminste 15 minuten.

Inademing:
In de frisse buitenlucht brengen. Bij moeizame ademhaling zuurstof toedienen. Een arts raadplegen bij aanhoudende symptomen.

---

5. BRANDBESTRIJDINGSMAATREGELEN

Geschikte blusmiddelen:
Gebruik waternevelstraal, kooldioxide of poeder.

BESCHERMENDE UITRUSTING
Volledige brandbeschermende kleding dragen. Zie sektie 8 (Maatregelen ter beheersing van blootstelling/ persoonlijke bescherming). Brandweerlieden en anderen die worden blootgesteld dienen een perslucht toestel te dragen.

SPECIALE GEVAREN
Bij blootstelling aan vuur containers koel houden door te bespuiten met water.

Non-Printing Label
geen

---

6. MAATREGELEN BIJ ACCIDENTEEL VRIJKOMEN VAN DE STOF OF HET PREPARAAT

Persoonlijke voorzorgsmaatregelen:
Indien de hoogte van de expositie niet bekend is, draag goedgekeurde onafhankelijke adembescherming. Indien de hoogte van de expositie bekend is, draag een goedgekeurd gelaatsmasker, geschikt voor dit expositieniveau. Draag een tweedelig PVC pak met capuchon of een PVC overall met capuchon bij de beschermende kleding / uitrusting genoemd in sectie 8 (Beheersing van blootstelling/Persoonlijke bescherming).

Reinigingsmethoden:
Gemorst materiaal laten absorberen aan inert materiaal en opscheppen. Spoel de omgeving waar gemorst is met water. Het produkt kan gevaar voor uitglijden opleveren. Indien gladheid voortduurt, meer absorptie materiaal gebruiken.

---

7. HANTERING EN OPSLAG

Hantering

geen

Opslag
Geen ijzeren, koperen of aluminium containers of materieel gebruiken om afbraak van het produkt en corrosie van het materieel te voorkomen. Vlampuntbepalingen op dit soort materialen dienen te moeten worden uitgevoerd, volgens voorschriften en wetenschappelijke standaards, met de Pensky-Martens Gesloten Beker testmethode. Deze methode geeft een vlampunt groter dan 93 C (200 F). Ofschoon tot 93 C (200 F) geen vlampunt werd gevonden, kwamen enige brandbare dampen vrij tijdens de test, aangetoond door het vergroten van de testvlam; daarom dient oplettendheid aanwezig te zijn tijdens opslag en transport.

OPSLAGTEMPERATUUR: Kamertemperatuur
REDEN: Integriteit.

8. MAATREGELEN TER BEHEERSING VAN BLOOTSTELLING/PERSOONLIJKE BESCHERMING

CONTROLE PARAMETERS

Petroleumdestillaat, hydrotreated, lichte fractie 64742-47-8

Germany: MAK (Maximale Arbeitsplatzkonzentration)	1000 mg/m³ 200 ppm (MAK)
ACGIH (TLV)	(hud)
Andere waarde	1200 mg/m³ (tillverkaren) 165 ppm (tillverkaren)

Technische maatregelen:
Waar dit materiaal niet in een gesloten systeem wordt gebruikt, zorgen voor omkasting en plaatselijke afzuiging, om blootstelling tegen te gaan.

Bescherming van de ademhalingswegen:
Waar blootstelling beneden de vastgestelde blootstellingsgrens ligt, is geen ademhalingsbescherming vereist.
Waar blootstelling de vastgestelde blootstellingsgrens overschrijdt, wordt het gebruik van ademhalingsbescherming aanbevolen geschikt voor deze stof en de mate van blootstelling.

Bescherming van de ogen:
Oog-en veiligheidsdouches moeten aanwezig zijn in afdelingen waar blootstellingsgevaar bestaat.
Draag oog-/gelaatsbescherming (zuurbril/gelaatsscherm).

BESCHERMING VAN DE HUID:
Draag ondoordringbare handschoenen en geschikte beschermende kleding.
Aanraking met de huid vermijden.

Bijkomend advies:
Gezicht en handen goed wassen met water en zeep voor het eten, drinken of roken.
Eten, drinken en tabakswaren niet meenemen, bewaren of gebruiken waar deze stof in gebruik is.

9. FYSISCHE EN CHEMISCHE EIGENSCHAPPEN

Kleur:	gebroken wit
Voorkomen:	vloeibaar
Geur:	koolwaterstof
Kookpunt/traject	Waterige fase ~100 C; Oliefase ~175 C
Smeltpunt:	Niet beschikbaar
Dampspanning:	gelijkaardig aan water
Soortelijk gewicht:	~1.0
Dampdichtheid:	gelijkaardig aan water
% VLUCHTIGE COMPONENTEN (op gewichtsbasis):	~50
pH:	3 - 4in water
Verzadiging in lucht (vol%):	Niet beschikbaar
Verdampingssnelheid:	Niet beschikbaar
OPLOSBAARHEID IN WATER:	Beperkt door viscositeit
Vluchtige Organische Stoffen (EU):	2.9 % (g/g)
Vlampunt:	>100 °C gesloten beker

9. FYSISCHE EN CHEMISCHE EIGENSCHAPPEN

ONTVLAMBAARHEIDS-GRENZEN (% per vol.):	Niet beschikbaar
Zelfontbrandingstemperatuur:	Niet beschikbaar
Ontledingstemperatuur:	Niet beschikbaar
Verdelingscoëfficiënt (n-octanol/water):	Niet beschikbaar

10. STABILITEIT EN REACTIVITEIT

Stabiliteit:	Stabiel
Te vermijden omstandigheden:	Contact met sterk oxyderende agentia vermijden.
Polymerisatie:	Kan niet optreden
Te vermijden omstandigheden:	Niet bekend
Te vermijden substanties:	Sterke oxydatiemiddelen.
Gevaarlijke ontledingsproducten:	ammoniak kooldioxide Koolmonoxide stikstofoxiden waterstofchloride

11. TOXICOLOGISCHE INFORMATIE

Mogelijke gevolgen voor de gezondheid
Irriterend voor de huid.

PRODUCT TOXICOLOGISCHE INFORMATIE

Oraal	rat	Acute LD50>5000 mg/kg
huid	konijn	Acute LD50>2000 mg/kg
Inademing	rat	Acute LC50 4 u>20.0 mg/l
Acute irritatie	huid	irriterend
Acute irritatie	oog	Niet irriterend
Sensibilisatie	huid	Geen gegevens
Sensibilisatie	Inademing	Geen gegevens
Ames Salmonella Assay	Geen gegevens	

GEGEVENS OVER HET GEVAARLIJK BESTANDDEEL

Acute toxiciteit
Alcoholen (ethoxylated C10-16),
Oraal rat Acute LD50 (daadwerkelijk) 1600 - 2500 mg/kg
huid konijn Acute LD50 (daadwerkelijk) > 2000 mg/kg
Alcoholen (ethoxylated C12-16),
Oraal rat Acute LD50 (daadwerkelijk) 1600 - 2500 mg/kg
huid konijn Acute LD50 (daadwerkelijk) > 2000 mg/kg
Citroenzuur
oraal (naar de maag) rat Acute LD50 (daadwerkelijk) 11700 mg/kg
C12-C14 ethoxylated alcohol
Oraal rat Acute LD50 (daadwerkelijk) 1.6 - 2.5 g/kg
huid konijn Acute LD50 (daadwerkelijk) > 2.0 g/kg
Petroleumdestillaat, hydrotreated, lichte fractie
Oraal rat Acute LD50 (daadwerkelijk) > 5 g/kg
huid konijn Acute LD50 (daadwerkelijk) > 3.16 g/kg

PLAATSELIJKE EFFECTEN OP DE HUID EN IN DE OGEN
Alcoholen (ethoxylated C10-16),
Acute oogirritatie konijn Veroorzaakt ernstige schade
Acute huidirritatie konijn Irriterend
Alcoholen (ethoxylated C12-16),
Acute huidirritatie Irriterend
Acute oogirritatie Veroorzaakt ernstige schade
Citroenzuur
Acute huidirritatie Niet irriterend
Acute oogirritatie Veroorzaakt ernstige schade
C12-C14 ethoxylated alcohol
Acute oogirritatie Veroorzaakt ernstige schade
Acute huidirritatie Irriterend
Petroleumdestillaat, hydrotreated, lichte fractie
Acute huidirritatie Niet irriterend
Acute oogirritatie Niet irriterend

14. INFORMATIE MET BETREKKING TOT HET VERVOER

Deze sectie bevat standaard informatie over transportclassificatie. Zie de toepasselijke transport regelgeving voor specifieke eisen.

ADR/RID
klasse NIET VAN TOEPASSING/NIET AAN VOORSCHRIFTEN ONDERHEVIG
IMO
Proper shipping name: NIET VAN TOEPASSING/NIET AAN VOORSCHRIFTEN ONDERHEVIG
ICAO / IATA
Proper shipping name: NIET VAN TOEPASSING/NIET AAN VOORSCHRIFTEN ONDERHEVIG
Verpakkings instructies / maximum netto hoeveelheid per colli:
Passagiersvliegtuig: -
Vrachtvliegtuig: -

15. WETTELIJK VERPLICHTE INFORMATIE

EU-MERKEN EN ETIKETTERING
Symbo(o)l(en): Xi - Irriterend

R-ZINNEN:
R38 - Irriterend voor de huid.

S-ZINNEN:
S61 - Gemorste stof is uiterst glad.

OPSLAGINFORMATIE
Europese Unie:
Alle bestanddelen van dit produkt komen voor in de Europese Inventaris van Bestaande Chemische Stoffen (EINECS) of hoeven niet opgenomen te worden in EINECS.

VS:
Alle bestanddelen van dit produkt komen voor in de TSCA Inventaris, of hoeven niet opgenomen te worden in de TSCA Inventaris.

Canada:
Alle bestanddelen van dit produkt komen voor in de Domestic Substances List (DSL), of hoeven niet opgenomen te worden in de DSL.

Australië Alle componenten van dit product zijn inbegrepen in de Australische Inventaris van Chemische Substanties (AICS) of niet om op AICS vereist worden vermeld.

China: Alle bestanddelen van dit produkt zijn opgenomen in de Chinese inventaris of behoeven niet te worden opgenomen in de Chinese inventaris.

16. OVERIGE INFORMATIE

REDEN VOOR UITGIFTE: Nieuw produkt

Petroleumdestillaat, hydrotreated, lichte fractie
- R65 - Schadelijk: kan longschade veroorzaken na verslikken.

Citroenzuur
- R36 - Irriterend voor de ogen.

Alcoholen (ethoxylated C12-16),
- R22 - Schadelijk bij opname door de mond.
- R38 - Irriterend voor de huid.
- R41 - Gevaar voor ernstig oogletsel.
- R50 - Zeer vergiftig voor in het water levende organismen.

C12-C14 ethoxylated alcohol
- R22 - Schadelijk bij opname door de mond.
- R38 - Irriterend voor de huid.
- R41 - Gevaar voor ernstig oogletsel.
- R50 - Zeer vergiftig voor in het water levende organismen.

Alcoholen (ethoxylated C10-16),
- R22 - Schadelijk bij opname door de mond.
- R38 - Irriterend voor de huid.
- R41 - Gevaar voor ernstig oogletsel.
- R50 - Zeer vergiftig voor in het water levende organismen.

Richard Moye, Product Regulatory, 1-251-662-1561

Appendix D: MSDS polymer BASF, zetag 9048 FS

Ciba® ZETAG® 9000 Series Inverse Emulsions

Liquid Grade Cationic Polyelectrolytes

Description

High molecular weight polyacrylamide based flocculants, which exhibit varying degrees of cationic charge. They are supplied as low viscosity free flowing liquids in Inverse Emulsion form.

Chemical Structure

Co-polymers of acrylamide and quaternised cationic monomer.

Principal Use

Polyelectrolytes for conditioning a variety of municipal and industrial substrates prior to mechanical or static solid/liquid separation.

These products are not suitable for use in potable water applications. If in any doubt regarding suitability for a given application please contact your local sales representative.

Benefits

Highly effective across a wide range of applications (eg mechanical dewatering and thickening, flotation and clarification). Operation over a wide pH range (4–9).

Typical Properties

Appearance:	Cloudy colourless to white liquid		
Specific gravity:	Approx. 1.03		
pH of 1% solution at 25°C:	3.6-4.1		
Viscosity as supplied:	Approx. 900cPs		
Molecular Weight:	Very High		
Apparent Viscosity (cP) at 25°C at conc. shown (%):	0.25%	0.50%	1.0%
	Approx. 650cP	Approx. 1350cP	Approx. 2860cP

	Product	Cationic Charge
Linear	**ZETAG 9012**	Low
	ZETAG 9014	Low-Medium
	ZETAG 9016	Medium
	ZETAG 9018	High
	ZETAG 9019	Ultra-High
Structured	**ZETAG 9044FS**	Low-Medium
	ZETAG 9046FS	Medium
	ZETAG 9066FS	Medium
	ZETAG 9048FS	High
	ZETAG 9068FS	High
	ZETAG 9049FS	Ultra High

Storage	Under normal storage conditions within the range 5 - 25°C, the product will be stable for at least 6 months. Storage outside the above specified temperature range for long periods may adversely affect the product over a long period and should thus be avoided, if possible. It is recommended that stock solutions at 0.25 - 0.5% are prepared regularly and for maximum effect such solutions should be used within 5 days. Beyond this period some loss in efficiency of the product may occur. Depending upon storage conditions and product age, product separation may occur. If separation is observed the product should be re-dispersed well by mixing or re-circulation before use to ensure maximum efficiency.
Storage Advice	• Avoid extreme temperatures especially frost and freezing conditions • Avoid contact with water prior to make up • Do not store IBC (Sotz) containers in direct sunlight • Do not store product in outdoor tanks that lack temperature control • Do not recirculate in bulk storage tanks too often (typically once per week, for ~1 hour, is all that is required). NOTE - Never recirculate continuously • Keep containers tightly closed in a dry, cool and well ventilated place. Packages should be kept sealed when not in use

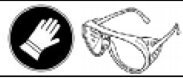
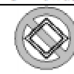
Shipping & Handling	As with all cationic polyelectrolytes the product exhibits toxicity towards fish. It is important that precautions are taken where the product may come into direct contact with fresh water courses, streams and rivers. Corrosion towards most standard materials of construction is very low. Stainless steel, fibreglass, polyethylene, polypropylene and rubberised surfaces are recommended. In some cases aluminium surfaces can be adversely affected. Packaging details are available on request from your local sales representative. Spilled product is slippery underfoot, very slippery when wet, stir before use. Please refer to the MSDS for methods of removing the polymer. The following materials should be avoided when handling neat inverse emulsions products; ✕ EPDM (Ethylene Propylene Rubber) ✕ Natural Rubber ✕ Polyurethane ✕ PVC
Handling Advice	• Use low shear pumps for neat product (progressive cavity or peristaltic) • Use and recommend the correct materials for stators in progressive cavity type pumps i.e. Nitrile rubber or Hypalon • If diaphragm pumps e.g. Prominent, LMI etc are used, maximise the stroke volume and minimise the stroke frequency, especially at low temperatures • Avoid pumping neat product through pipe work < 10 mm in diameter • Do not pump or use product at low temperatures

Health & Safety	Detailed information on the product described in this leaflet can be found in our relevant Health and Safety Information (Material Safety Data Sheet).
Contact	For further information contact your regional office, details of which can be obtained on our website; www.cibasc.com
Important	All trademarks mentioned are either property of or licensed to Ciba and registered in relevant countries. The following supersedes Buyer's documents. SELLER MAKES NO REPRESENTATION OR WARRANTY, EXPRESS OR IMPLIED, INCLUDING OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. No statements herein are to be construed as inducements to infringe any relevant patent. Under no circumstances shall Seller be liable for incidental, consequential or indirect damages for alleged negligence, breach of warranty, strict liability, tort or contract arising in connection with the product(s). Buyer's sole remedy and Seller's sole liability for any claims shall be Buyer's purchase price. Data and results are based on controlled or lab work and must be confirmed by Buyer by testing for the intended conditions of use. The product(s) has (have) not been tested for, and is (are) therefore not recommended for, uses for which prolonged contact with mucous membranes, abraded skin, or blood is intended; or for uses for which implantation within the human body is intended. Please note that products may differ from country to country. If you have any queries, kindly contact your local Ciba representative. Further information at website: http://www.ciba.com

Appendix E: MSDS sludge

ArcelorMittal

Material Safety Data Sheet

WHMIS	Protective Clothing	TDG Road/Rail
		

Section I - Product Identification and Uses		
Common/Trade Name	**ACTIVATED SLUDGE**	MSDS # **9966**
Synonyms	Clarifier overflow, Mixed Liquor, Waste/Return Activated Sludge, autotrophic and heterophic bacteria	
Chemical Name	Not available	
Chemical Formula	Not available	
Chemical Family	Not available	
Supplier	ARCELORMITTAL DOFASCO INC. P.O. BOX 2460 HAMILTON, ON. CANADA L8N 3J5 (905) 548-7200 EXT. 4051 (By-Product Sales)	
Material Uses	Internally Generated By-Product	

Section IA - First Aid Measures	
Eye Contact	Flush with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Seek medical attention if irritation persists.
Skin Contact	Wash with soap and water. Seek medical attention if irritation persists. Launder contaminated clothing before reuse.
Inhalation	Remove person to fresh air. Seek medical attention if symptoms persist.
Ingestion	Do not induce vomiting. Seek medical attention.

Section II - Composition and Information on Ingredients				
Name	**CAS#**	**% by Weight**	**TLV/PEL**	**LC_{50}/LD_{50}**
1. WATER	7732-18-5	99	Not available	Not available
2. TOTAL SUSPENDED SOLIDS (autotrophic, hetertrophic bacteria)			Not available	Not available
3. NITROGEN	7727-37-9	0.05	Simple asphyxiant	Not available
4. AMMONIA	7664-41-7	0.01-0.02	TWA: 25 STEL: 35 (ppm) from ACGIH (TLV)	GAS (LC50): Acute: 2115 ppm 4 hour(s) [Mouse]
5. PHOSPHORUS	7723-14-0	0.005	TWA: 0.1 (mg/m^3) from ACGIH (TLV)	ORAL (LD50): Acute: 30.303 mg/kg [Rat]
6. SODIUM THIOCYANATE	540-72-7	0.005		
7. PHENOL	108-95-2	0.0006	TWA: 5 (ppm) from ACGIH (TLV)	

Section III - Toxicological Properties	
Routes of entry	Eye contact. Ingestion. Inhalation. Skin contact.
TLV	Not available
Toxicity for animals	LD50: Not available LC50: Not available
Chronic effects on humans	**CARGINOGENIC EFFECTS:** Not available **MUTAGENIC EFFECTS:** Not available **TERATOGENIC EFFECTS:** Not available **DEVELOPMENTAL TOXICITY:** Not available. Repeated or prolonged exposure may cause dermatitis.
Acute effects on humans	Eye and skin contact may cause irritation. Contact with broken skin may cause minor infections. Inhalation of vapour may cause upper respiratory tract irritation. Ingestion of fluid may cause irritation and digestive upset.

Section IV - Physical Data

Physical State and Appearance	Liquid and semi-solid slurry	**Vapor Pressure**	Not available
pH	7.1	**Evaporation Rate**	Not available
Odor Threshold	Not available	**Viscosity**	Not available
Volatility	<1%	**Water/Oil Dist. Coeff.**	Not available
Melting/Sublimation Point	Not available	**Critical temperature**	Not available
Boiling/Condensation Point	Not available	**Instability temperature**	Not available
Specific Gravity	1.0	**Conditions of instability**	Not available
Vapor Density	Not available	**Solubility**	Not available
Dispersion Properties	Not available	**Odor**	Earthy odour
		Color	Brown

Section V – Fire and Explosion Data

The product is	Will not burn and will not support combustion
Auto-ignition temperature	Not applicable
Fire degradation products	None
Flash Points	Not applicable
Flammable Limits	Not applicable
Fire Extinguishing Procedures	Use extinguishing media suitable for surrounding materials. Use SCBA during fire fighting.
Flammability	Not available
Risks of explosion	Risks of explosion of the product in presence of mechanical impact: Not applicable Risks of explosion of the product in the presence of static discharge: Not applicable

Section VI – Reactivity Data

Stability	The product is stable
Hazardous Decomp. Products	Not available
Degradability	Not available
Products of Degradation	Not available
Corrosivity	Not available
Reactivity	Not available

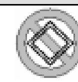
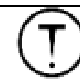
Section VII – Preventive Measures

Waste Information	Dispose of in accordance with local, provincial and federal regulations.
Storage	Not applicable.
Precaution	After handling, always wash hands and face thoroughly with soap and water. Avoid breathing mists or vapours. Avoid contact with skin and eyes. Launder contaminated clothing prior to reuse.
Small spill and leak	Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements. Use appropriate personal protective equipment during clean-up.
Large spill and leak	Refer to small spills.

Section VIII – Protective Measures

Protective Clothing	Safety glasses with side shields. Face shield if splashing is likely to occur. Neoprene gloves to prevent contact.	
Engineering Controls	General ventilation under normal conditions.	

Section IX – Classification

TDG Road/Rail	Not controlled under TDG (Canada). Not applicable.	
Maritime Transportation	Not available	
WHMIS	WHMIS CLASS D-2B: Material causing other toxic effects (TOXIC)	
Federal and Provincial Regulations	No products were found.	

Section IX – Classification

TDG Road/Rail	Not controlled under TDG (Canada). Not applicable.	
Maritime Transportation	Not available	
WHMIS	WHMIS CLASS D-2B: Material causing other toxic effects (TOXIC)	
Federal and Provincial Regulations	No products were found.	

Section X – Other Information

References	ArcelorMittal Dofasco Material Safety Data Sheet

If the use of this material is other than that specified by the supplier, additional precautions may be required.

Effective Date: March 1, 2013

EMERGENCY CONTACT: 1-760-476-3962
3E COMPANY CODE: 333211

To the best of our knowledge, the information contained herein is accurate. However, neither the above named supplier nor any of its subsidiaries assumes any liability whatsoever for the accuracy or completeness of the information contained herein. Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

Appendix F: Schematic view filter plate

In this appendix the dimensions of the filter plate is shown below. The filter plate is used for both wastewater treatment plant in Heerenveen and Garmerwolde. The sludge is pumped through the feed channel into the chambers. The feed channel has a diameter of 150 mm. The water, which is separated from the sludge, is drained by four channels located in every corner.

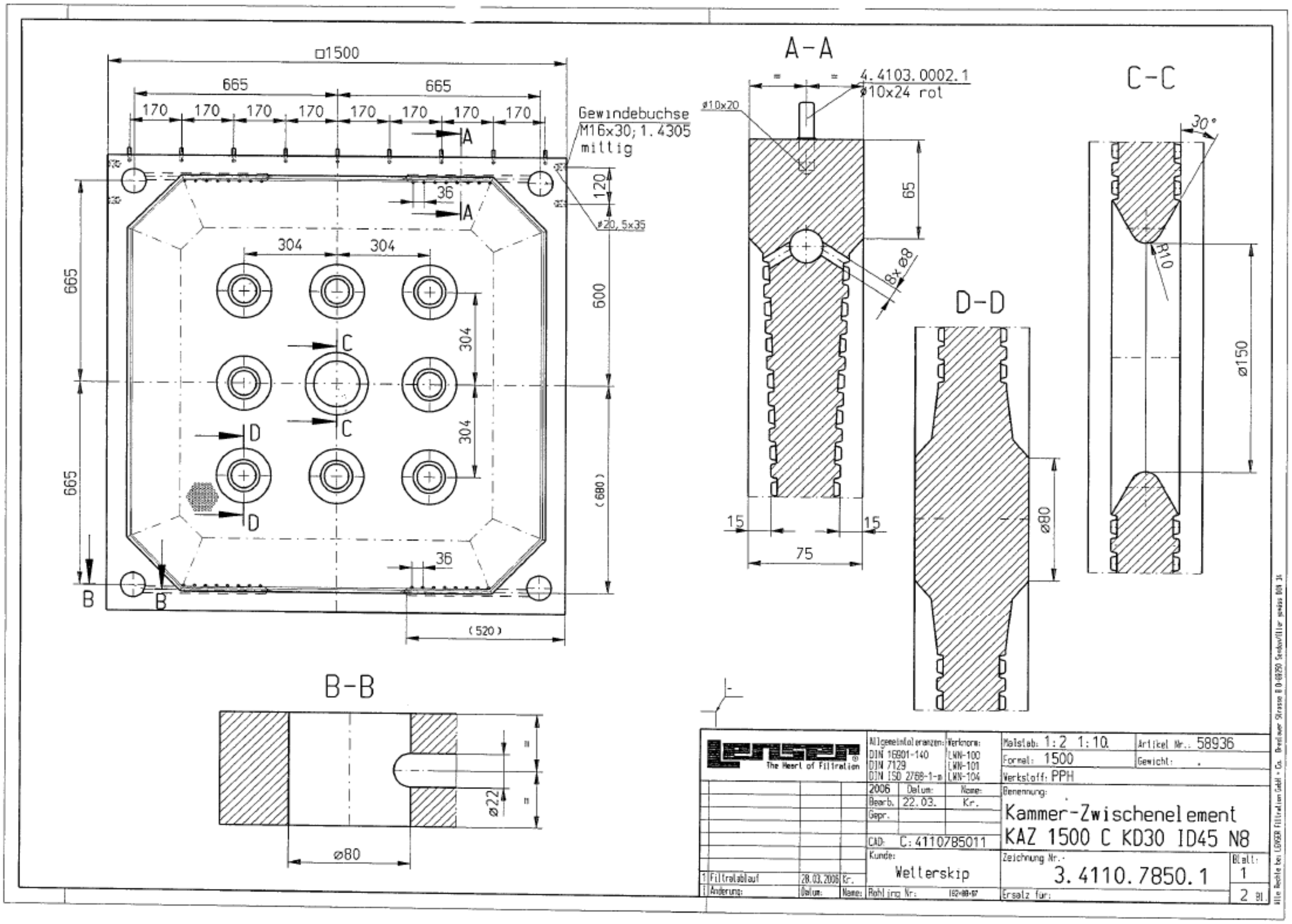


Figure 66: Dimensions chamber filter plate

Appendix G: Pressure curves

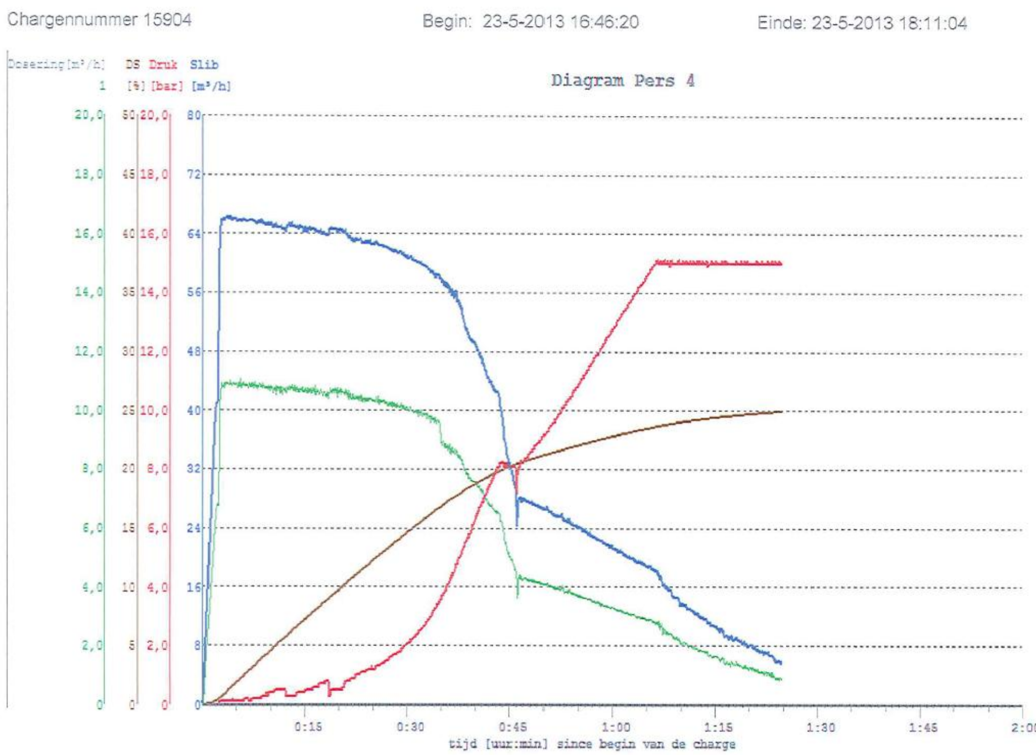


Figure 67: Pressure gradient Heerenveen

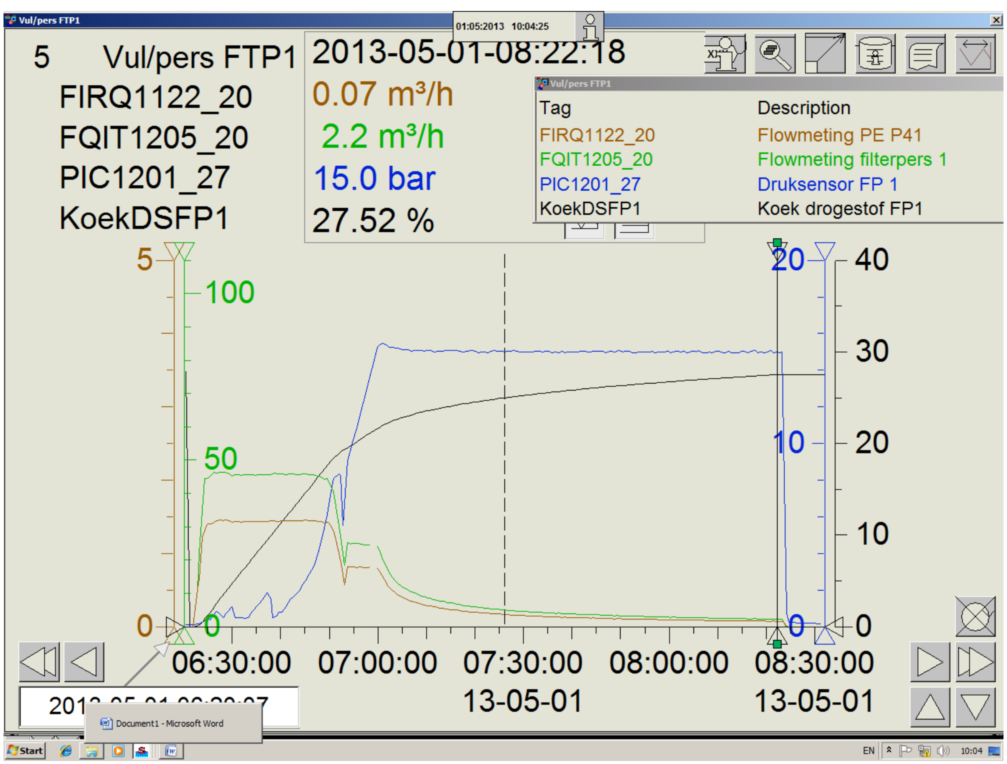


Figure 68: Pressure gradient Garmerwolde

Appendix H: P&ID/PFD Heerenveen equipment specifications

SDP-1

sludge buffertank T1101/T1102		**sludgemixer M1101/M1102**		**slicer K1101/K1102**		**sludge supply pump P1101/1102**	
number	2	number	2	number	2	number	2
volume (m3)	1000	power (kW)	10	capacity (m3/h)	50	capacity (m3/h)	40
diameter (m)	21.5	proppelordiameter (mm)	580	speed (rpm)	49	speed (rpm)	275
side depth (m)	2.75	speed (rpm)	475	power (kW)	2.2	power (kW)	5.5
						head (kPa)	200
sludgemixer M1401		**low pressure pump P1401/P1403**		**high pressure pump P1402/P1404**		**filter press**	
number	1	number	2	number	2	number	2
diameter (mm)	950	capacity (m3/h)	5- 75	capacity (m3/h)	2.5-24	number of chambers	126
speed (rpm)	142	head (kPa)	1200	head (kPa)	1500	power total (kW)	10.3
power (kW)	7.5	speed (rpm)	60-341	speed (rpm)	60-341	hydra-unit (kW)	7.5
		power (kW)	30	power (kW)	22	afspuit (kW)	0.92
						plate transporter (kW)	0.75
						drippan (kW)	1.1
sludge silo V1401		**$FeCl_3$ buffer V1201**		**$FeCl_3$ dosage pump P1201/P1202**		**PE buffer V1301**	
volume (m3)	100	number	1	number	2	volume (m3)	12
		volume (m3)	12	capacity (m3/h)	1.2	diameter (m)	2.5
		diameter (m)	2.5	head (kPa)	200	height (m)	2.5
		height (m)	2.5	speed (rpm)	11 - 66		
				power (kW)	0.55		
conditioned sludgebuffer tank T1401		**transporter J1401/J1402**		**PE dosage pump P1301/P1302**			
number	2	capacity (m3/h)	40	number	2		
volume (m3)	40	power (kW)	22	capacity (m3/h)	0.5 - 18		
height (m)	4			head (kPa)	800		
				power (kW)	18.5		

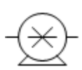
SDP-2

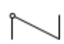
sludge buffertank T2101/T2102/T2103		**sludgemixer M2101/M2102/M2103**		**slicer K2101/K2102**		**sludge supply pump P2101/2102**	
number	3	number	3	number	2	number	2
volume (m3)	1000	power (kW)	15	capacity (m3/h)	50	capacity (m3/h)	40
diameter (m)	21.5	proppelordiameter (mm)	850	speed (rpm)	49	speed (rpm)	275
side depth (m)	2.75			power (kW)	2.2	power (kW)	5.5
						head (kPa)	200
sludgemixer M2401		**low pressure pump P2401/P2403**		**high pressure pump P2402/P2404**		**filter press**	
number	1	number	2	number	2	number	2
diameter (mm)	950	capacity (m3/h)	15- 70	capacity (m3/h)	2.5-24	number of chambers	154
speed (rpm)	133	head (kPa)	800	head (kPa)	800	power total (kW)	9.2
power (kW)	9.2	speed (rpm)	380	speed (rpm)	80 - 230	hydra-unit (kW)	7.5
		power (kW)	22	power (kW)	30	afspuit (kW)	0.92
						plate transporter (kW)	0.75
sludge silo V2401							
volume (m3)	125	**$FeCl_3$ buffer V2201/V2202**		**$FeCl_3$ dosage pump P2201/P2202**			
diameter (m)	6	number	1	number	2	**PE 0.15 wt% buffer V2303**	
height (m)	4.5	volume (m3)	16	capacity (m3/h)	0.6	volume (m3)	40
		diameter (m)	3	head (kPa)	150		
				speed (rpm)	1410		
				power (kW)	0.55		
conditioned sludgebuffer tank T2401		**PE 0.5 wt% buffer V2302**		**PE 50wt% buffer V2301**		**transporter J2401/J2402**	
number	2	volume (m3)	5	volume (m3)	16	capacity (m3/h)	40
volume (m3)	40					power (kW)	22
height (m)	4						
PE dosage pump P2301/P2302							
number	2						
capacity (m3/h)	1.5-24						
head (kPa)	800						
power (kW)	18.5						
speed (rpm)	31-310						

Appendix I: P&ID/PFD Garmerwolde equipment specifications

Extern undigested sludge buffer T1201/T1202		**Filter F-1201/F-1101**		**Homogenisation buffer T-1203**	
number	2	number	2	number	1
volume (m3)	1000	width (mm)	3	volume (m3)	100
Digestion tanks V-1301/V-1302		**Digestion sludge buffer T-1301/T-1302**		**conditioned slubbuffer tank T-1601**	
number	2	number	2	number	1
volume (m3)	4600	volume (m3)	1300	volume (m3)	30
height (m)	10			height (m)	3
filter press S-1601/S-1602/S-1603		**filter press S-1604/S-1605**		**FeCl3 (40wt%) buffer V-1401**	
number	3	number	2	number	1
number of chambers	92	number of chambers	105	volume (m3)	55
capacity (m3/h)	35-45	capacity (m3/h)	35-45		
volume (m3)	6.3	volume (m3)	5.9		
PE (50 wt%) buffer V-1501		**PE (1 wt%) buffer V-1502/V-1503**		**slibmixer tank T-1601**	
number	1	number	2	number	1
volume (m3)	30	volume (m3)	7	power (kW)	10
				speed (rpm)	4
low pressure pump P-1601/P-1603/P-1605/P-1607/P-1609		**hig pressure pump P-1602/P-1604/P-1606/P-1608/P1610**		**FeCl3 dosage pump P-1401/P-1402**	
number	5	number	5	number	2
capacity (m3/h)	10-80	capacity (m3/h)	5 -- 25	capacity (l/h)	0-530
head (kPa)	1200	head (kPa)	1500		
speed (rpm)	60-341	speed (rpm)	60-341		
power (kW)	30	power (kW)	22		
thickener pump P-1207/P-1206/P-1102/P-1103/P-1104/P-1105		**extern/digest pump P-1305/P-1306/P-1307**		**PE dosage pump P-1501/P-1502-P-1505**	
number	4	number	3	number	5
capacity (m3/h)	0-60	capacity (m3/h)	0-120	capacity (m3/h)	0.1-5
				head (bar)	15

In the P&ID diagrams different symbols are used. Extra information is given below.

 Progressive cavity pump

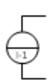
 Non-return valve

 Powered valve

 Flanges

 Gate valve

 Strainer

 Level meter

 Signal

 Indicator/Tranmitter/Controller

TI Temperature Indicator

FI Flow Indicator

ATC Air to Close

PI Pressure Indicator

ATO Air to Open

FIC Flow Indicator Controller

TIC Temperature Indicator Controller

PIC Pressure Indicator Controller

Appendix J: Wetterkip Fryslan WWTP

In the figure below, the district of water board Wetterskip Fryslan is shown. The purple triangles indicate the sewage water pumping stations, which discharges sewage water to the wastewater treatment plant. The WWTP is indicated with a blue circle with a black dot inside. The blue lines are discharge pipes. (scale 1:350000)

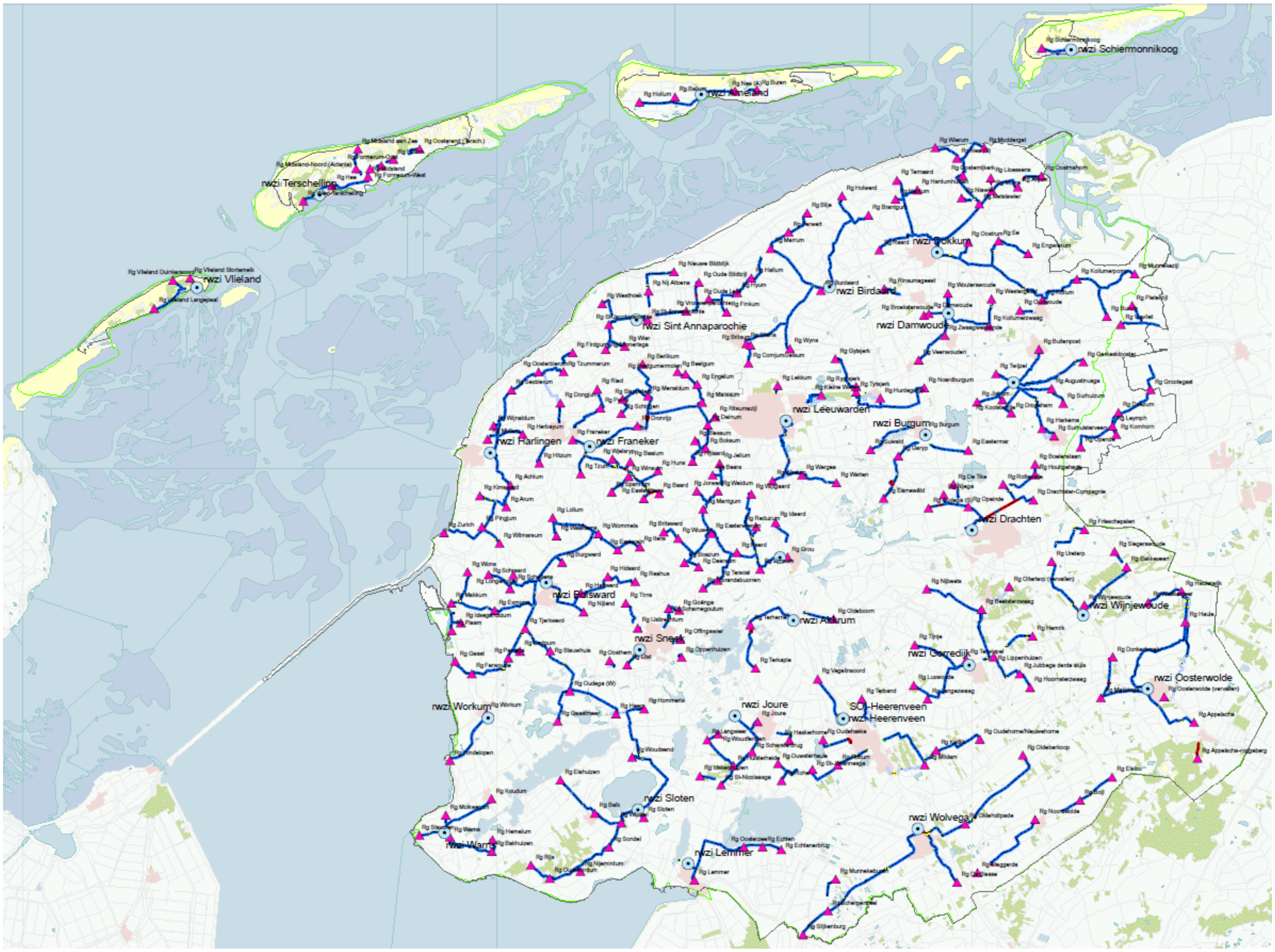


Figure 69: WWTP's and discharge pipes

Appendix K: Methane Safety Analysis

In the digestion tanks the organic part of the sludge is converted into biogas. Biogas consists mainly of methane (60 %) and carbon dioxide (30%). A safety analysis is made for methane. The physical and chemical properties are given in a MSDS shown below.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE, ODOR AND STATE: Colorless, odorless, flammable gas.
MOLECULAR WEIGHT: 16.04
BOILING POINT (1 atm): -258.7 °F (-161.5 °C)
SPECIFIC GRAVITY (Air = 1): 0.554
FREEZING POINT / MELTING POINT: -296. 5 °F (-182.5 °C)
VAPOR PRESSURE (At 70 _F (21.1 _C)): Permanent, noncondensable gas.
GAS DENSITY (At 70 _F (21.1 _C) and 1 atm): 0.042 lb/ft^3
SOLUBILITY IN WATER (vol/vol): 3.3 ml gas / 100 ml

Figure 70: Physical and chemical properties

Also a DOW Fire and Explosion index (FEI) and a DOW Chemical Exposure index (CEI) are made. The Dow FEI is a ranking system that gives a relative index to the risk of individual process units due to potential fires and explosions. The CEI provides a simple method of rating the relative acute health hazard potential to people of neighboring plants from possible chemical release incidents.

The information of methane needed for the FEI and CEI index is given below.

	data	
name	[-]	methane
formula	[-]	CH_4
Molecular weight(MW)	[kg/kmol]	17
atmospheric boiling point (Tb)	[°C]	-161
Melting point (Ts)	[°C]	-183
Flash point (Tv)	[°C]	-175
Ignition temperature (Tz)	[°C]	670
"exothermic start" temperature (Ta)	[°C]	670
Substance is self-reporting (ZMS of NZMS)	[-]	ZM
NFPA -code Health	[-]	1
NFPA -code Flammability	[-]	4
NFPA -code Reactivity	[-]	0
Combustion temperature (Hc)	[MJ/kg]	20.0
Heat capacity liquid (Cp)	[kJ/kg°C]	0.00
Evaporation heat (Hv)	[kJ/kg]	0.00

ratio Cp/Hv (CpHv)	[1/°C]	0.0044
Vapor pressure (at 20°C) (Po)	[bar]	0.00
Acute toxicity (TOX)	[mg/m^3]	0
L.E.L value in air (LEL)	[vol.%]	5.0
U.E.L value in air (UEL)	[vol.%]	15.8
Density liquid at Tp (sm)	[kg/m^3]	500

Table 30: Data methane

The results for the DOW-FEI analysis are shown below.

	methane		
DOW F&E Index			
Material Factor (MF)	**21**		**Liquids & Gases Flammability or Combustibility**
Process temperature (FEITp)	**37**	**[°C]**	**Temperature adjustment MF**
Outside temperature (FEITo)	**10**	**[°C]**	**Default should be 10°C.**
Material Factor T corrected (MFt)	**21**		
1. General Process Hazards:			
A. Exothermic Chemical Reactions:	**0.30**		Applies to process unit.
1a. Hydrogenation	0.3		Addition of hydrogen atoms to both sides of a double or triple bond
B. Endothermic Process:			Applies only to reactors.
0. No Endothermic Process			
C. Material Handling and Transfer:			Applies to pertinent Proces Units.
0. No Material Handling and Transport			
2. No inrack-sprinklers installed	0.2		Only if warehouse or yard storage applicable.
D.Enclosed or Indoor Process Units:			
0. No enclosed area involved.			
No mechanical ventilation present			Only applicable if enclosed area.
E. Access:			1. Access from at least two sides and 2. one access approaches from the roadway.
0. Adequate access present			
F. Drainage and Spill Control:	**0.50**		Only applicable if Tv < 60 °C.
2c. Exposure of utility lines possible and diking design (3 sides), 2% slope to impounding basin, distance > 15 m, sufficient capacity.	0.5		

General Process Hazards Factor (F1):	**1.80**		
2. Special Process Hazards:			
A. Toxic Material(s):	**0.20**	1.20	Based on NFPAH.
B. Sub-Atmospheric Pressure:		1.20	
0. No Sub-Atmosferic Pressure involved.			
C. Operation In or Near Flammable Range (OINFR):		1.20	
0. Not applicable.			No operation in or near flammable range anticipated.
1d. Inerted, closed vapour recovery system is used and its air-tightness can be assured.			Applicable if C. 1a., 1b. or 1c. is used.
D. Dust Explosion:		1.20	
0. No dust explosion possible; NFPAF=0 or no dust.			
0. Not applicable.			Applicable to dust with NFPAF>0
E. Relief Pressure (RP):	**0.15**	1.35	
Operating Pressure (Pp):	**1.02**	[bar]	pressure in bar absolute.
Relief Pressure (Pr):	**3.4**	[bar]	
1. Flammable & Combustible liquids (FEITp>Tv or Tv<FEITo).	0.16		based on Pp not corrected for Pr.
2a. Compressed gases used alone.	1.20		Only applicable if over pressure.
F. Low Temperature:		1.35	
0. Not applicable due to material choice or absence of needed abnormal operating conditions.			
G. Quantity of Flammable/Unstable Material:	**2.37**	3.71	
Liquid volume involved (Qhv):	**1000**	[m^3]	calculation based on density sm.
1. Liquids or Gases in Process.	2.37		Tv<60°C or FEITp > Tv or NFPAH>1.
H. Corrosion and Erosion:		3.71	NHPAF>1
0. No corrosion is anticipated.			
I. Leakage - Joints and Packing:	**0.10**	3.81	NHPAF>1
1. Some minor leakage is likely.	0.10		Pump with gland seals.
J Use of Fired equipment:		3.81	NHPAF>1
Distance to anticipated process unit (Df):	50	[m]	
0. No fired equipment is used.			
K. Hot Oil Heat Exchange System:		3.81	Depending of TpHO, TvHOandTbHO.
Quantity of heat exchanger system (active part)		[m^3]	
Process temperature HO (TpHO):		[°C]	
Flash point HO (TvHO):		[°C]	
Boiling point HO (TbHO):		[°C]	
0. No hot oil heat exchanger system is used.			
L. Rotating Equipment:			
0. No high power rotating equipment:			

Special Process Hazards Factor (F2):	3.8		
Process Unit Hazards Factor (F1*F2)=F3:	6.9		
Fire and Explosion Index (F3*MF=F&EI):	**144**		**Degree of Hazard HEAVY**
	36	[m]	**Radius of exposure**

Table 31: DOW FEI index

The conclusion of the above results is as follows: the degree of hazard is HEAVY and a radius exposure of 36 meters exists.

The results for the DOW-CEI analysis are shown below.

Physical appearance op of "Loss of Containment":		
Scenario:	During flow out	**gas cloud consisting of single gas**
	After flow out	**gas remains in the gas phase in the gas cloud**

CCN-calculations / closed system:	Factor:		**methane**
Hazard toxicity (HD)	0	**Cctox**	**No acute toxic gas cloud**
Hazard Distance air displacement (Hdlv)	**11**	**[m]**	**Suffocation within specified radius.**
Hazard Explosion and fire danger (HD) o.b.v. L.E.L	17.2	**Cclel**	**Explosion very likely**
Hazard m.b.t. Effect of explosive and fire	8.2	**Ccex**	**explosive gas cloud consisting only gas that is flammable**
Hazard Explosion and fire danger (HDstof)	0.6	**Ccstof**	

Table 32: DOW-CEI index