Faculty of Science and Technology

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EVALUATION OF TOC CONCEPT IN INDUSTRIAL WASTEWATER AT SART AS

Master in Environmental Technology - Specialization
Water Science and Technology

Dimitar Todorov

Spring 2011
ACKNOWLEDGEMENTS

I am heartily thankful to my teacher and academic advisor Professor Torleiv Bilstad, who gave me the opportunity to complete my master studies at the University of Stavanger and providing guidance, support and advices throughout this interesting master project.

I would also like to express my sincere gratitude to my external supervisor Martin Severin Løklingholm for his assistance, patience and continuous support during the project. I am very grateful as well to all employees at SART for providing assistance in the laboratory.

Sincere thanks to Professor Roald Kommedal for his support and advices during the experimental part of my project.

Big sincerely thanks for the encouragements, love and faith to my brother Goran, my mother Lelka, my father Todor (R.I.P.) and my girlfriend Vesna to whom I dedicate this work.

Finally I would also like to thank to all my friends in Macedonia, Norway and Mongolia for their continuous support during my studies.
Approximately 98 % of the industrial wastewater that SART receives comes from offshore activities. Unlike municipal waste water, this wastewater contains relatively high Total Organic Carbon (TOC), and very little Nitrogen (N) and Phosphorus (P). The objective is to reduce TOC, and therefore nutrients N and P are added to the biological reactor. For the chemical and the biological processes, Dissolved Air Flotation (DAF) units are coupled with activated sludge. Combining chemical and biological processes is effective in reducing harmful components in the wastewater.

In order to follow biodegradation on samples with different TOC concentrations, three laboratory bench tests were considered. Sludge washing of activated sludge and flocculation tests on selected water samples was done before start up of the bench tests. Samples before start up and at the end of each bench test were sending externally for Hydrocarbon (HC) analyses. During bench experiments more than 90 % of the initial DOC concentration was degraded within 3 days showing good effectiveness of activated sludge process. GC/MS results showed that most of the compounds identified before cycles belonging to glycol and glycol ethers that are known to be rapidly degraded.

Overview of Advanced Oxidation Processes (AOP) for treating slowly biodegradable components is given.

**Keywords:** Industrial wastewater, TOC, DOC, Biodegradation, Activated sludge, VSS, Flocculation, Coagulation, Dissolved Air Flotation, AOP
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ABBREVIATIONS:

AOP        Advanced Oxidation Processes
BOD        Biochemical Oxidation Demand
BTEX       Benzene, Toluene, Ethylbenzene and Xylene
COD        Chemical Oxidation Demand
C1         Single- Carbon Compounds
C2         Double carbon compounds
DAF        Dissolved air flotation
DOC        Dissolved Organic Carbon
DS         Dissolved Solids
EC         Electrical Conductivity
GC/MS      Gas Chromatography – Mass Spectrometry
HC         Hydrocarbons
KLIF       Norwegian state pollution authorities
MLVSS      Mixed Liquor Volatile Suspended Solids
MLSS       Mixed Liquor Suspended Solids
NPOC       Non Purgeable Organic Carbon Method
PV         Permanganate Value
PAH        Polycyclic Aromatic Hydrocarbons
RO         Reverse Osmosis
RBCOD      Readily Biodegradable Soluble Substrate
SART       SAR Treatment AS
TC         Total Carbon
TS         Total Solids
TDS        Total Dissolved Solids
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>TIC</td>
<td>Total Inorganic Carbon</td>
</tr>
<tr>
<td>TOC</td>
<td>Total Organic Carbon</td>
</tr>
<tr>
<td>TOD</td>
<td>Total Oxygen Demand</td>
</tr>
<tr>
<td>TSS</td>
<td>Total Suspended Solids</td>
</tr>
<tr>
<td>SS</td>
<td>Suspended Solids</td>
</tr>
<tr>
<td>SRT</td>
<td>Sludge Retention Time</td>
</tr>
<tr>
<td>SBCOD</td>
<td>Slowly Biodegradable Particulate Substrate</td>
</tr>
<tr>
<td>VSS</td>
<td>Volatile Suspended Solids</td>
</tr>
<tr>
<td>2, 4, 5 - T</td>
<td>2, 4, 5 - Trichlorophenoxyacetic Acid</td>
</tr>
<tr>
<td>2, 4 – D</td>
<td>2, 4 - Dichlorophenoxyacetic Acid</td>
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INTRODUCTION

Industrial wastewaters are composed of a broad spectrum of organic and inorganic compounds depending on the type of industry. “Industrial wastewaters are always priority issue for the protection of the environment. They should be considered as the most significant components of any water quality management programs”[1]. The objective of discharge requirements is protection of the environment. It should associate correctly with the wastewater characteristics and with the specific treatment scheme [1].

The thesis contains a combination of laboratory work and theoretical work on biodegradation.

Laboratory work was done on:

- Determining Total Organic Carbon (TOC) concentration on different water samples at SAR Treatment AS (SART).
- Small and large scale flocculation tests on selected water samples.
- Sludge washing of activated sludge.
- Small scale simulation test on biodegradability.

Due to complexity and high cost of Gas Chromatography – Mass Spectrometry (GC/MS) analysis of Hydrocarbons (HC), samples before and after each bench test were send to external laboratory for HC scanning.

The objective of the thesis is:

a. Detailed analyses of TOC content in the waste water at SART.
b. Investigation on biodegradation of HC.
c. Investigation on which part of the TOC is easily biodegradable.
d. Technical potential for treatment of slowly biodegradable TOC.
1. BACKGROUND AND LITERATURE REVIEW

1.1. WASTEWATER CHARACTERISTICS AND TOC INTRODUCTION

Large number of microorganisms and compounds in wastewater are able to create pollution that can be displayed in many ways. Therefore entire wastewater chemical and microbial analysis is not done, but the wastewater components are determined in terms of categories such as organic material, inorganic material and microbial content [2].

1.1.1. Organic constituents

The wastewater organics consist of a large number of compounds which can be oxidized both chemically and biologically to yield CO₂ and water.

Oxidation of glucose is given as an example (Equation 1).

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} \]  \hspace{1cm} (Eq. 1)

In order to indicate the amount of organic material present in the wastewater, oxidation reactions are carried out both microbialy and by use of chemical oxidation agents. These are known as non specific tests.

If biological oxidation is applied, the test parameter is biochemical oxidation demand (BOD). The terms chemical oxidation demand (COD), permanganate value (PV) or the total oxygen demand (TOD) are used for chemical oxidations [2].

The advantages and disadvantages of each of these tests are summarized in Table 1.
Table 1: Advantages and disadvantages of the non-specific test parameters [2].

<table>
<thead>
<tr>
<th>Test</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>BOD</td>
<td>Very simple and well known. Gives information on carbonaceous and nitrogenous oxygen demand.</td>
<td>Time-consuming incubation period. Poor reproducibility and sensitive to inhibition by many industrial wastes.</td>
</tr>
<tr>
<td>PV</td>
<td>Demands inexpensive apparatus and data are available within 40 min. It has good reproducibility.</td>
<td>Not many of the organic components are oxidized by the mild oxidation conditions. Some inorganic components can contribute a high oxygen demand.</td>
</tr>
<tr>
<td>COD</td>
<td>Demands inexpensive apparatus and data are available within 3 hours. It has good reproducibility.</td>
<td>It cannot oxidize ammonia. Great number of non-biodegradable organic components exerts an oxygen demand. Obstructions by higher concentrations of chloride ions.</td>
</tr>
<tr>
<td>TOC</td>
<td>Data are available in minutes. It has excellent reproducibility.</td>
<td>Demands expensive apparatus and experienced technician. Not much comparative data is available.</td>
</tr>
</tbody>
</table>

1.1.2. Inorganic nonmetallic compounds

Inorganic compounds which contribute to serious pollution are limited in industrial wastewater and can be detected by performing simple analyses [2].

- **Nitrogen (N) and phosphorus (P)**

N and P are known as nutrients because they are essential for the growth of microorganisms, animals and plants. N and P are considered the two major nutrients of importance. They occur in wastewater in the following forms: Ammonium (NH$_4^+$), nitrite (NO$_2^-$), nitrate (NO$_3^-$), orthophosphate (PO$_4^{3-}$). They come from different sources such as manufacturing processes, animal wastes from farms and effluents from sewage treatments [2].

- **pH**

Significant quality parameter for wastewaters is the hydrogen - ion concentration. Expressing the hydrogen ion concentration is by pH.

“**pH is defined as negative logarithm of the hydrogen - ion concentration**” [3].
\[ \text{pH} = -\log_{10}(H^+) \]  \hspace{1cm} \text{(Eq. 2)}

The pH concentration range tolerable for most biological life is typically pH 6 – 9. For treated wastewater effluents pH varies between pH 6.5 - 8.5 [3].

**- Alkalinity**

“Alkalinity in wastewaters results from the presence of hydroxides \([\text{OH}^-]\), carbonates \([\text{CO}_3^{2-}\)]\) and bicarbonates \([\text{HCO}_3^-]\) of elements such as calcium, magnesium, sodium, potassium and ammonia” [3].

Calcium and magnesium bicarbonates are the most usual [3]. The significance of alkalinity is based on its capacity to resist acid/base influences. Conventional titration with acid to an end pH of 4.5 is used to measure the alkalinity. Higher alkalinity indicates greater buffer capacity [4].

**1.1.3. Metallic constituents**

Macro and micro amounts of metals are required for living organisms for their proper growth. They can however be toxic above certain concentrations. The following metals are of importance in waters: Arsenic (As), Lead (Pb), Cadmium (Cd), Copper (Cu), Chromium (Cr), Nickel (Ni), Zinc (Zn), Molybdenum (Mo), Tin (Sn), Vanadium (V), Mercury (Hg) and Barium (Ba) [3].

**1.1.4. Physical characteristics**

**- Wastewater solid content characterization**

\[ \text{Total solids (TS)} = \text{Suspended Solids (SS)} + \text{Dissolved Solids (DS)} \]

\[ \text{Total solids (TS)} = \text{Organic TS + inorganic TS = Volatile TS + Fixed TS} \]

\[ \text{Suspended Solids (SS)} = \text{Organic SS + inorganic SS = Volatile SS + Fixed SS} \]

\[ \text{Dissolved Solids (DS)} = \text{Organic DS + inorganic DS = Volatile DS + Fixed DS} \]

The terms volatile TS, SS, DS as well as fixed TS, SS and DS refer respectively to the organic and inorganic solid content [5]. All matter that remaining as residue after evaporation of water at 103 – 105 °C is total solids (TS). TS are further classified as Suspended Solids (SS) which are non filterable and Dissolved Solids (DS) which are filterable through a 0.45 \(\mu\)m nominal pore size filter. The Suspended Solids fraction consists of the settleable solids which represent the approximate measure of the sludge quantity that will be removed by sedimentation.
The Dissolved Solids (DS) fraction contains colloidal (0.001-0.45 µm) and truly dissolved solids. For removing of the colloidal fraction coagulation followed by sedimentation is common. Further classification of the TS, SS and DS is on the basis of their volatility at 600°C. At this temperature the organic fraction will oxidize and inorganic fractions remain as ash [6].

- **Temperature**

Temperature is important parameter because of chemical and biological reaction rates and possible impact on aquatic life. For example, increased temperature can influence changes in the fish species near receiving waters. In warm water oxygen is less soluble compared with cold water.

“The increase in the rate of biochemical reactions that accompanies an increase in temperature, combined with the decrease in the quantity of oxygen present in surface water, can often cause a serious depletions in dissolved oxygen concentrations in the summer months”[3].

Rapid change in temperature can influence high mortality rate of aquatic life. High temperature conditions can bring growth of wastewater fungus and undesirable plants [3].

Temperature control is essential in the biological treatment system. This is where the biological process brings the temperature from ambient 10-15 degrees up to 35-45 degrees[7].

- **Conductivity**

“The Electrical conductivity (EC) of water is a measure of the ability of a solution to conduct electrical current”[3].

Conductivity increases with the increasing ion concentration. The capability of the water for irrigation can be determined by electrical conductivity. By measuring the electrical conductivity, estimation can be made for using of salinity of treated wastewater for irrigation. Expression of the electrical conductivity in SI units is as milisimens per meter (mS/m). EC is used as a surrogate of total dissolved solids (TDS) and also salinity [3].

- **Density**

Density (ρ) is determined as mass per unit volume expressed in SI units as g/L or kg/m³. Because of the potential of density currents in sedimentation tanks, chlorine contact tanks etc. density represents significant physical characteristic of wastewater [3]. Sometimes specific gravity parameter of the wastewater is used instead of the density of wastewater.
\( S_w = \frac{\rho_w}{\rho_0} \)  
(Eq. 3)

\( S_w \) = specific gravity of the wastewater  
\( \rho_w \) = density of the wastewater  
\( \rho_0 \) = density of water  

\( S_w \) and \( \rho_w \) parameters are dependent of the temperature and the total solids concentration in wastewater [3].

### 1.1.5. Biological characteristics

Biological characteristics of waste water are essential in controlling diseases caused by microorganisms. Bacteria, viruses, archae, algae, fungi, protozoa and rotifers are microorganisms found in wastewaters [3].

Tables 2 and 3 provide the comparisons of the composition of domestic sewage and some industries wastewater.

**Table 2:** Composition of untreated domestic sewage [2].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Manchester (UK)</th>
<th>Mafraq (Abu Dhabi town)</th>
<th>Campina Grande (NE Brazil)</th>
<th>Amman (Jordan)</th>
<th>Nairobi (Kenya)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD (mg O_2/l)</td>
<td>240</td>
<td>228</td>
<td>240</td>
<td>770</td>
<td>520</td>
</tr>
<tr>
<td>COD (mg O_2/l)</td>
<td>520</td>
<td>600</td>
<td>570</td>
<td>1830</td>
<td>1120</td>
</tr>
<tr>
<td>PV (mg O_2/l)</td>
<td>----</td>
<td>75</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Suspended solids (mg/l)</td>
<td>210</td>
<td>198</td>
<td>392</td>
<td>900</td>
<td>520</td>
</tr>
<tr>
<td>Ammonia (as N) (mg/l)</td>
<td>22</td>
<td>35.2</td>
<td>38</td>
<td>100</td>
<td>33</td>
</tr>
<tr>
<td>Ph</td>
<td>7.4</td>
<td>7.6</td>
<td>7.8</td>
<td>---</td>
<td>7.0</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>14</td>
<td>---</td>
<td>26</td>
<td>22</td>
<td>24</td>
</tr>
</tbody>
</table>
Table 3: Composition of untreated effluents from industries [2].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pharmaceuticals (India)</th>
<th>Textiles (India)</th>
<th>Beet-sugar waste (USA)</th>
<th>Coke –oven liquor (UK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD (_5)</td>
<td>15250</td>
<td>2000</td>
<td>930</td>
<td>1200</td>
</tr>
<tr>
<td>COD (mg O(_2)/l)</td>
<td>28540</td>
<td>5000</td>
<td>1601</td>
<td>3900</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>5400</td>
<td>4000</td>
<td>1015</td>
<td>950</td>
</tr>
<tr>
<td>Ammonia (as N)</td>
<td>-----</td>
<td>-----</td>
<td>6.3</td>
<td>4.5</td>
</tr>
<tr>
<td>pH</td>
<td>9.3</td>
<td>12.0</td>
<td>7.1</td>
<td>5.5</td>
</tr>
<tr>
<td>Total N</td>
<td>5166</td>
<td>----</td>
<td>16.4</td>
<td>490</td>
</tr>
</tbody>
</table>

Municipal wastewaters are generally the same with low organic load and high content of ammonia. Industrial wastewaters depending of the source have average or high organic load and high suspended solid concentration but little or no ammonia. They are generally more concentrated compared with domestic sewage in the terms of COD. The COD can have different values starting from 500 - 100.000 mg/l, according to the type of the industry. However, COD of majority of industrial effluents is in the range of 1000 – 2000 mg/l [1].

1.1.6. Introduction of Total Organic Carbon (TOC)

“Total organic carbon (TOC) is the amount of carbon bound in an organic compound and is often used as a non-specific indicator of water quality”[8].

As Metcalf & Eddy indicates, to measure the pollution characteristic of waste water the TOC tests can be used. These tests are very fast and reliable to complete. The time interval is around 5 – 10 minutes [3].

“The test methods for TOC utilize heat and oxygen, ultraviolet radiation, chemical oxidants or some combination to convert organic carbon to carbon dioxide which is measured with an infrared analyzer or by other means”[3].

A continuous on-line TOC analyzer has been developed lately. These TOC analyzers can detect TOC concentration in the ppb (parts per billion) range. They have found use in microfiltration and Reverse Osmosis (RO) treatment units, for uncovering residual TOC in the treated effluent. When valid relationship is established among results from TOC and BOD tests, applying of TOC test for process control is recommended [3].
1.2. **BACTERIAL GROWTH**

“Bacterial growth is a complex process involving numerous anabolic (synthesis of cell constituents and metabolites) and catabolic reactions (breakdown of constituents and metabolites)”[9].

1.2.1. **Bacterial growth in a batch reactor**

Bacterial growth in a batch reactor is characterized by phases shown on Figure 1. Four growth phases can be distinguish as substrate is consumed [3].

![Figure 1: Bacterial growth in a batch reactor with biomass and substrate changes versus time][3]

**a) The lag phase**

Lag phase is the first phase where rate of growth is essentially zero [9]. The lag phase corresponds with the acclimation of organisms into a new environment. During this phase enzyme induction can happen and/or the cells can be acclimating to salinity, pH and temperature changes [3].
b) The exponential phase

“During the exponential growth phase, bacterial cells are multiplying at their maximum rate, as there is no limitation in substrate and nutrients. The biomass growth curve increases exponentially during this period. The only factor that affects the rate of exponential growth is temperature” [3].

The biomass increase rate in this phase is proportional to the initial cell concentration and can be presented by a first – order reaction:

\[
\frac{dX}{dT} = \mu X
\]  
(Eq. 4)

In Equation 4, the first-order rate constant (\(\mu\)) is noted as the specific growth rate [2].

c) The stationary phase

“During the stationary phase the biomass concentration remains relatively constant with time. In this phase, bacterial growth is no longer exponential and the amount of growth is offset by the death of the cells”[3].

There are several reasons for reaching the stationary phase. First reason is when carbon or important nutrient is completely consumed. “When a carbon source is used up it does not necessarily mean that all growth stops. This is because dying cells can lyse and provide a source of nutrients. Growth on dead cells is called endogenous metabolism” [9]. Another reason for the stationary phase is when the waste products inhibit the growth or are toxic to cells [9].

d) The death phase

The final phase in the batch reactor is the death phase. The death phase is characterized with no growth, because the substrate has been depleted and due to the cell death there is a decrease of biomass concentration [3].

1.2.2. Effect of substrate concentration on microbial growth

As it can be seen from the Figure 1, there is decline in bacterial growth at the end of exponential growth. As N,J,Horan stated, this decline is regarding to the depletion of a growth-limiting nutrient that can be the organic carbon, nitrogen, phosphorus or any other factor essential for bacterial growth [2].

Jacques Monod was first who described the relationship between specific growth rate of the microorganism and the substrate concentration (Figure 2).
\[ \mu = \mu_m \frac{S}{K_s + S} \]  

(Eq. 5) [2]

\( \mu \) is known as the specific growth rate.

\( \mu_m \) is the maximum specific growth rate.

\( S \) is the concentration of the growth limiting substrate.

\( K_s \) is a saturation coefficient [2].

---

**Figure 2**: Relationship between substrate concentration and bacterial growth [10]

The result of the competition among microorganisms for a limited supply of food can be described by saturation coefficient \( K_s \) [2]. Saturation coefficient is defined as “the substrate concentration at which growth occurs at one half the value of \( \mu_m \)” [9]. The preference of organism towards substrate is greater as the value of \( K_s \) is lower [2].
Substituting the Equation 5 in Equation 4, result in expression (Equation 6) that according to N.J.Horan allows providing the kinetics of elimination of substrate for microorganisms growing at various substrate concentrations [2].

\[
\frac{dX}{dt} = \frac{\mu_m S}{K_S + S} X
\]  
(Eq. 6)

There are two limiting cases for the Monod equation [9]. The first case the substrate concentration is high in comparison with \(K_s\) indicating zero order of the microorganisms’ growth rate:

\[
\frac{dX}{dt} = \mu_m X
\]  
(Eq. 7) [2]

The second case occurs at low substrate concentration compared to \(K_s\), resulting in first order dependence on substrate concentration [9]:

\[
\frac{dX}{dt} = \frac{\mu_m S}{K_s} X
\]  
(Eq. 8) [2]

Equation 8 may be used for activated sludge systems that are described by low substrate concentration with microorganisms showing a high saturation coefficient [2].

### 1.2.3. Bacterial growth and biomass yield

"In biological treatment processes, cell growth occurs concurrent with the oxidation of organic and inorganic compounds. The ratio of the amount of biomass produced to the amount of substrate consumed (g biomass/g substrate) is defined as the biomass yield, and typically is defined relative to the electron donor used " [3].

\[
\text{Biomass yield } Y = \frac{\text{g biomass produced}}{\text{g substrate utilized (i.e., consumed)}}
\]  
(Eq. 9)

The yield for aerobic heterotrophic reactions with organic substrates can be written as g biomass / g organic substrate [3].
1.3. BIODEGRADATION

“Biodegradation can be defined as the biologically catalyzed reduction in complexity of chemicals” [11].

This process covers conversion of organic compounds into less complex metabolites by biotransformation or conversion of organic substrate into inorganic minerals, $\text{H}_2\text{O}$, $\text{CO}_2$ (aerobic) or $\text{CH}_4$ (anaerobic) by mineralization. Bacteria and fungi have been studied for their capability to degrade pollutants such as halogenated hydrocarbons, polycyclic aromatic hydrocarbons and nitro aromatic compounds. The initial transformation stages are done with specific enzymes. These enzymes are converting pollutants to metabolites, which can be integrated within more central bacterial pathways [12].

There are six major divisions of enzymes presented in Table 4.

Table 4: Divisions and distribution of enzymes by Enzyme Commission (EC) in the University of Minnesota Biocatalysts / Biodegradation Database (UM-BBD) [13].

<table>
<thead>
<tr>
<th>EC no.</th>
<th>Enzyme class</th>
<th>No. of class in UM-BBD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oxidoreductase</td>
<td>260</td>
</tr>
<tr>
<td>2</td>
<td>Transferase</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Hydrolase</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>Lyase</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>Isomerase</td>
<td>14</td>
</tr>
<tr>
<td>6</td>
<td>Ligase</td>
<td>10</td>
</tr>
</tbody>
</table>

In order for biodegradation to occur the following conditions must be met:

a) An organism with the necessary enzymes must exist in the environment where the chemical is contained.

b) The chemical must be available to the organism.

c) If the enzyme catalyzing the degradation is extracellular, for functioning of the catalyst, the bonds must be exposed.

d) If the enzyme catalyzing the degradation is intracellular, the molecule must penetrate to the internal sites where the enzyme acts.

e) Environmental conditions must enable proliferation of the potentially microorganisms [11].
The incapacity of a microorganism to function or his absence from a particular environment means that the compound will disappear slowly. If the above conditions are not satisfied, the pollutant will be long lived. When microorganisms are not functioning, act slowly or don’t exist, the pollutants will be persistent [11].

1.3.1. Acclimation

“Prior to the degradation of many organic compounds, a period is noted in which no destruction of the chemical is evident” [11]. This period is named as acclimation period or the lag time.

One of the definitions related with acclimation is the time interval between chemical entrance into the environment and the initial loss detected. As it can be seen on the Figure 3, during the acclimation period the concentration of the 2, 4, 5- Trichlorophenoxyacetic acid (2, 4, 5-T) is not changed, after which the rapid destruction takes place.

Figure 3: Soil degradation of 2, 4, 5-T in Puerto Rico (PR), Nigeria (NI), Trinidad (TR) and Philippines (Ph)
Presence of a lag phase is evident for most of the chemicals degraded in the environments [14]. Acclimation period length can vary from minutes to months. At the beginning of detectable biodegradation, the acclimation phase is considered finished. The most common causes of the acclimation are the following mechanisms: Proliferation of small populations, toxicity, predation by protozoa, appearance of novel genotypes and diauxic growth [11].

The size of a lag time is affected by the following factors: a) Initial chemical, b) Initial biomass density, c) Temperature, d) pH, e) Nutrients, f) e acceptor availability g) Grazing, h) Growth history [14].

1.3.2. Detoxification and activation

Detoxification is defined as induced changes in a molecule that makes it less harmful to species during biodegradation [14]. This is one of the microorganisms’ most important roles in pollutants transformation. With detoxification the toxicologically active substance is inactivated, with the enzymatic steps usually occurring within the cell. The following processes which result in detoxification are only the first step in Figure 4 [11].

Detoxification reactions are following:
- Hydrolytic cleavage
- Hydroxylation
- Dehalogenation
- Demethylation and dealkylations
- Methylation
- Nitroreduction
- Deamination
- Ether cleavage
- Amidification of nitriles
- Conjugations to a metabolic intermediate [14]
One of the most unwelcome microbial transformations aspects is the production of toxicants \[11\]. Activation is a process during biodegradation consisting of formation of toxic products from less toxic substrates \[14\]. Activation may occur in active microorganism environments such as water, wastewater and soil. Products formed can be subject to rapid or slow mineralization, or persistence for a long period as shown on Figure 5 \[11\].

**Figure 4:** Fate of detoxified chemicals \[11\]

**Figure 5:** Activation associated processes \[11\]
Biosynthesis of carcinogens, mutagens, teratogens etc are the consequences of activation\cite{11}.

Activation reactions are:

- Dehalogenation (TCE $\rightarrow$ VC)
- Halogenations
- Nitrosations of sec-amines
- Epoxidations
- Phosphothionate conversion to phosphates
- Oxidation of thioesters
- Hydrolysis of esters to acids \cite{14}.

### 1.3.3. Kinetics of biodegradation

Kinetics of biodegradation is important for the evaluation of the organic pollutant persistence and exposure assessing \cite{11}.

The following classes of kinetics exist:

- Non-growth related kinetics
- Growth related (autocatalytic) kinetics \cite{14}.

#### a) Non-growth related kinetics

Models for Non-growth kinetics relates to the variable substrate concentration. Non - growth zero order kinetics (Equation 10) is used when there is constant supply of limiting nutrients, low water solubility and high biomass and substrate concentrations. Non-growth first order kinetics (Equation 11) are used in environmental fate models and when the soluble substrate is bellow $K_S$ and $\mu-k_d$ is close to zero \cite{14}.

Differential form for zero order kinetics is:

$$\frac{dS}{dt} = -k_z$$  \hspace{1cm} (Eq. 10)

Differential form for first order kinetics is:

$$-\frac{dS}{dt} = k_1 \cdot S$$ \hspace{1cm} (Eq. 11)

$K_1$ - first order rate constant \cite{11}.\]
b) **Growth related kinetics**

Individual dynamic expressions for biomass \((X)\) and substrate \((S)\) are used by growth related (autocatalytic) models. Some models are utilized to reflect substrate limitations and some models although involve biomass do not take into account the density of the degrading population as variable. Secondly mentioned are:

- Logarithmic model
- Logistic model \((k = \mu_{\text{max}}/K_S)\) [14]

Logarithmic kinetics (Equation 12) of disappearance of substrate may be written as:

\[
\frac{dS}{dt} = \mu_{\text{max}} \cdot \left( S_0 + X_0 - S \right) \tag{Eq. 12}
\]

\(S_0\) is initial concentration of the substrate

\(X_0\) is the substrate amount needed for initial population production

\(S\) is substrate concentration

Logarithmic kinetics conditions are completed when \(S_0 \gg K_S\).

When \(S_0 \ll K_S\), different kinetics of growth apply. Growth on substrate concentrations much beneath \(K_S\) is known as logistic growth (Equation 13). Logistic kinetics can be expressed as:

\[
-\frac{dS}{dt} = dS \cdot \left( S_0 + X_0 - S \right) \tag{Eq. 13} \text{[11]}
\]

1.3.4. Thresholding

“**Metabolic thresholds are the lowest substrate concentrations that sustain growth of bacteria**” [14]. One of the evidence for thresholding comes from studies of biodegradable synthetic compounds in water. According to these studies, during the test period below certain concentration biodegradation doesn’t take place, or the biodegradation rate is less than expected. Mineralization data of 2, 4-dichlorophenoxyacetic acid \((2, 4 – D)\) added at different concentrations in river water is shown on figure 6 [11].
Figure 6: Example of mineralization of 2, 4 – D after addition at different concentrations [11].

In a standard growth models, decay rates and maintenance requirements assign the threshold value [14].

1.3.5. Sorption

Some substances which are attacked by microorganisms, however, are not being biodegraded, although they are biodegradable. There are several reasons for this: a) Microbial proliferation and metabolism are precluded when the concentration of the toxins are high b) Too low concentration of nutrients for microbial growth and too low substrate concentration for microorganism’s replication c) Lack of readily available form of substrate for the microorganisms [11].

“The term sorption is used to include both adsorption and absorption” [11]. The term adsorption is associated to the solutes retention by the solid material surface, while absorption is associated with solutes retention within the mass of the solid.
Microenvironment adjacent to the solid material is the zone where sorption occurs. Many organic compounds can be sorbed by soil components, wastewaters, sediments etc. Factors like pH, temperature, type and concentration of solutes, type and quantity of clay minerals, the amount of organic matter can affect sorption of organic compounds. Although sorption reduces the biodegradation rate, it doesn’t prevent it totally. Microorganisms can use sorbed molecules as C-source, energy, N-source and other elements, resulting in transformation of compounds. How sorbed molecules are becoming available to microorganisms it’s still confusing. Three hypotheses are explaining the mechanism of utilization. According to first hypothesis, “The organism use the chemical that is initially in solution, and it also metabolizes the compound that enters the aqueous phase as a result of spontaneous desorption from the solid” [11]. Equilibrium exists between sorbed chemical and chemical in ambient liquid:

\[
\begin{align*}
\text{Sorbed chemical} & \rightleftharpoons \text{chemical in solution} \\
k_1 & \\
k_2 & \\
\end{align*}
\]

(k\(_1\)) desorption rate constant
(k\(_2\)) adsorption rate

The second hypothesis explains that metabolites excreted by microorganisms facilitate desorption so that biodegradation rate is larger than the spontaneous desorption rate when microorganisms are lacking. In compliance with the third hypothesis, microorganisms utilize directly the sorbed compound because of the same surface adherent.

For the biodegradation of sorbed compounds, several models have been proposed. The main assumption of these models is that substrate has to be in an aqueous solution so that it can be metabolized. In one of the early models there is use of desorption rate constant (k\(_1\)), adsorption rate (k\(_2\)) and biodegradation rate (k\(_3\)) [11].

\[
\begin{align*}
\text{Sorbed chemical} & \rightleftharpoons \text{chemical in solution} \\
k_1 & \\
k_2 & \\
k_3 & \\
\end{align*}
\]

Products of biodegradation

If the compound is toxic or a toxic intermediate, the sorption can have positive kinetic effects [14].
1.3.6. Cometabolism

Cometabolism is defined as “Transformation of an organic compound by a microorganism that is unable to use the substrate as a source of energy or of one of its constituent’s elements“ [11]. Variety of organic compounds is known to be transformed cometabolically, with the cometabolic product mostly excreted to the environment [14].

Explanations for cometabolism are:

1. Initial enzymes are present and they convert the substrate to a product which is not converted further.
2. The initial substrate is converted into products that inhibit further metabolism.

1.3.7. Aerobic versus anaerobic microorganisms in biodegradation

The dominant metabolic pathways are determined by the presence or absence of oxygen[15]. Much more is known about biodegradation under aerobic conditions, compared with anaerobic degradation [13].

Some of the general trends are given below:

- Aerobic lag times are shorter than equivalent anaerobic lag times which can last 6 months to 1 year before biodegradation occurs.
- Aerobic degradation proceeds in pure cultures and anaerobic degradation involve complex bacterial consortia
- High energy xenobiotics seem to be degraded much faster by aerobes, because of the high energy yield, larger number of generated ATP equivalents, and generation of more biomass.
- Kinetics of degradation is higher for aerobic guilds than anaerobic consortia.
- Organic compounds like Alkanes demand oxygenase activation by introducing molecular oxygen derived from oxygen atom(s).
- Other organic compounds require anaerobic reduction (eg. Dehalogenation), or at least, pre-anaerobic degradation intensify the process kinetics before aerobic mineralization [15] [13].
1.3.8. Metabolic logic and pathway maps

a) C1 Metamap

Single-carbon compounds (C1), are metabolized with short and simple metabolism by microorganisms such as methanothrops and methylothrops. These compounds pass through three intermediates [15]. Single-carbon compounds are transformed by enzymes into the following intermediates: methanol, formaldehyde and formate, as it can be seen on Figure 7. After that oxidation and assimilation processes can proceed [13].

![Figure 7: C1 Metamap](image)

b) C2 Metamap

Double carbon compounds like Ethyne, Ethene and Ethane can be transformed to one or more of the nine metabolic intermediates from ethanol to oxalic acid as shown in Figure 8 [15].

“Ethene and ethyne are catabolized by bacteria, with functionalization of the carbon atoms leading to the loss of the carbon-carbon multiple bond”[13]. Ethene is oxidized to an epoxide and after hydrated to ethylene glycol (C2H6O2) [15] [13].
Acetaldehyde will be produced from the acting of alkyne metabolism mechanism on the ethyne \[13\]. In the case of halogenated double carbon compounds, the functional groups are taken away by dehalogenation to give glycolate \[15\].

![Figure 8: C2 Metamap \[17\]](image)

c) Cycloalkane Metamap

“Cycloalkanes are alkanes that contain rings of carbon atoms. Simple cycloalkanes are named like acyclic (noncyclic) alkanes, with the prefix cyclo – indicating the presence of a ring“ \[18\].

Example for cycloalkanes metamap is illustrated through Cyclohexane in Figure 9. Biodegradation of cyclohexane progress by monooxygenation to create cyclic alcohol - cyclohexanol. Dehydrogenation gives a ketone. Next step is the reaction called Baeyer - Viliger monooxygenation by inserting oxygen atom into the ring structure. After the cyclic
ester formation, hydrolysis of the ring ester and further metabolism of the remaining carboxylic acid follows [13] [15].

Figure 9 Cycloalkane Metamap [19]

d) BTEX Metamap: Aerobic Metabolism

“Monoaromatic hydrocarbons such as benzene, toluene, ethylbenzene and xylene, collectively known as BTEX, are commonly found in gasoline and are highly volatile substances “ [12].

Aerobic metabolism of BTEX compounds has been investigated especially under aerobic conditions, as shown on Figure 10. Oxygen activating enzymes for oxidation of BTEX compounds are dioxygenases or monooxygenases in different organisms. For example, toluene is oxidized by dioxygenases to cis-1,2-dihydroxydihydro-3-methyl-3,5-cyclohexadiene. This intermediate is oxidized by dehydrogenase to 3-methylcatechol.

Dioxygenase – dependant pathways capture more overall energy compared with monooxygenase – dependent pathways [13].
Ethylbenzene often comes in contact with the environment resulting from petroleum industrial discharges or spills. Ethylbenzene is an example of n-alkylbenzenes (C2-C7), that is been utilized by Pseudomonas sp. strain NCIB 10643. Dioxygenation is the initial step of aerobic degradation of Ethylbenzene, followed by extradiol ring cleavage \[21\] (Figure 11).
Figure 11: Ethylbenzene pathway map [21]
e) PAH Metamap

PAHs or Polycyclic aromatic hydrocarbons are containing two or more benzene rings in their structure. Compared with monoaromatics they are more hydrophobic and therefore lower solubility. PAHs come in contact with the environment from discharges from oil refineries, accidental oil spills or domestic runoffs [12].

In case of naphthalene (Fused benzene – ring PAHs), dioxygenation by naphthalene dioxygenase will result in dihydrodiol (not shown in figure 12, top) [13]. Enzymatic dehydrogenation on dihydrodiol intermediate will give naphthalene catechol. The existence of the two hydroxyl groups activates the catecholic ring. These facilities a ring cleavage reaction by mono- and dioxygenases and three carbon units pare away. The resulting orthohydroxyaromatic acid (salicylate) can be oxidatively decarboxylated to a second catechol[15]. The reaction can be repeated to deconstruct the next aromatic ring [13].

In petroleum industry there are examples of non aromatic five and six member rings fused to aromatic rings. One simple example is Acenaphthene (Figure 12, bottom). Acenaphthene degrade by hydroxylation of nonaromatic ring first, followed by second hydroxylation and dehydrogenation to give diketone. Oxygen insertion is a key reaction that results in a naphthalene dicarboxylic acid followed by dioxygenation and decarboxylation to make approximate pathway to naphthalene metabolism [13].

Figure 12: PAHs metamap of fused benzene ring PAHs and Fused mixed alicyclic and benzene ring PAHs [22]
1.4. SAR TREATMENT WASTEWATER PLANT

1.4.1. Characteristic of the plant

SAR Treatment owned by SAR AS (60%) and Nature Technology Solution AS (40%) is one of the leading companies in Norway within environmental technology. SAR Treatment provides treatment of industrial wastewater from the offshore industry, ships and onshore activities. The company purifies big quantities of waste water like oil-contaminated water, ballast water, engine-room slop and heavy-metal-contaminated waste water. Variety of methods is used to treat these contaminated fluids such as flocculation/coagulation of oil, heavy metals and suspended particles, as well as biodegradation of dissolved organic compounds. SAR Treatment has permission to handle 60,000 m3 of waste water annually [23].

Figure 13 provides schematically an explanation of the SAR treatment plant.
Figure 13: SART Water treatment flowchart
1.4.2. Overview of unit processes at SART

a) Physical process

For separation of wastes consisting of liquids and solids, physical treatment is usually the first step. This treatment process consists of a range of separation methods that have been used in the industry.

Typical physical treatment processes are:

- Screening
- Adsorption
- Sedimentation
- Clarification
- Evaporation
- Centrifugation
- Filtration
- Distillation
- Stripping
- Membrane filtration
- Flotation [24]

“Sedimentation is the most widely used method for removal of floating and coarsely dispersed oils from wastewater” [25].

Oil particles can be separated by gravity, due to the difference in density between oil and water [25]. SAR Treatment uses sedimentation, which relies on gravity to achieve separation (Figure 14).

![Figure 14: Gravity separator tanks](image)
Oil, which has lower density than water, will form an apparent boundary layer on the top of the tank. Suspended solids which are the larger particles, will settle to the bottom of the tank.

Three gravity separation tanks of 1000 m$^3$ each are implemented in the SAR treatment plants which allow suspended solids removal.

b) Chemical process

- Coagulation and Flocculation

“Coagulation and flocculation can enhance the precipitation process and assist in separation of suspended solids from liquids”[24].

Every colloidal particle is surrounded by electrical double layers, which can stabilize a colloid particle. (Figure 15). The inner layer (Stern layer), is made up of ions with the opposite charge of the colloidal particle [27]. The outer region is diffusive layer. Notional boundary (Slipping plane) exists within the diffusive layer, making the particle acts as a single unit [28].

![Negatively charged colloid particle](image)

**Figure 15:** Negatively charged colloid particle [28]
The potential at slipping plane is known as the Zeta Potential. (Figure 16) which is the overall charge around the particle. In order to maintain a stable colloid, double layer needs a charge of 30 mV. As it can be seen from the figure 16, particles with zeta potentials more positive than +30mV and more negative than -30mV are considered stable [28]. The colloid particles will form a floc in a stable colloid system because of the electric attraction between them [27].

Figure 16: Zeta potential of the particle [28]

Clay, silica, heavy metals and organics are colloids found in wastewater. Due to lack of insufficient settling time during the treatment, colloids require coagulation for increasing the particle size and settling rates. According to Løklingholm, M.S. coagulation is a process described as rapid mixing of added coagulant, neutralizing charges to effect agglomeration and settling, and flocculation is process described as gentle agitation/mixing in order to allow bridging of floculants chemical and forming of large settle able flocks from agglomerated colloids [27]. Some of the coagulants and flocculants used in clarification of water are aluminum salts and iron salts [24].

- **(DAF) Dissolved air flotation**

Dissolved air flotation (DAF) removes hydrocarbons and protects the biological treatment that follows DAF. The DAF process consists of two different stages:

a) The chemical stage, where emulsion breaking and formation of solid aggregates (coagulation and flocculation) occurs.

b) The physical stage, where aggregates from the liquid phase are separated by introducing of air bubbles [29].

From Figure 17 after treating feed water with chemicals, it is send to a flotation tank from where the portion of the effluent is recycled with recycle pump into a small pressure vessel (Air drum).
Here compressed air is introduced that will saturate the pressurized effluent water with air. The pressure release will result in air bubbles being released. The bubbles will attach to suspended matter which floats to the surface and skimmed off by mechanical device [30].

![Diagram of Dissolved Air Flotation Unit](image)

**Figure 17:** A typical dissolved air flotation unit (DAF) [31]

DAF units typically remove more than 95 percent of the oil and 75 percent of the solids. So DAF greatly reduces loads on downstream biological treatment unit [32].

Two DAF units are implemented at the SAR Treatment plant, both of them connected with sludge tanks of 60 m$^3$ volumes each. At the inlet of the flotation tank, samples are taken to the lab (1-2 times a week) to determine the amount of TOC removed by coagulation/flocculation. At the outlet of each of the DAF units, samples are taken for TOC measurement to check the effectiveness of DAF units.

c) Biological process

Physical and chemical treatment methods contribute to partial removal of wastewater organic material. For effective removal of organic content in industrial effluents, there is need of biological treatment as well. "The activated sludge process is by far the preferred treatment scheme for this purpose” [1].

SAR treatment plant has two bioreactor tanks 120 m$^3$ and 350 m$^3$ each, and settling chambers of 2 x 60 m$^3$ allowing settled sludge to be recycled to the inlet of the two bioreactors. Bioreactors are equipped with sensors which measure pH and temperature. Analyses are done in order to estimate the content of N and P that needs to be added as nutrients in reducing TOC.
In the bioreactors the oxygen concentration is due to the equilibrium among oxygen addition and oxygen consumption. Therefore to avoid limitations, dissolved oxygen must be in excess. Dissolved oxygen concentrations lower than necessary will affect growth and TOC removal rate, and higher concentration than needed will affect the economics of the process [33].

- **Activated sludge:**

The activated sludge process shown in Figure 18 is treatment system combined of an aerobic bioreactor where with help of aeration the biomass is kept in suspension and a second part known as clarifier where biomass and particles are settled [1]. Sludge that is most settled is recycled back to the inlet of the aerobic bioreactor, therefore retention of high biomass concentrations is allowed [34].

![Activated Sludge Mass Balance](image)

**Figure 18:** Activated Sludge Mass Balance

Equations for mass balance of the activated sludge

**Hydraulic retention time (HRT):**

\[
HRT = \frac{V}{Q} \quad \text{(volume)}
\]

\[
HRT = \frac{V}{Q} \quad \text{(volume out)}
\]  

(Eq. 14)

**Solids retention time (SRT):**

\[
SRT = \frac{V \cdot X}{Q_{\text{waste}} \cdot X_r} \quad \text{(mass)}
\]

\[
SRT = \frac{V \cdot X}{Q_{\text{waste}} \cdot X_r} \quad \text{(mass out)}
\]

(Eq. 15)

**Presumptions:**

Steady state: \( dX/dt = 0 \)

Sterile influent: \( X_{\text{in}} = 0 \)

Finished solids separation: \( X_e = 0 \)
Correlation between growth rate and Sludge Retention Time can be determined by finding solution of the mass balance for biomass

\[ \mu - k_d = \frac{Q_{\text{waste}} \cdot X_r}{X \cdot V} \Rightarrow \mu - k_d = \frac{1}{SRT} \]

SRT is reversed of growth rate. \hspace{1cm} (Eq. 16)

The growth rate is given by Monod’s equation:

\[ \mu = \frac{\mu_{\text{max}} \cdot C}{K_s + C} \]

\[ \frac{\mu_{\text{max}} \cdot C}{K_s + C} - k_d = \frac{1}{SRT} \Rightarrow C = \frac{K_s (k_d + 1/SRT)}{\mu_{\text{max}} - (k_d + 1/SRT)} \]

Sufficient SRT is selected so that certain treatment efficiency can be accomplished [35].

- **Biomass concentration**

The biomass is the amount of growth (substrate removal), decay and waste. Biomass concentration is determined by finding solution of the mass balance for substrate:

\[ V \frac{dC}{dt} = Q(C_{in} - C_e) - \frac{\mu XV}{Y} \]

as well as

\[ \mu - k_d = \frac{1}{SRT} \Rightarrow \mu = k_d + \frac{1}{SRT} \]

\hspace{1cm} (Eq.19)

When steady state is assumed and \( \mu \) (from Equation 19) is replaced will result in Equation 20.

\[ 0 = Q(C_{in} - C_e) - \frac{X V}{Y} \left( k_d + \frac{1}{SRT} \right) \Rightarrow X = \frac{Q(C_{in} - C_e)Y \cdot SRT}{V(k_d + \frac{1}{SRT})} = \frac{Q(C_{in} - C_e)Y \cdot SRT}{V(SRT \cdot k_d + 1)} \] (mg/l) \hspace{1cm} (Eq.20)

The equation for biomass indicates when more substrate that is taken away and when the longer SRT is, the biomass concentration is higher.

The total mass of biomass is the product of bioreactor volume and concentration:

\[ MX = V \cdot X = \frac{Q(C_{in} - C_e) \cdot Y \cdot SRT}{(SRT \cdot k_d + 1)} \] (mg) \hspace{1cm} (Eq.21) [35]
- **Sludge concentration in the bioreactor**

The sludge in a bioreactor includes biomass and non viable organic and inorganic compounds. The inorganic compounds are represented by metals, sand and clay that are existent in the influent. The organic compounds are dead cells residues (unbiodegradable) as well as unbiodegradable particulate organic components in the wastewater.

Mixed Liquor Suspended Solids (MLSS) corresponds to the total solids concentration in a bioreactor and the organic solids concentration in a bioreactor is known as Mixed Liquor Volatile Suspended Solids (MLVSS). The inorganic and unbiodegradable organic solids from the wastewater accumulate in the sludge (MLSS) in compliance with SRT. They do not take part in reactions in the bioreactor. The key assumption in a bioreactor when a fraction of the organisms die is that the rest of the living cells degrade the main organic fraction of the organisms (around 80 – 90 %) while the residue (10 – 20 %) corresponds to organic solids ($f_d$) that are unbiodegradable and they accumulate in the bioreactor. The endogenous residue accumulation represents a function of organism’s concentration, SRT and the rate of decay.

The composition of the organic sludge in the bioreactor is:

Organic fractions = Biomass + Unbio. Org. + Endogenous residue

$$MLVSS = X + X_{i,R} + X_{E,R}$$  (Eq.22)

By analysing the MLVSS/MLSS ratio which is between 0.7 and 0.8, the inorganic fraction can be determined [35].

### 1.5. CHROMATOGRAPHY – MASS SPECTROMETRY

Gas chromatography – mass spectrometry (GC/MS) is a powerful tool being used for the analysis of complex organic and biochemical mixtures [36]. GC/MS instruments are utilized for the identification of components found in the natural and biological systems [37].

#### 1.5.1. Gas chromatography-mass spectrometry (GC/MS) instrument

The GCMS instrument consists of two parts, Gas Chromatography (GC) and Mass Spectrometer fraction (MS) (Figure 19).
The GC fraction separates the chemical mixtures by their volatility and the MS is used for qualitative analyses of the chemicals.

a) Gas chromatography (GC) consists of:

Injection port – Solvent is injected into the GC. Then by the help of inert gas, the sample is carried through the instrument. By heating the injection port up to 300° C, the chemicals become gases.

Oven – Oven represents the external part of the GC. Molecules through the column are passing by heating of the column up to 320° C.

Column – Column is a 30 meter long thin tube inside the oven. Chemicals are transported through the column by the help of inert gas and are separated based on their volatility [39].

b) Mass Spectrometer (MS) consists of:

Ionization Source – After entering the MS... “the molecules are blasted with electrons, which cause them to break into pieces and turn into positively charged particles called ion”[39]. This is essential, because in order to pass through the filter the particles must have charge [39]. Electron- impact ionization and chemical ionization are most common ion sources used in GCMS analyses [37].

Filter – Electromagnetic field is filtering the ions based on mass. The range of masses allowed through the filter is selected by technicians.
**Mass Detector** – Number of ions with a specific mass is given by mass detector. This message is forwarded to a computer where mass spectrum is produced

c) Computer

Received data is plotted on a graph called a mass spectrum. Mass spectrum represents the number of ions with different masses. It consists of x-axis which is a mass and the y-axis which represents abundance or quantity \([39]\).

### 1.6. ALTERNATIVE TECHNOLOGIES FOR TREATMENT OF SLOWLY BIODEGRADABLE TOC

Advanced oxidation processes (AOP) can be useful when components in wastewater are chemically stable and/or they have low biodegradability. Even AOPs are using different reagent systems, they have in common that they all produce HO• radicals that are very reactive, not highly selective and powerful oxidants by which the organic compounds are attacked at high rate \([40]\). “Hydroxyl radicals are effective in destroying organic chemicals because they are reactive electrophiles (electron preferring) that react rapidly and no selectively with nearly all electron-rich organic compounds” \([41]\).

\[
\text{AOPs} \rightarrow \text{HO•} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{inorganic ions} \quad \text{(Eq.23)} \quad \text{[40]}
\]

Radical addition (Eq.24), hydrogen abstraction (Eq.25) and electron transfer (Eq.26) are types of hydroxyl radicals attacks on organic compounds \([41]\).

\[
R + \text{HO•} \rightarrow \text{ROH} \quad \text{(Eq.24)}
\]

\[
R + \text{HO•} \rightarrow R^- + \text{H}_2\text{O} \quad \text{(Eq.25)}
\]

\[
\text{Rn} + \text{HO•} \rightarrow \text{Rn-1} + \text{OH}^- \quad \text{(Eq.26)}
\]

\(R\) – Organic compound \([41]\)

Reaction rate constants for ozone and hydroxyl radicals with various organic compounds are presented in Table 5.

**Table 5**: Reaction rate constants (k, M\(^{-1}\) s\(^{-1}\)) of ozone compared with hydroxyl radical \([42]\).

<table>
<thead>
<tr>
<th>Compound</th>
<th>O(_3)</th>
<th>HO•</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorinated alkenes</td>
<td>(10^4) - (10^5)</td>
<td>(10^2) - (10^{11})</td>
</tr>
<tr>
<td>Phenols</td>
<td>(10^1)</td>
<td>(10^2) - (10^{10})</td>
</tr>
<tr>
<td>N-containing organics</td>
<td>(10) - (10^2)</td>
<td>(10^5) - (10^{10})</td>
</tr>
<tr>
<td>Aromatics</td>
<td>(1) - (10^2)</td>
<td>(10^5) - (10^{10})</td>
</tr>
<tr>
<td>Ketones</td>
<td>(1)</td>
<td>(10^5) - (10^{10})</td>
</tr>
<tr>
<td>Alcohols</td>
<td>(10^2) - (1)</td>
<td>(10^5) - (10^9)</td>
</tr>
</tbody>
</table>
Methods for generating hydroxyl radicals can be divided into non-photochemical and photochemical.

### 1.6.1. Non – Photochemical Methods

Non–photochemical methods generate HO• radicals with no use of light energy:

1. Ozonation at elevated pH (pH>8.5)
2. Ozone + hydrogen peroxide (O₃/H₂O₂)
3. Ozone + catalyst (O₃/CAT)
4. Fenton system (H₂O₂/Fe²⁺)

- **Ozonation at higher pH**

Ozone’s decomposition rate is increased at higher pH levels. Molecular ozone reactions combined with HO• radicals reaction can oxidize organic species. Three molecules of ozone gives two HO• radicals that have 10⁶ to 10⁹ faster rate of attack than corresponding molecular ozone (Eq.27).

\[ 3 O_3 + OH^- + H^+ \rightarrow 2OH^- + 4O_2 \]  
(Eq.27)

Electricity cost for generation of ozone is the capital operating cost for the ozone oxidation process [42].

- **Ozone + hydrogen peroxide (O₃/H₂O₂)**

Hydrogen peroxide is the simplest peroxide. “Oxidizing capacity of hydrogen peroxide is so strong that it is considered a highly reactive oxygen species” [43]

By adding this strong oxidizer to ozone, decomposition cycle of ozone is initiated by HO• radicals that are formed. Two ozone molecules give two HO• radicals

\[ 2O_3 + H_2O_2 \rightarrow 2OH^- + 3O_2 \]  
(Eq. 28)/42/

Some studies suggesting that best treatment efficiency were achieved when hydrogen peroxide was added after oxidation with ozone [42] [44].

- **Ozone + catalyst (O₃/CAT)**

Heterogeneous and homogeneous catalysts are investigated as possibility of acceleration of ozonation reactions. A significant result in destruction of the compounds was carried out by metal oxides and metal ions such as Fe₂O₃, MnO₂, Al₂O₃–Me, Fe²⁺, TiO₂–Me, etc. [42].

In some studies that were investigating AOP for chlorobenzenes oxidation in wastewater, concluded more efficient reduction of TOC achieved with ozone + catalyst compared with ozonation at high pH alone [42] [45].
Evaluation of TOC concept in industrial wastewater at SART AS

"Fenton's reagent is a solution of hydrogen peroxide and an iron catalyst that is used to oxidize contaminants or waste waters. Fenton's reagent can be used to destroy organic compounds such as trichloroethylene (TCE) and tetrachloroethylene (PCE)" [46].

In the presence of hydrogen peroxide, Fe (II) is oxidized very fast to Fe (III), a hydroxyl anion and a hydroxyl radical. (Eq. 29) Iron (III) is reduced back to iron (II), a proton and peroxide radical by the same hydrogen peroxide (Eq.30) [46].

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + OH^-$$  \hspace{0.5cm} (Eq.29)

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + H^+ + OOH^-$$  \hspace{0.5cm} (Eq.30)

Fenton system is used for wastewater treatment because iron is not toxic and highly abundant element and hydrogen peroxide is easy to manage and environmental gentle [42].

1.6.2. Photochemical Methods

Complete oxidation reactions of organics resistant to non photochemical methods can be done with addition of UV radiation. This is because many organic compounds absorb UV (in the range of 200 – 300 nm) and due to photolysis decompose or they turn into more reactive compounds with chemical oxidants [42].

Photochemical methods are:

1. Ozone and UV radiation (O₃/UV)
2. Hydrogen Peroxide and UV radiation (H₂O₂/UV)
3. Ozone, hydrogen peroxide and UV radiation (O₃/H₂O₂/UV)
4. Photo-Fenton and Fenton-like systems
5. Photocatalytic oxidation (UV/TiO₂)[42].

- Ozone and UV radiation (O₃/UV)

Photolysis of the ozone is the first reaction when AOPs are using combination of ozone and UV during which hydroxyl radicals are produced [40].

$$H_2O + O_3 \xrightarrow{hv} 2HO• + O_2$$  \hspace{0.5cm} (Eq.31)

$$2HO• \rightarrow H_2O_2$$  \hspace{0.5cm} (Eq.32) [40]
If organics in waste water absorb greatly UV, then no additional effects will be given by UV to ozone. [42]. Total mineralization of organics with short molecular chain can be done by ozone and UV [42] [47]. The efficiency of Ozone and UV in removing tetrachloroethylene from water compared to ozonation and photolysis alone was investigated by Peyton et al. [42] [48].

- **Hydrogen Peroxide and UV radiation (H\textsubscript{2}O\textsubscript{2}/UV)**

Photolysis of hydrogen peroxide produces hydroxyl radicals.

\[
\text{H}_2\text{O}_2 \xrightarrow{\text{hv}} 2\text{HO}\cdot
\]  
(Eq.33)

Hydrogen peroxide anion that is in an acid base equilibrium with H\textsubscript{2}O\textsubscript{2}, absorbs UV in the wavelength of 254 nm.

\[
\text{H}_2\text{O}_2 \rightleftharpoons \text{HO}_2^- + \text{H}^+ \quad \text{(Eq.34)}
\]

\[
\text{HO}_2^- \xrightarrow{\text{hv}} \text{HO}^\cdot + \text{O}^- \quad \text{(Eq.35)}
\]

H\textsubscript{2}O\textsubscript{2}/UV was investigated and proved successful in destruction of chlorophenols and other chlorinated compounds [42].

- **Ozone, hydrogen peroxide and UV radiation (O\textsubscript{3}/H\textsubscript{2}O\textsubscript{2}/UV)**

Addition of Hydrogen peroxide to O\textsubscript{3}/H\textsubscript{2}O\textsubscript{2} speed up ozone decomposition resulting in increased HO • radicals production [42].

\[
2\text{O}_3 + \text{H}_2\text{O}_2 \xrightarrow{\text{hv}} 2\text{HO}^\cdot + 3\text{O}_2 \quad \text{(Eq.36) [40]}
\]

These processes are expensive. Costs vary with wastewater flow rate, concentration and type of contaminants and the required removal level [42].

- **Photo-Fenton and Fenton-like systems**

Addition of Fe\textsuperscript{3+} ions to H\textsubscript{2}O\textsubscript{2}/UV results in a photo – Fenton type oxidation process. At lower pH around 3 due to acidic environment Fe (OH)\textsuperscript{2+} is produced. When this complex is exposed to UV is decomposed and results in HO• and Fe\textsuperscript{2+} ions (Equation 37).

\[
\text{Fe}^{3+} + \text{H}_2\text{O} \longrightarrow \text{Fe} \,(\text{OH})^{2+} + \text{H}^+ \quad \text{(Eq.37)}
\]

\[
\text{Fe} \,(\text{OH})^{2+} \rightleftharpoons \text{Fe}^{3+} + \text{OH}^- \quad \text{(Eq.38)}
\]

\[
\text{Fe} \,(\text{OH})^{2+} \xrightarrow{\text{hv}} \text{Fe}^{2+} + \text{HO}^\cdot \quad \text{(Eq.39) [42]}
\]

The efficiency of these systems is due to Photo reduction of ferric ion and efficient use of light quanta [42]. Due to its simplicity, these kind of reactions are used often to eliminate obstinate components [40].
2. METHODOLOGY

2.1. METHODS FOR DETERMINING TOC CONCENTRATIONS

Direct Non Purgeable Organic Carbon (NPOC) method and difference method are two methods for determining TOC. This is because there are inorganic carbon components together with the organic substances in an aqueous sample. Authentic TOC results will come from the selection of appropriate determination method according to predomination of the carbon compounds in the sample. The instruments on the market can detect TOC by either NPOC method or difference method.

➢ Direct determination - (NPOC) method

Removing of the inorganic carbon compounds (TIC) from the sample is the first step in NPOC method. Removal of TIC can be externally-outside the TOC analyzer, or internally in the TIC reactor part. Removal of the TIC is done by addition of acid to pH 2, and afterwards purging the carbon dioxide produced by an auxiliary gas. After purging, by injection the sample into the digestion unit of the analyzer, the remaining component of the organic carbon is identified. Due to its simple handling and reliability, NPOC method has become approved as the most frequent method of TOC determination.

➢ Difference method

The difference method requires two measurements. First, part of the sample is injected into the TIC reactor. Here usually with addition of acid and in a stream of carrier gas, the carbonate-derived portion of CO₂ is detected as TIC. Second step takes place in the digestion unit of the analyzer, where untreated sample is introduced and the total carbon (TC) is determined. Thus TOC is calculated as:

\[
\text{TOC} = \text{TC} - \text{TIC} \ [49].
\]

“The method has been standardized worldwide through a large number of standards. Besides the ASTM and EPA standards, the international standard ISO 8245 and the European standard EN 1484 are the conventions most frequently considered” [49].

Comparisons of the two methods are given in Table 6.

**Table 6**: Advantages and disadvantages of direct and difference TOC determining method [49].

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference method</td>
<td>Volatile organic compounds in the samples are detected as well.</td>
<td>Unsuitable at high TIC concentrations (TIC &gt;&gt; TOC). Measurement times are long.</td>
</tr>
<tr>
<td>Direct-NPOC method</td>
<td>Favorable at high TIC concentrations (TIC &gt;&gt; TOC). Gives quick results.</td>
<td>Volatile organic compounds in the samples are not detected.</td>
</tr>
</tbody>
</table>
2.2. OVERVIEW OF THE ANALYTICAL TECHNIQUES AT SART

Description of the various analytical techniques used at SAR treatment plant.

- **TOC and total N measurements**

For the measurement of TOC and Nitrogen content SAR Treatment is using multi N/C® 2100 Analyzer produced by Analytic Jena AG (Figure 20). TOC/TN_b analyzer gives data of total carbon and total nitrogen from every wastewater sample.

" **Characteristics multi N/C® 2100:**

- Focus Radiation NDIR-Detector®
- VITA® Flow Management System*
- Easy Cal®*
- Auto-protection
- Catalytic high-temperature oxidation up to 950°C
- Valve-free direct-injection technology
- Suitable also for small injection volumes
- Upgradable for simultaneous TN_b determination
- A catalyst for simultaneous TOC/TN_b determination in the entire measurement range
- Option of HT 1300 or double furnace technology for solid analysis
- Compact system with integrated, fully automated auto sampler " [50]

*model-specific

![Figure 20: TOC/TN_b analyzer [50]](image)

- **Density measurements**

For density measurements of wastewater samples a hydrometer device is used (Figure 21). Hydrometer is composed of a long-necked glass bulb that is weighted and sealed. Liquid density is determinate by depth of the flotation [51].
Sometimes SART also use a weight and measure the weight of one liter of the wastewater.

- **Photometer for determining the content of P in water samples**

Photometer is an instrument that measures the electromagnetic radiation from ultraviolet to infrared range and along with the visible spectrum [53]. SAR treatment for this purpose uses Spectroquant® NOVA 60 (Figure 22).

“Spectroquant® NOVA 60 is an instrument for the routine analysis of all water types and is capable of measuring both the ready-to-use cell tests as well as inexpensive reagent tests” [54].

---

**Figure 21: Hydrometer [52]**

**Figure 22: Spectroquant® NOVA 60 Photometer [55]**
- **JAR testing**

Jar test or coagulation test are used for simulating full scale coagulation and flocculation processes (Figure 23). It is performed in laboratory to determine optimum chemical (coagulant) dosage. The Jar tests can be used for selection of the most effective coagulation chemical and its optimum dosage [56].

For doing the Jar test analyses SAR Treatment is using coagulants PAX L60 and Polymer, and for pH adjusting HCL and NaOH are used. Specifications of PAX XL 60, Polymer, HCL and NaOH are given in Appendixes C, D, E and F.

![Figure 23: JAR test model](image)

- **pH and conductivity measurement**

For this purpose SAR Treatment is using instrument pH 100 produced from WWR. Conductivity is measured by “Combo pH & EC” By Hanna.

- **Alkalinity measurement**

For alkalinity measurement pH 100 apparatus is used.

If SART is unsure on the biological degradation of wastewater, small scale biological lab experiments are done. Measure the TOC after addition of the test water mixed with biomass and water from the biological rector. TOC is measured after 24 and 48 hours. This will give an idea if the water is biologically treatable.

### 2.3. LAB WORK AT SART FOR TOC CONCENTRATIONS

To get an overview of the TOC concentrations for wastewater at SART, a total 40 samples were analyzed, 5 from each month starting from July 2010 till February 2011. TOC in each sample was determined by using direct determination - NPOC method.
First step in removal of inorganic carbon compounds (TIC) from the sample was dilution of 2.5 ml sample with distilled water in 50 ml test tube and acidifying by adding 0.5 ml of hydrochloric acid (Figure 24).

**Figure 24:** Dilution of the sample

After that purging hose was inserted into the test tube purging the carbon dioxide generated by additional gas. Purging lasted for two minutes. This step was done externally - outside the TOC analyzer (Figure 25).

**Figure 25:** Removing of inorganic carbon compounds (TIC) from the sample
After TIC removal the MultiWIN evaluation software was started. Micro liter syringe of 500 μL was used for taking the sample and injecting into the digestion unit of the analyzer. In this way the remaining component of the organic carbon was determined [49]. The injection procedure consisted of two steps. Figure 26 shows injecting the sample in the TC port of the apparatus for 5 seconds. For another 10 more seconds (Figure 27) the syringe stayed in the port before it was removed and the port was closed.

**Figure 26:** Injecting the sample in the TC port of the analyzer

**Figure 27:** Second step of injection procedure of the sample
The procedure was repeated twice more for each sample. The MultiWIN evaluation software is set up for 2(2-3) repetitions, and it takes the average of the 2 closest values in the 3 repetitive measurements [49].

2.4. JAR TESTING AT SART

2.4.1. Small scale flocculation method

Small scale flocculation methods were done in order to find out the potential reaction. 100 ml of each sample was taken in a sample glass (Figure 28), followed by addition of 200 µl PAX XL 60 per 100 ml sample. Addition of PAX was done by 100 – 1000 µl automatic pipette. After that the sample glass was rapid mixed and the pH was measured. The next step was to adjust pH to 7 with NaOH, after which flocks in the water could easily be seen in Figure 29. The last step was addition of 3 ml of Polymer, which was injected with syringe in the water sample followed by slow mixing (Figure 30).

Figure 28: Water sample in a sample glass
Figure 29: Flocks in the water

Figure 30: Comparison of water samples, before and after small scale flocculation
2.4.2. Large scale flocculation method

Large scale flocculation tests were done on the same samples which later were sent to the UIS for Small Scale Simulation Test on biodegradability. A 2 L flask was used where 1500 ml of water sample was introduced followed by addition of 2000 µl PAX XL 60 per 1000 ml sample. Addition of PAX was done by 0.5 – 5 ml automatic pipette. Thereafter the sample was placed into jar test, and mixed at 100 ppm. (Figure 31). pH was measured by pH meter - pH 100. The mixing was typically about 1 min. Next step was adjusting the pH to 7 with NaOH, after which flocks in the water could easily be seen (Figure 32). The last step was addition of 3 ml of Polymer, which was injecting with syringe into the water sample. Mixing was then reduced to 30 r/min to provide gentle agitation and the flocks were allowed to settle. The sample settled for some time (Figure 33) before transferred to a sample tube (Figure 34) [56].

The TOC of the flocculated sample was measured using NPOC method for determining TOC concentration on the sample after flocculation.

![Figure 31: Rapid mixing of the sample](image-url)
Figure 32: Flocks in the water

Figure 33: Settling of flocks before taking the sample for biodegradation test
2.5. SMALL SCALE SIMULATION TESTS ON BIODEGRADABILITY

Small scale simulation tests on biodegradability were done in order to follow the degradation in the bioreactor at SART. 1 liter of sample water was saved for GC/MS scanning for hydrocarbons before start up and ends of each cycle of the bench tests.

2.5.1. Experimental procedure

Sludge washing on the activated sludge was done at SART before start up of each of the laboratory bench tests. By doing sludge washing, the TOC is removed from the water leaving only bacteria. The purpose of doing this is that no TOC should be left in the water phase but only clean sludge that is thereafter used for doing laboratory bench test. The activated sludge was collected from the bioreactor tank at SART (Figure 35).
The procedure for sludge washing was addition of 1000 ml sludge from bioreactor into measuring cylinders and settling the sludge for approximately 1 hour (Figure 36). After settling, the clear phase was decanted out of cylinders (Figure 37), before refilled with seawater up to 1000 ml and mixed. Seawater was stored for 24 hours at room temperature before addition to the cylinders.
The steps settling, decanting and refilling with seawater were repeated three more times. For the final washing step after decanting, the settled sludge from all cylinders was poured off into sample bottle and taken to the laboratory for start up of the bench tests (Figure 38).

**Figure 37:** Pouring out the clear phase

**Figure 38:** Transferring sludge into sample bottle
The laboratory bench test consisted of five by 1800 ml flasks. First flask was used for blank control, second for negative control and last three flasks were run in parallel where the degradation of the flocculated wastewater sample was monitored. All of the flasks were equipped with magnetic stirrers for establishing sufficient mixing and uniform distribution of biomass and substrate in the flasks. Oxygen in the flasks was provided by air diffusers for sufficient oxygen supply (Figure 39) /33/.

**Figure 39:** Schematic diagram of the bench test

Legend:

- Stirring and temperature control,  
- Magnetic stirrer,  
- Air pump,  
- Air diffuser

Before the start up of the tests, the temperature on the hotplate magnetic stirrers was adjusted to around 34 °C to simulate the temperature in the bioreactor at SART (Figure 40).

**Figure 40:** Adjusting the temperature on hotplate magnetic stirrers to 34 °C
In order to avoid temperature shock on the bacteria, flocculated wastewater was stored to room temperature 24 hours before each run of the bench tests. Biomass was distributed equally to all 5 flasks corresponding to the level in sample bottle (Figure 41), following by addition of seawater in the flasks.

**Figure 41:** Sludge for distribution in flasks

Macronutrients, micronutrients, vitamins and amino acids were mixed in separate flask with flocculated wastewater sample so the pH could be adjusted to 7 (Using NaOH), to avoid low pH before distribution to the flasks. Optimum pH range of microorganisms is pH 7 - 8. pH outside this range may reduce growth, treatment rate and even kill bacteria[33]. Flocculated wastewater sample was distributed in 3 flasks in parallel and in one for the negative control (Figure 42) and diluted till 1800 ml by seawater. The blank control consisted of biomass, nutrients and seawater without wastewater sample. In the flask for blank control seawater was added together with nutrients till 1800 ml. Aeration of the bench test was started and it was left during the night (Figure 43).

**Figure 42:** Distribution of the flocculated water with nutrients in each flask
Total of three bench experiment were done. Table 7 shows the bench test content before start of the experiments [58].

**Table 7: Bench test configuration**

<table>
<thead>
<tr>
<th>Bench test</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative control</td>
<td>Biomass, nutrients, flocculated water and seawater</td>
</tr>
<tr>
<td>Blank Control</td>
<td>Biomass, nutrients and seawater</td>
</tr>
<tr>
<td><strong>Test control</strong></td>
<td></td>
</tr>
<tr>
<td>Flask 1</td>
<td>Biomass, nutrients, flocculated water and seawater</td>
</tr>
<tr>
<td>Flask2</td>
<td>Biomass, nutrients, flocculated water and seawater</td>
</tr>
<tr>
<td>Flask3</td>
<td>Biomass, nutrients, flocculated water and seawater</td>
</tr>
</tbody>
</table>

From the beginning of each cycle of bench test, the total suspended solids and volatile suspended solids were measured daily to follow the biomass growth. The retained filtrate from TSS/VSS analyzes was filtered daily through 0.22 µm Nylon acrodisc filters, and TOC of filtrate was measured as Dissolved Organic Carbon (DOC). DOC is a general description of the organics capable to pass through 0.22 µm size filter [59]. Dissolved oxygen (DO) was measured during the first day and parameters temperature and pH were measured a couple of times daily. In test flasks VSS growth and DOC removed were corrected for the blank.
2.5.2. Analytical procedures during the bench test

- **Calculation of flocculated sample volume (Vs)**

Addition of the flocculated water sample volume (Vs) for each bench run was calculated according to the mass balance.

\[ C_s \times V_s = C_0 \times V_0 \]  

(Eq.40)

Where:

- \( C_s \) - Concentration of the flocculated water sample
- \( V_s \) - Volume of the flocculated water sample
- \( C_0 \) - Initial concentration of the flocculated water sample
- \( V_0 \) - Initial Volume of the flasks

\( C_0 \) for every run was set at 1200 mg/l.

Addition of macronutrients was calculated according to ratio C: N: P 100:20:5. After calculations 2 ml/L of 40 % Urea (\( \text{NH}_2\text{CO} \)) was added as a source of N and 0.4 ml/L of 75% Phosphoric acid (\( \text{H}_3\text{PO}_4 \)) was added as a source of P. 1 ml of micronutrients and 0.2 ml of Vitamins and Amino acids were added together with macronutrients in each flask. Specification of 75 % Phosphoric acid is given in Appendix G, and specifications for micronutrient solution in Appendix H.

- **Temperature and pH**

Temperature on the hotplate magnetic stirrers was adjusted to 34 °C to simulate the temperature at bioreactor at SART. Temperature together with pH was monitored with instrument Metrohm 744 pH meter.

- **Dissolved Oxygen (DO)**

Dissolved oxygen was measured with WTW Multi 3410.

- **Analyses of TSS and VSS**

TSS analyses were done using Whatman glass microfiber filters GF/F - 47 mm with 1 um pore size. First filters were dried at 105 °C for at least 15 minutes prior to weighting to assure completely dryness. After drying, the filters were cooled in desiccator and weight was measured as \( m_{\text{filter}} \). The appropriate sample volume was allowed to settle for around 30 minutes prior to filtration and the clear liquid was filtered first while the settled solids were added after so the filtering procedure went much faster. The filtered liquid was used for dissolved organic carbon analysis. Determination of TSS was after drying the filters with support dishes for a minimum of 2 hours in oven at 103-105°C and cooling them in desiccator.
After cooling, filter + solids weight was measured and was noted as \( m_{\text{filter} + \text{solids}} \).

Calculation of TSS:

\[
TSS \left[ \frac{mg}{l} \right] = \frac{m_{\text{filter} + \text{sample}} - m_{\text{filter}}}{V_{\text{sample}}} 
\]  
\text{(Eq.41)}

For determination of VSS, the filters with porcelain dishes were combusted in muffle oven at 550°C for 30 minutes. After combustion the dishes with filters were cooled for a short time in air before transferred to desiccator. The weight of filters and ignited residual was measured on analytical balance and noted as \( m_{\text{filter} + \text{ignited residual}} \).

Calculation of VSS:

\[
VSS \left[ \frac{mg}{l} \right] = TSS - \frac{m_{\text{filter} + \text{ignited residual}} - m_{\text{filter}}}{V_{\text{sample}}} 
\]  
\text{(Eq.42) [60]}

- **Dissolved Organic Carbon (DOC)**

For Dissolved Organic Carbon measurements, 1 ml of filtered liquid from TSS analyses was taken with syringe and filtered through 25 mm W/0.2 µm Nylon membrane Syringe filters. After 1:20 dilution, the samples were taken to SART where TOC of filtrate was measured as DOC.

- **Calculation for DOC degradation**

By using the equation below the degradation percentage was calculated.

\[
D_t = \left[ 1 - \frac{C_t - C_{bl(t)}}{C_0 - C_{bl(0)}} \right] \cdot 100 
\]  
\text{(Eq.43)}

Where:

\( D_t \) = percentage of DOC degradation at time \( t \),

\( C_0 \) = DOC starting concentration

\( C_t \) = DOC concentration at time \( t \),

\( C_{bl(0)} \) = starting concentration of DOC in the blank,

\( C_{bl(t)} \) = concentration of DOC in the blank at time \( t \) [61]
3. RESULTS AND DISCUSSION

3.1. RESULTS FROM LAB WORK ON DETERMINING TOC CONCENTRATION

TOC concentrations on 40 water samples were analyzed at SART. According to Figure 44, TOC concentration in receiving water at SART ranges from 2000 to over 10000 mg/l.

![Average TOC](image)

Figure 44: Average TOC during period of 8 months

3.2. RESULTS FROM JAR TEST

Table 8 shows TOC concentration after flocculation and filtering on selected samples. These samples with various TOC concentrations were used as $C_{\text{sample}}$ for the three bench tests at UiS in order to follow the HC degradation. As degradation of sample with the highest TOC concentration (12000 mg/l) during the first run went very fast (in two days) for the second and third run, therefore, $C_{\text{sample}}$ with less TOC concentration were chosen.
Table 8: TOC concentration after flocculation

<table>
<thead>
<tr>
<th>Cycle No.</th>
<th>Sample ID</th>
<th>TOC concentration (mg/l) after flocculation $(C_{\text{sample}})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>STR10-219</td>
<td>12000 mg/l</td>
</tr>
<tr>
<td>2</td>
<td>STR10-256 and STR10-155</td>
<td>2500 mg/l</td>
</tr>
<tr>
<td>3</td>
<td>Water taken from DAF outlet unit mixed with water from mixing chamber</td>
<td>1900 mg/l</td>
</tr>
</tbody>
</table>

3.3. RESULTS FROM SMALL SCALE TESTING FOR BIODEGRADABILITY

3.3.1. First bench cycle

For the first bench test, sample with relatively high concentration of carbon was chosen $(C_s = 12000$ mg/l) and 250 ml biomass was added in each flask. After aeration for one day, 4 g Sodium Azide (NaN$_3$) was added in the negative flask control for biological inactivation of bacteria. Initial DOC in test flasks was unfortunately not calculated during the first day. This was however performed later by (1:10) dilution of 2 ml sample substrate by 18 ml de-ionized water in 22 ml vial. Thereafter the normal procedure for DOC measurements was followed.

a) Discussion

Results from this cycle were not as expected. They were therefore considered inaccurate due to analytical errors in VSS measurements and not being able to biologically inactivate bacteria in the negative control flask. Results from this cycle are presented in Appendix A. What was interesting is that DOC removal rate was very rapid with most of the organics removed by day 2 (Figure A8 in Appendix A). However, this was a good learning experience and led to the following changes in the next run by:

a. Reducing the initial $C_{\text{sample}}$ and initial biomass concentration
b. Increasing the accuracy in VSS analysis
c. Measuring initial VSS and DOC concentrations
d. Measuring DO concentrations during the first day
e. Autoclaving of the negative control flask before addition of NaN$_3$
3.3.2. Second bench cycle

For the second bench test, sample with less carbon was chosen \( (C_s = 2500 \text{ mg/l}) \) and less biomass \( (150 \text{ ml}) \) was added in each flask compared with the first bench run. After addition of the test compound, foam started to occur but was stabilized by adding 3 ml of foam inhibitor. Initial concentrations of DOC and VSS were measured in all flasks approximately 1 hour after feeding. During the first day of measuring DO concentrations it was established that the test flasks were anoxic with DO concentrations at around 0.5 mg/l. Pumps were not efficient to provide enough oxygen which resulted in reducing the initial carbon and biomass concentrations in third cycle.

a) Results from second bench cycle

- Environmental factors

Temperature and pH are presented in Figure 45 and Figure 46. As mentioned earlier, temperature on the hotplates with magnetic stirrers was adjusted to around 34 °C before the start up of the bench tests to simulate temperature at SART full scale bioreactor.

![Figure 45: Temperature during second bench run](image-url)
Figure 46 shows pH values in test flasks between 7 and 8.

![Figure 46: pH during second bench run](image)

**Figure 46:** pH during second bench run

- **Correlation between VSS and DOC**

In the blank control test (Figure 47), DOC differences of 50 mg/l were noticeable.

![Figure 47: Blank control during second bench run](image)
For the second run, negative flask control (Figure 48) was autoclaved for 1 hour at 120 °C followed by addition of 5 g Sodium Azide. Despite autoclaving and addition of chemicals there was still noticeable increase in the biomass growth during the first day. Additional 5 grams of Sodium Azide was added after the first day followed by a slight decrease in biomass. The pH during the second run was kept below 6 by addition of HNO₃ (Figure 46).

![Negative control](image)

**Figure 48:** Negative control during second bench run

Figures 49, 50 and 51 are representing test flasks where rapid increase in VSS corresponds to utilization of readily biodegradable soluble organics (RBCOD).

![Flask 1](image)

**Figure 49:** Test flask 1 during second bench run
Figure 50: Test flask 2 during second bench run

Figure 51: Test flask 3 during second bench run

Figure 52 show that the degradation curve reached a plateau after 2.5 days with more than 90% DOC removal. Average DOC removals from the test flasks gives DOC concentration below 200 mg/L after 2.5 days (Figure 53) [58].
Figure 52: Degradation curve for the test sample

Figure 53 represents average VSS growth and average DOC removal in the test flasks with standard errors.

Figure 53: Average VSS growth and average DOC removal in test flasks with standard errors
b) Discussion

This run was ended after day 4 due to low DO and assuming constant removal of DOC. For third cycle sample with less carbon and less sludge was therefore used and was operated during 10 days. During second cycle of bench test the temperature was stable in the range of 35 – 37 °C. Temperature significantly influence biological growth rate. The biological growth rate is increasing exponential as a function of temperature [33]. PH was within the optimum pH range (Figure 46). When pH dropped below 7 and increased above 8 it was adjusted to 7 with NaOH / HNO₃. Optimum pH range for microorganisms is pH 7 – 8 with acceptable range of about 6 – 9. PH outside this range may lower growth and removal of TOC significantly, and even kill bacteria. In addition, high pH can cause salts to precipitate causing problems for the process and enhance sludge production [33].

The results from VSS analyses were considered accurate. Degradation of substrate that occurred in blank control was probably due to residual DOC from biomass (i.e. DOC adsorbed to biomass during sludge washing). From the negative control flask after analyzing the DOC concentration, no decrease in substrate was observed after day one during the second run. Due to the growth of VSS in the negative control flask of the second cycle, for the third cycle was performed autoclaving of the negative flask together with air diffuser and air hose, followed by lowering the pH below 2 with HNO₃.

In the beginning of the degradation process, as it can be seen from the Figures 49 to 51, there is rapid uptake of substrate resulting in large increase in VSS and decrease in DOC. This corresponds with day 2 in Flasks 1 and 3 and somewhere after 1,5 days in flask 2.

During this period the bacteria in the wastewater are consuming the readily biodegradable soluble substrate (RBCOD). RBCOD is taken rapidly by the sludge and metabolized at high rate [62]. The period after day 2 should correlate with utilization of slowly biodegradable particulate substrate. (SBCOD). “SBCOD requires to be adsorbed and stored by the organisms, breaking down to simpler chemical units by extracellular enzymes and then absorbing and metabolizing by the organism “ [62].

Calculation of degradation curve gave more than 90 percent DOC removal during the first 2.5 days meaning rapid degradation (Figure 52).

During the experiment there were some errors due to analyses of the samples and errors from the TOC instrument. Figure 53 presents calculated standard errors for the mean VSS growth and mean DOC removal. It shows higher content of variation of results calculating the average VSS growth compared with lower content of variation of results for average DOC removal given by the instrument.
3.3.3. THIRD BENCH CYCLE

For the third bench test, sample with further less carbon ($C_s = 1800$ mg/l) and less biomass (30 ml) were added in each flask compared with the second bench run. Reduction in carbon source and biomass were due to ineffectiveness of the pumps providing insufficient oxygen into the flasks resulting in low DO concentrations. After addition of the test compound foam occurred and was stabilized by addition of 3 ml foam inhibitor. Initial concentrations of VSS and DOC were measured in all flasks approximately 1 hour after feeding. For the negative control test after autoclaving, $C_s$ and seawater was added to the 1800 ml and 2 mol HNO$_3$ was added to bring the pH below 2. Additional, air from the pump was filtered before distributing it to the flask,

a) Results from third bench cycle

- Environmental factors

Figure 54 shows that temperatures during the third cycle were in the range of 34 to 37, except for the blank that was bellows 34.

![Figure 54: Temperature during third bench run](image)

As observed from the Figure 55, pH in test flasks was within the range of 7 – 8 except for days 7 and 8 in flasks 2 and 3 where pH dropped to around 6.5.
Figure 55: pH during third bench run

Figure 56 shows the bench test during the third cycle.

Figure 56: Bench test during third run
- Correlation between VSS and DOC

In the blank control test, a change of 160 mg/l DOC was noted (Figure 57).

![Blank Control Graph](image)

**Figure 57:** Blank control during third bench run

The pH distribution for the negative control is shown in Figure 55. During the third cycle in the negative control flask there was no growth of VSS and very slight decrease of DOC as seen in Figure 58.

![Negative Control Graph](image)

**Figure 58:** Negative control during third bench run
For the test flasks from Figures 59, 60 and 61 there is rapid increase in VSS corresponding to utilization of readily biodegradable soluble organics (RBCOD).

**Figure 59: Test flask 1 during third bench run**

**Figure 60: Test flask 2 during third bench run**
Calculation of DOC degradation gave more than 90% DOC removal after 2.5 – 3 days of batch test (Figure 62). Average DOC concentration from the test flasks presented with standard error after 2.5 - 3 days was below 200 mg/L (Figure 63) indicating rapid degradation/58/.

**Figure 61**: Test flask 3 during third bench run

**Figure 62**: Degradation curve for the test sample
b) Discussion

The results from third cycles are considered accurate. Temperatures were within the range of 34-37 °C. A pH drop for days 7 and 8 in flasks 2 and 3 was probably due to nitrification process in activated sludge. Nitrification is a two step process where group of bacteria known as Nitrosomonas oxidize ammonium to nitrite (Equation 44) and then another group of autotrophic organisms known as Nitrobacter oxidize nitrite to nitrate (Equation 45)\[^4\]. During the nitrification process acid is produce that lowering the pH. The pH drop was neutralized by addition of 0.1 mol NaOH.

\[
\begin{align*}
\text{NH}_4^+ + 1.5 \text{O}_2 & \rightarrow \text{NO}_2^- + \text{H}_2\text{O} + 2\text{H}^+ & \text{(Eq. 44)} \\
\text{NO}_2^- + 0.5\text{O}_2 & \rightarrow \text{NO}_3^- & \text{(Eq. 45)}
\end{align*}
\]

Elimination of Volatile Organic Compounds (VOC) from activated sludge system correlate with biodegradation, adsorption onto solids and air stripping removal. Use of oxygen is very effective in prediction of VOCs elimination by air stripping \[^63\]. During this experiment, bacteria in negative control flask were biologically inactivated successfully and the observed slight decline in DOC is probably due to small content of VOCs air stripping contributing to the overall degradation process.

Degradation in test flasks gave rapid increase in VSS and decrease in COD due to utilization of RBCOD. RBCOD are considered small molecules which are utilized relatively fast by the biomass \[^35\]. They pass straightforwardly through the cell wall and are metabolized at high rates resulting in a rapid uptake equivalent to a VSS increase \[^62\]. The visible constant removal of DOC after day 2 (day 3 in Flask 3), represents utilization of slowly biodegradable particulate organics, SBCOD. SBCOD are large complex molecules and suspended particles that prior to uptake must be hydrolyzed to simple compounds, RBCOD \[^35\].

Figure 63: Average VSS growth and average DOC removal in test flasks with standard errors
SBCOD is first adsorbed onto microorganisms followed by storage. The stored organic compounds helped by extracellular enzymes are broken down, passed through the cell wall and metabolized. The enzymatic breakdown rate is very slow and is around one tenth of the RBCOD rate [62]. That is why utilization of SBCOD is slower than utilization of RBCOD. The growth rate of biomass is lower as organics are not directly received. During this phase there is more death of bacteria than growth, corresponding to slow decline in VSS.

DOC degradation curve gave more than 90 percent removal of DOC after 2.5 – 3 day indicating rapid degradation (Figure 62).

3.4. RESULTS FROM GC/MS ANALYSES

Analyses of samples before and after each bench cycle were performed externally at ALS Laboratory Group Norway AS for screening of semi volatile compounds using GC/MS. Following method was used: Samples were extracted with n-hexane and analyzed by GC / MS. After separations in gas chromatographic column organic compounds were determined by looking at the characteristic mass of the / those compounds (GC-MS). Mass spectrum can compare the components in a library of mass spectrums from organic compounds or with spectra of equal reference values. In this way an appropriate organic compound in the sample can be determined qualitatively.

Although additional time for GC / MS analyses was required by the external laboratory, they have managed to identify the compounds only in the samples from first two bench cycles. The second sample from the third bench cycle was unfortunately misplaced by the external laboratory and no results from this cycle were given back.

Without signal from the internal standard, the following semi-volatile compounds were identified and presented in tables 9 –12.
Table 9: Identified compounds before the start up of the first bench cycle

<table>
<thead>
<tr>
<th>Peak No</th>
<th>Sample before first bench cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Butoxyethanol</td>
</tr>
<tr>
<td>2</td>
<td>Butoxypropanol</td>
</tr>
<tr>
<td>3</td>
<td>Phenol</td>
</tr>
<tr>
<td>4</td>
<td>2-Ethyl-1-hexanol</td>
</tr>
<tr>
<td>5</td>
<td>Methylphenol</td>
</tr>
<tr>
<td>6</td>
<td>1-octanol</td>
</tr>
<tr>
<td>7</td>
<td>Isooctane</td>
</tr>
<tr>
<td>8</td>
<td>Butoxyethoxyethanol (glycol)</td>
</tr>
<tr>
<td>9</td>
<td>Octanoic acid</td>
</tr>
<tr>
<td>10</td>
<td>Hydroxypropoxyethanol (glycol)</td>
</tr>
<tr>
<td>11</td>
<td>Alkane</td>
</tr>
<tr>
<td>12</td>
<td>Glycol</td>
</tr>
<tr>
<td>13</td>
<td>Triethylene glycol monododecyl ether (or similar)</td>
</tr>
<tr>
<td>14</td>
<td>Octaethylene glycol</td>
</tr>
<tr>
<td>15</td>
<td>Glycols and glycolmonoether</td>
</tr>
</tbody>
</table>

Table 10: Identified compounds at the end of the first bench cycle

<table>
<thead>
<tr>
<th>Peak No</th>
<th>Sample after first bench cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Benzothiazole</td>
</tr>
<tr>
<td>17</td>
<td>Dodecamethylcyclohexasiloxane</td>
</tr>
<tr>
<td>18</td>
<td>Phenol</td>
</tr>
<tr>
<td>19</td>
<td>2-Ethyl-1-hexanol</td>
</tr>
<tr>
<td>20</td>
<td>Tetrahydroquinoline</td>
</tr>
<tr>
<td>21</td>
<td>Benzophenone</td>
</tr>
<tr>
<td>22</td>
<td>Alkane</td>
</tr>
<tr>
<td>23</td>
<td>TCEP (tris(2-carboxyethyl)phosphine)</td>
</tr>
<tr>
<td>24</td>
<td>N-Butyl-benzenesulfonamide</td>
</tr>
<tr>
<td>25</td>
<td>Alkene</td>
</tr>
<tr>
<td>26</td>
<td>Bisphenol A</td>
</tr>
<tr>
<td>27</td>
<td>Diisooctyl phosphate</td>
</tr>
<tr>
<td>28</td>
<td>Squalene or similar</td>
</tr>
</tbody>
</table>
Table 11: Identified compounds at the beginning of the second bench cycle

<table>
<thead>
<tr>
<th>Peak No</th>
<th>Sample before second bench cycle No. N00145484</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Butoxyethanol</td>
</tr>
<tr>
<td>2</td>
<td>Butoxypropanol</td>
</tr>
<tr>
<td>3</td>
<td>Phenol</td>
</tr>
<tr>
<td>4</td>
<td>2-Ethyl-1-hexanol</td>
</tr>
<tr>
<td>10</td>
<td>Hydroxypropoxyethanol (glycol)</td>
</tr>
<tr>
<td>11</td>
<td>Alkane</td>
</tr>
<tr>
<td>12</td>
<td>Glycol</td>
</tr>
<tr>
<td>13</td>
<td>Triethylene glycol monododecyl ether (or similar)</td>
</tr>
<tr>
<td>14</td>
<td>Octaethylene glycol</td>
</tr>
<tr>
<td>15</td>
<td>Glycols and glycolmonoether</td>
</tr>
</tbody>
</table>

Table 12: Identified compounds at the end of the second bench cycle

<table>
<thead>
<tr>
<th>Peak No</th>
<th>Sample after second bench cycle No. N00145485</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>Glycol ether</td>
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<tr>
<td>30</td>
<td>Indole</td>
</tr>
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<td>21</td>
<td>Benzophenone</td>
</tr>
<tr>
<td>25</td>
<td>Alkene</td>
</tr>
<tr>
<td>31</td>
<td>Pentadecanoic acid</td>
</tr>
<tr>
<td>27</td>
<td>Diisooctyl phthalate</td>
</tr>
<tr>
<td>32</td>
<td>Phthalate esters (technical mix)</td>
</tr>
<tr>
<td>33</td>
<td>Polypropylene glycol</td>
</tr>
</tbody>
</table>

Because of the internal standard not visible in chromatograms due to high signal of the substances, semi quantification with internal standard is not possible. The extracts from the samples N00145482 and N00145484 were evaporated and the residue was weighed.

N00145482: 18 mg/l.

N00145484: 135 mg/l [64].

Chromatograms are in Appendix B.
3.4.1. Discussion

Results presented are from qualitative GC/MS analyzes without concentrations of the organic compounds before and after the experiments. At the beginning of the degradation process both RBCOD and SBCOD are present. From Tables 9 and 11 similar compounds were detected in the samples before degradation. Compounds identified are belonging to glycols, glycol ethers, phenols, fatty alcohols, fatty acids and alkanes. They all have been found to be easy biodegradable compounds, RBCOD. Assumption is made that similar compounds could be expected in the third experiment as well. Slowly biodegradable compounds, SBCOD, were detected as well but due to the overlap of the chromatogram peaks they are not shown in the tables (see chromatogram). Most of the compounds identified as RBCOD are glycols and glycol ethers. Means & Anderson followed the aerobic biodegradation of ethylene glycol using five different procedures where ethylene glycol was rapidly degraded in all tests [65]. According to some laboratory studies on biodegradation of glycol ethers it was found that these compounds have very good biodegradation characteristics and they are expected to go through rapid degradation in activated sludge systems [66].

At the end of the degradation process RBCOD are utilized and only SBCOD and some unbiodegradable compounds are left. Compounds in Tables 9 and 11 are identified as organo sulfur compounds, cyclic siloxanes, amides, benzophenone compounds and phthalate esters. Most of them are SBCOD and some of them are stable against biodegradation. Incomplete removal of Benzophenone has been reported from wastewater treatment process showing recalcitrance of this compound [67]. Benzothiazole is reported as a toxic and slowly biodegradable compound [68]. Biodegradation of different sulfonamides were investigated using a respirometric and activated sludge simulation tests and it was concluded that sulfonamides cannot be placed as readily biodegradable compounds [69].

According to Rene Huppmann et al, cyclic siloxanes like dodecamethyl cyclohexasiloxane and tetradecamethyl cyclohexasiloxane are highly volatile and very stable to biochemical degradation [70].

A type of Pentanoic acid was found to be a byproduct of Phenol to catechol degradation pathway [71].
4. CONCLUSION AND RECOMMENDATIONS

This research proved that biological treatment using activated sludge is very effective in removal of organics from industrial wastewaters. According to the bench tests results, wastewater received at SART is very biodegradable. Although using wastewater samples with various TOC concentrations ranked from 1900 to 12000 mg/l, DOC removal rate was very rapid with approximately 90 percent of DOC removed within 2 - 3 days. Taking into consideration the VSS growth and DOC removal in test flasks and degradation curves the wastewater from SART is composed of around 90 % of RBCOD and the rest is slowly biodegradable particulate organics and unbiodegradable substrates. During the third cycle it was found that small percent of air striping of VOCs probably contribute to the overall degradation process.

Results from the GC/MS analyze shows that most of the compounds identified before each cycle is belonging to glycol and glycol ethers that are known to be rapidly degraded. Biodegradability of slowly biodegradable particulate organic compounds like organo sulfur compounds, cyclic siloxanes, amides, benzophenone compounds etc can be improved by use of Advanced Oxidation Processes.

Recommendation for future research is that Oxygen Utilization Rate (OUR) measurements are performed during bench tests. These results can be used to distinguish more precise the RBCOD from SBCOD substrate utilization. Performing bench test for evaluating effectiveness of AOP in destroying compounds correlate as SBCOD can be done and calculation of biodegradation parameters and implementation of experimental data in AQUASIM software for parameter estimation ($\mu_{\text{max}}$, $K_s$ and $Y_{x/s}$) is also recommended.
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49. AG, A.J., *Fundamentals, instrumentation and techniques of Sum Parameter Analysis.*


APPENDIX A

Results from first bench cycle
- Environmental factors

**Figure A1:** Temperature during first bench run

**Figure A2:** pH during first bench run
- **Correlation between VSS and DOC**

**Figure A3:** Blank control during first bench run

**Figure A4:** Negative control during first bench run
Figure A5: Test flask 1 during first bench run

Figure A6: Test flask 2 during first bench run
Figure A7: Test flask 3 during first bench run

Figure A8: Average DOC removal during first bench run
Appendix B

GC/MS Chromatograms
Appendix C

Specifications on PAX XL-60
1. Identifikasjon av kjemikaliets navn og ansvarlig firma

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</tr>
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<td>Kjemikaliets bruksområde</td>
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**Produsent**

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<th>Kemira Chemicals AS</th>
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</tr>
<tr>
<td>Org. nr.</td>
<td>941559190</td>
</tr>
<tr>
<td>Kontaktperson</td>
<td>Tore Hunn</td>
</tr>
<tr>
<td>Nødtelefon</td>
<td>22591300</td>
</tr>
</tbody>
</table>

2. Stoffblandingers sammensetning og stoffenes klassifisering

<table>
<thead>
<tr>
<th>CAS-nr.</th>
<th>EC-nr.</th>
<th>Komponentnavn</th>
<th>Innhold</th>
<th>Merking/klassifisering</th>
<th>Anm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1327-41-9</td>
<td>215-477-2</td>
<td>Polyaluminiumkloridhydroksidsilikat</td>
<td>30</td>
<td>Xi; R36/38</td>
<td></td>
</tr>
<tr>
<td>7732-18-5</td>
<td>231-791-2</td>
<td>Vann</td>
<td>70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Kolonneforklaring**

CAS-nr. = Chemical Abstracts Service; EU (Einecs- eller Elincsnummer) = European inventory of Existing Commercial Chemical Substances; Ingrediensnavn = Navn iflg. stoffliste (stoffer som ikke står i stofflisten må oversettes hvis mulig). Innhold oppgitt i; %, %vkt/vkt, %vol/vkt, %vol/vol, mg/m³, ppb, ppm, vekt%, vol%.

**Symbolforklaringer**

T+ = Meget giftig, T = Giftig, C = Etsende, Xn = Helseskadelig, Xi = Irriterende, E = Eksplosiv, O = Oksiderende, F+ = Ekstremt brannfarlig, F = Meget brannfarlig, N = Miljøskadelig.

3. Viktigste faremomenter

**Farebeskrivelse**

Irriterer øyne og huden. Produktet er ikke brannfarlig. Store utslipp kan innvirke negativt i vannmiljø pga lokal pH-senkning.

4. Førstehjelpstiltak

**Innånding**

Frisk luft. Skyll nese, munn og svelg med vann.
Hudkontakt

Øyekontakt

Svelging

Informasjon til helsepersonell
Hvis lege skal kontaktes, anvendes dette HMS-datablad som informasjonskilde.

5. Tiltak ved brannslukning
Passende brannslukningsmiddel
Ikke brannfarlig, velg slukningsmiddel etter omgivelserne.

Uegnet brannslukningsmiddel
Ingen restriksjoner

Brann- og eksplosjonsfarer
Ikke brannfarlig. Ved oppvarming dannes giftige og etsende gasser (saltsyregass).

Personlig verneutstyr
Bruk selvforsynt åndedrettsvern, friskluftmaske og beskyttelsesklær. Risiko for dannelse av giftige gasser.

6. Tiltak ved utilsiktet utslipp
Sikkerhetstiltak for å beskytte personell

Sikkerhetstiltak for å beskytte ytre miljø
Større mengder må ikke tømmes i kloakk og dem opp for spredning av utslipp til ytre miljø. Nøytraliser med kalk og absorber i sand.

Metoder til opprydding og rengjøring
Gjør rent med vann. Ved større utslipp till vann, kontakt politi/redningstjeneste.

7. Håndtering og oppbevaring
Håndtering
Håndter produktet slik at søl og damp ikke oppstår.

Oppbevaring

8. Eksponeringskontroll og personlig verneutstyr
Eksponeringskontroll
Begrense eksponering på arbeidsplassen

Åndedrettsvern
Gasmaske med patron for partile (P2).

Håndvern
Hansker av naturgummi, neopren, nitril, PVC eller viton. Gjennomtrengningstid > 8 timer.

Øyevern
Bruk tettsittende vernebriller. Øyesypleflasker skal være tilgjengelig.

Annet hudvern enn håndvern
Fullstendig kjemikaliebeständig dress og støvler ved behov.

9. Fysiske og kjemiske egenskaper
Tilstandsform
Flytende

Lukt
Ubetydelig

Farge
Svakt gulfarget klar væske

Løselighet i vann
Fullstendig løselig ved 20°C

Løselighet i fett
Ikke fettløslig

Relativ tetteth
1300-1330 kg/m3

Smeltepunkt/smeltepunktsintervall
-25

Kokepunkt/ kokepunktintervall
Verdi: °C

Verdi: °C

Dette HMS-databladet er utarbeidet i ECO Publisher (ECOOnline)
10. Stabilitet og reaktivitet

<table>
<thead>
<tr>
<th>Forhold som skal unngås</th>
<th>Unngå høye temperaturer og frysing.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materialer som skal unngås</td>
<td>Stål, galvaniserte overflater. Unngå kontakt med kloritt, hypokloritt, sulfitt, nitritt, nitrat og ulegert stål.</td>
</tr>
<tr>
<td>Farlige spaltningsprodukter</td>
<td>Ved oppvarming &gt;200°C kan saltsyregass dannes.</td>
</tr>
<tr>
<td>Stabilitet</td>
<td>Produktet er stabilt ved normal lagring.</td>
</tr>
</tbody>
</table>

11. Opplysninger om helsefare

**Toksikologisk informasjon**

| Oral toksisitet | LD50, rotte (mg/kg) >2000 |

**Øvrige helsefareopplysninger**

| Generelt | Damp virker irriterende på slimhinner, øyne og åndedrettsorganer |
| Innånding | Innånding av aerosoler kan gi sving, hoste og pustebesvær. |
| Hudkontakt | Irritasjon, rødflammethet og eksemlignende besvær |
| Øyekontakt | Damp kan virke irriterende på øyne |
| Svelging | Svelging kan gi magesmerter og oppkast. Kan virke irriterende i mun, svelg og mage. |

12. Miljøopplysninger

**Toksikologisk informasjon**

| Akvatisk kommentarer | Bioakkumuleres ikke. Log pow <<3 |

**Øvrige miljøopplysninger**

| Økotoksicitet | LC50/96h/Danio rerio: > 1000 mg/l |
| EC50/48h/Daphnia magna: 98 mg/l |
| IC50/72h/Alga: Ikke relevant i algetest da fosfor er maskert av algevekstmedium i testen (pkt. 16.4). |
| NOEC Danio rerio: >1000 mg/l |
| NOEC Daphnia magna: 40 mg/l (= 3.6 mg total Al/l, både i løslig og utfelt form) |
| Da langtidsønskeligheten (28 dager) ligger i området 0.006 - 0.035 mg/Al/l, blir ikke stoffet klassifisert som farlig for miljøet. |
| Klassifiseres ikke som giftig eller skadelig i vannmiljø (pkt. 16.4). |
| Bioakkumulasjonspotensial | Bioakkumuleres ikke. Log pow <<3 |

13. Fjerning av kjemikalieavfall

| Avfallskode EAL | 060314 |
| NORSAS | 7132 |
| Produktet er klassifisert som farlig avfall | Ja |

**Annen informasjon**

14. Opplysninger om transport

<table>
<thead>
<tr>
<th>Varenavn (nasjonalt)</th>
<th>Polyaluminiumkloridhydroksidsilikat løsning</th>
</tr>
</thead>
<tbody>
<tr>
<td>UN-nr.</td>
<td>3264</td>
</tr>
<tr>
<td>Farlig gods ADR/RID</td>
<td>Ja, Klasse:8 Føre nr.:80</td>
</tr>
<tr>
<td>Farlig gods IMDG</td>
<td>Ja, Klasse:8 Emballasjejeglepper:III</td>
</tr>
<tr>
<td>Farlig gods ICAO/IATA</td>
<td>Ja, Klasse:8 Emballasjejeglepper:III</td>
</tr>
<tr>
<td>Fareseddel</td>
<td>8</td>
</tr>
<tr>
<td>Andre relevante opplysninger</td>
<td>Produktet er klassifisert som farlig gods da det er svakt etsende på metaller iflg ADR-test 2800 (3) (f).</td>
</tr>
</tbody>
</table>

15. Opplysninger om lover og forskrifter

**Faresymbol**

<table>
<thead>
<tr>
<th>Sammensetning på merkeetiketten</th>
<th>Polyaluminiumkloridhydroksidsilikat: 30 %, Vann: 70 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC-nr.</td>
<td>215-477-2</td>
</tr>
<tr>
<td>R-setninger</td>
<td>R-36/38 Irriterer øynene og huden.</td>
</tr>
</tbody>
</table>

**Referanser (Lover/Forskrifter)**

1. Klassifisering og merking av farlige kjemikalier i Norge (stofflisten).
2. Administrativ norm for arbeid med kjemikalier.
3. Forskrift om vern mot eksponering for kjemikalier på arbeidsplassen (kjemikalieforskriften).
4. Databladforskriften, revidert forskrift nr 1323 per 16.07.02.
5. Lov om transport av farlig gods.

16. Andre opplysninger av betydning for helse, miljø og sikkerhet

**Erstatter HMS-datablad av**

| 10.07.2005 |

**Liste over relevante R-setninger (i seksjon 2)**

| R36/38 Irriterer øynene og huden. |

**Viktigste kilder ved utarbeidelsen av HMS-databladet (Ikke norske)**

1. Hommel, Handbuch der gefährlichen Güter
2. European Standard SS-EN 883
3. NIVA Study G 003/1-3
4. Fraunhofer-Institute for Molecular, Germany. Ecotoxicology-study pkt. 12.
5. Säkerhetsdatablad Kemwater TM PAX-XL60 25.10.2002 Skjelmose/Wall

**Opplysninger som er nye, slettet eller revidert**

Endringer i pkt. 2

**Leverandørens anmerknings**

Innholtet i dette HMS-databladet er basert på de opplysninger som vi er kjent med ved bladets siste utgave.
Appendix D

Specifications on Polymer - Polyacrylamide
# HELSE-, MILJØ- og SIKKERHETSDATABLAD
## Superfloc emulsjoner anioniske (4812RS, 4814RS)

### 1. Identifikasjon av stoffet / produktet og av selskapet / foretaket

- **Utgitt dato**: 30.03.2005
- **Revisjon**: 01.03.2008
- **Kjemikaliets navn**: Superfloc emulsjoner anioniske (4812RS, 4814RS)
- **Kjemisk navn**: Anionisk polyakrylamid
- **Deklarasjonsnr.**: 60956
- **Kjemikaliets bruksområde**: Flokkuleringsmiddel for rensing av avløpsvann og/eller slamavvannning.

### Importør

- **Firma navn**: Kemira Chemicals AS
- **Besøksadresse**: Øravelien 14
- **Postn.**: 1630
- **Poststed**: Gamle Fredrikstad
- **Land**: N
- **Telefon**: 6935855
- **Telefaks**: 69358595
- **E-post**: kemira.nc@kemira.com
- **Hjemmeside**: http://www.kemira.no
- **Org. nr.**: 941559190
- **Nødtel**: 22591300

### 2. Farlige egenskaper

- **Farebeskrivelse**: Irriterer huden

### 3. Sammensetning /opplysning om innholdsstoffer

<table>
<thead>
<tr>
<th>Komponentnavn</th>
<th>Identifikasjon</th>
<th>Merking/klassifisering</th>
<th>Innhold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum destillater</td>
<td>CAS-nr.: 64742-47-8</td>
<td>Xn; R65</td>
<td>22 - 25</td>
</tr>
<tr>
<td></td>
<td>EC-nr.: 265-149-8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammoniumhydroksyd</td>
<td>CAS-nr.: 1336-21-6</td>
<td>C,N; R34, R50</td>
<td>0.15 - 0.9 %</td>
</tr>
<tr>
<td></td>
<td>EC-nr.: 215-647-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etoksilater oleyl amin</td>
<td>CAS-nr.: 26635-93-8</td>
<td>Xn,N; R22, R38, R41, R50, R51, R52</td>
<td>1.2 - 1.6 %</td>
</tr>
<tr>
<td>Alcohol (C12-16) etoksilater</td>
<td>CAS-nr.: 68551-12-2</td>
<td>Xn,N; R22, R38, R41, R50</td>
<td>0 - 3.6 %</td>
</tr>
<tr>
<td>Alcohol (C10-16) etoksilater</td>
<td>CAS-nr.: 68002-97-1</td>
<td>Xn,N; R22, R38, R41, R50</td>
<td>0 - 3.6 %</td>
</tr>
<tr>
<td>Kolonneforklaring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FH/FB/FM</td>
<td>T+ = Meget giftig, T = Giftig, C = Etsende, Xn = Helseskadelig, Xi = Irriterende, E = Eksplosiv, O = Oksiderende, F+ = Ekstremt brannfarlig, F = Meget brannfarlig, N = Miljøskadelig.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4. Førstehjelpstiltak

- **Innånding**: Flytt ut i frisk luft. Gå til lege hvis det oppstår problemer.

Dette HMS-databladet er utarbeidet i ECO Publisher (ECOonline)

Revisjon 01.03.2008
5. Tiltak ved brannslukning

Passende brannslukningsmiddel: Bruk vann, karbondicksyd eller tørt kjemikalie.
Personlig verneutstyr: Bruk beskyttelsesklær og friskluftmaske.
Annen informasjon: Benedire i nærheten av brann bør flyttes eller kjøles med vann.

6. Tiltak ved utilstekt utslipp

Sikkerhets tiltalt for å beskytte ytre miljø: Må ikke slippes ut i omgivelserne.
Metoder til opprydding og rengjøring: Lekkasjer av opp løst polymer skyllles med vann. Varmt vann gjør skylningen lettere.
Andre anvisninger: Med fare for forurensning av drikkevann, må politi og helsevesen varsles.

7. Håndtering og lagring

Oppbevaring: For å unngå nedbryting av produktet og korrosjon av utstyr, må jern-, kobber- eller aluminiumbeholder ikke benyttes. Fastleggingen av flattepunkt for materialer av denne type skal, ifølge visse bestemmelser og vitenskapelige normer, utføres ved hjelp av en Pensky-Martens prøvernemodetyp, lukket opp. Dette kan dekker et flattepunkt over 200°F (93°C). Derfor bør det utvises forsiktighet ved lagring og omgånd med materialet. Lagringstemp.: <32°C

Spesielle egenskaper og farer: Utspedde løsninger som er laget for bruk, må ikke betraktet som ufarlig vann på produktets egenskaper.

8. Eksposeringssikrosetting / personlig verneutstyr

Administrative normer

Komponentnavn: Petroleum distillate
Identifikasjon: CAS-nr.: 64742-47-8
EC-nr.: 265-149-8
Enhet: 8 l.; 165 ppm
Verdi: 1200 mg/m3
Norm År: 2003

Eksposeringssikrosetting

Begrensning av eksposering på arbeidsplassen: Unngå sel. Risiko for glette gulv/overflater.
Åndedrettsvern: Sørg for egnet ventilasjon.
Håndvern: Beskyttelseshansker (PVC, neopren, butylgummi).
Øyevern: Tettsittende vernebriller. Øyespleflaske med rent vann.

9. Fysiske og kjemiske egenskaper

Tilstandsform: Flytende væske
Lukt: Oljelignende lukt
Farge: Mørkegrønn til melkaktig
Løselighet i vann: Begrenset av viskositet
Relativ tetthet: Verdi: 1.03 -1.06
Smeltepunkt/smeltepunktsintervall: Verdi: -20 °C
Kokepunkt/ kokepunktsintervall: Verdi: Som vann
pH (bruksløsning): Verdi: < 9.5
Flammepunkt: Verdi: > 100.6 °C

Dette HMS-databladet er utarbeidet i ECO Publisher (ECOonline) Revisjon 01.03.2008
10. Stabilitet og reaktivitet
Farlige spaltningssubstrater: Termisk dekomponering kan frigjøre gasser av ammoniakk, svoveloksyd, karbondioksyd, nitrogenoksid og karbonmonoksid.

11. Toxikologisk information
Toksikologisk informasjon
Oral toksisitet: LD50, rotte mg/kg > 5000
Akutt dermal toksisitet: LD50, kanin mg/kg > 2000
Innåndingstoksisitet: LC50, 4h rotte mg/l > 20.0
Andre toksikologiske data: Petroleum destillator
   Akutt LD50 oral rotte > 5 g/kg t
   Akutt LD50 dermal kanin > 3.16 g/kg
   Ammoniumhydroksyd:
   Akutt LC50-(1hr)-rotte 7338 ppm
   Etoksilater oleyl amin:
   Akutt LD50 oral rotte 1500 mg/kg
   Alkohol (C10-16) etoksilater:
   Akutt LD50 oral rotte 1600-2500 mg/kg
   Akutt LD50 dermal kanin > 2000 mg/kg
   Alkohol (C12-16) etoksilater:
   Akutt LD50 oral rote 1600 - 2500 mg/kg
   Akutt LD50 dermal kanin > 2000 mg/kg

Øvrige helsesføreopplysninger
Hudkontakt: Kan forårsake mild hudirritasjon.
Annen informasjon: Lokale virkninger på hud og øyne:
   Ammoniumhydroksyd
   Akutt øyeirritasjon - gir alvorlige skader
   Akutt dermal irritasjon - korrosiv
   Petroleum destillator
   Akutt dermal irritasjon - ikke irriterende
   Akutt øyeirritasjon - ikke irriterende
   Alkohol (C10-16) etoksilater
   Akutt øyeirritasjon kanin - gir alvorlige skader
   akutt dermal irritasjon kanin - irriterende
   Alkohol (C12-16) etoksilater
   Akutt dermal irritasjon - irriterende
   Akutt øyeirritasjon - gir alvorlige skader
   Etoksilater oleyl amin
   Akutt dermal irritasjon - irriterende
   Akutt øyeirritasjon - gir alvorlige skader

12. Miljøopplysninger
 Øvrige miljøopplysninger
Økotoksisitet: Testresultater alger:
   Green Algae (Cylindra menisco), 72 h, IC50: > 100 mg/l
   Testresultater fisk:
   Zebra Fish (Brachydanio rerio), 96 h, LC50: > 100 mg/l
   Testresultater virvellese dyr:
   Water Flea (Daphnia magna), 48 h, EC50: > 100 mg/l
Mobilitet: Relativ liten mobilitet.
Persistens og nedbrytbarhet: På grunn av høy polymerstruktur er biodegradering av et slikt produkt lav.
Andre skadevirkninger / annen informasjon: Utspeede løsninger som er lagret for bruk, må ikke betraktes som ufarelig vann pga produktets egenskaper.
### 13 Fjerning av kjemikalievefall

<table>
<thead>
<tr>
<th>Avfallskode</th>
<th>EAL</th>
<th>070112</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORSAS</td>
<td>7152</td>
<td></td>
</tr>
<tr>
<td>Produktet er klassifisert som farlig avfall</td>
<td>Ja</td>
<td></td>
</tr>
<tr>
<td>Egnete metoder til fjerning av kjemikaliet</td>
<td>Må leveres til godkjent mottak for farlig avfall.</td>
<td></td>
</tr>
</tbody>
</table>

### 14. Transportinformasjon

### 15. Opplysninger om lover og forskrifter

**Faresymbol**

<table>
<thead>
<tr>
<th>Sammensetning på merkeetiketten</th>
<th>Petroleum destillater: 22 - 25 %, Ammoniumhydroksyd: 0.15 - 0.9 %, Etoxilater oleylamin: 1.2 - 1.6 %, Alkohol (C12-16) etoksilater: 0 - 3.6 %, Alkohol (C10-16) etoksilater: 0 - 3.6 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-setninger</td>
<td>R38 Irriterer huden.</td>
</tr>
<tr>
<td>S-setninger</td>
<td>S81 Spill er meget glatt.</td>
</tr>
<tr>
<td>Referanser (Lover/Forskrifter)</td>
<td>1. Klassifisering og merking av farlige kjemikalier i Norge (stofflisten).</td>
</tr>
<tr>
<td></td>
<td>2. Administrativ norm for arbeid med kjemikalier.</td>
</tr>
<tr>
<td></td>
<td>3. Forskrift omvern mot eksponering for kjemikalier på arbeidsplassen (kjemikalieforskriften).</td>
</tr>
<tr>
<td></td>
<td>4. Databladforskriften, revidert forskrift nr 1323 per 16.07.02.</td>
</tr>
<tr>
<td></td>
<td>5. Lov om transport av farlig gods.</td>
</tr>
</tbody>
</table>

### 16 Andre opplysninger

**Liste over relevante R-setninger (i seksjon 2 og 3).**

- R22: Farlig ved svelging.
- R34: Farlige ved ansikt.
- R38: Irriterer huden.
- R41: Fare for alvorlig øyeskade.
- R50/53: Meget giftig for vannlevende organismer, kan forårsake uønskede langtidsvirkninger i vannmiljøet.
- R50: Meget giftig for vannlevende organismer.
- R51: Giftig for vannlevende organismer.
- R55: Skadelig for vannlevende organismer.
- R65: Farlig: kan forårsake lungeskadde ved svelging.

**Viktige kilder ved utarbeidelsen av HMS-databladet (ikke norske).**

- EEC-EINECS: Alle dette produktets bestanddeler er oppført på Den Europeiske Lagerliste med eksisterende Kjemiske Stoffer (EINECS) eller er polymerer, hvis bestanddeler er i EINECS, i overensstemmelse med Rådsdirektiv 67/548/EEFs endringer.
- USA-TCCA: Dette produktet fremstilles i overensstemmelse med alle bestemmelser i Loven om kontroll med kjemiske stoffer, 15 U.S.C.2601 et.seq.
- CANADA-DLS: Stoffene i dette produktet er rapportert til canadisk miljø i overensstemmelse med punkt 25 i den canadiske miljøbeskyttelsesloven og er oppført på den lokale stofflista.

**Leverandørens anmerkninger**

- Gjelder for produktene: 4812RS og 4814RS

**Ansvarlig for HMS-datablad**

- Kemira Chemicals AS
Appendix E

Specifications on 25% HCL
1. Identifikasjon av stoffet / produktet og av selskapet / foretaket

Utgitt dato: 02.11.2005
Revisjon: 19.10.2007
Kjemikaliets navn: SALTSYRE > 25 %
Kjemisk navn: Hydrogenkloridløsning
Synonymer: Saltsyre 30%. Saltsyre 33-35%.
Deklarasjonsnr.: 30 %: under deklarering. 33-35 % : 70214.
EC-nr.: 231-595-7
Indeksnr.: 017-002-01-X
Kjemikaliets bruksområde: pH-regulerende midler, industrirengjøringsmidler, prosesskjemikalier.

Nedstrømsbruker

Firmanavn: SOLBERG INDUSTRI AS
Besøksadresse: Rosenlund Allé
Postadresse: Boks 628
Postnr.: 1616
Poststed: FREDRIKSTAD
Land: Norway
Telefon: +47 69382908
Telefaks: +47 69382901
E-post: cathrine.lillestrand@solbergindustri.no
Hjemmeside: http://www.solbergindustri.no/
Kontaktperson: Cathrine Lillestrand
Utarbeidet av: Teknologisk Institutt as v/ Monica Rustad
Nødtelefon: Giftinformasjonen:22 59 13 00

2. Farlige egenskaper

Klassifisering: C; R34
Xi; R37
Brann og eksplosjon: Produktet er ikke klassifisert som brannfarlig.
Miljø: Produktet regnes ikke som miljøskadelig.

3. Sammensetning /opplysning om innholdsstoffer

<table>
<thead>
<tr>
<th>Komponentnavn</th>
<th>Identifikasjon</th>
<th>Merking/klassifisering</th>
<th>Innhold</th>
</tr>
</thead>
<tbody>
<tr>
<td>saltsyre</td>
<td>EC-nr.: 231-595-7</td>
<td>C; R34, R37</td>
<td>25 - 35 %</td>
</tr>
<tr>
<td>vann</td>
<td>CAS-nr.: 7732-18-5 EC-nr.: 231-791-2</td>
<td></td>
<td>65 - 75 %</td>
</tr>
</tbody>
</table>

Kolonneforklaring

Symbolforklaringer

T+ = Meget giftig, T = Giftig, C = Etsende, Xn = Helseskadelig, Xi = Irriterende, E = Eksplosiv, Ö = Oksiderende, F+ = Ekstremt brannfarlig, F = Meget brannfarlig, N = Miljøskadelig.

Komponentkommentarer: Se seksjon 16 for forklaring av risikosetninger.
4. Førstehjelpstiltak

Generelt  I tvilstilfelle bør lege kontaktes.

Innånding  Frisk luft, ro og varme. Kontakt lege hvis ikke alt ubehag gir seg.


Svelging  Gi straks et par glass melk eller vann hvis den skadde er ved full bevissthet. Fremkall ikke brekninger. Kontakt lege.

Informasjon til helsepersonell  Behandles som etseskader/brannskader.

5. Tiltak ved brannslukning

Passende brannslukningsmiddel  Velges i forhold til omgivende brann.

Uegnet brannslukningsmiddel  Bruk ikke full vannstråle. Ved bruk av bikarbonatholdige pulver kan det være fare for sprut pga. utvikling av karbondioksid.

Brann- og eksplosjonsfarer  Produktet kan utvikle noen av et ekklement. Ved kontakt med brandermidler kan det oppstå eksplosjoner.

Personlig verneutstyr  Bruk friskluftmaske når produktet er involvert i brann. Ved rømning brukes godkjent rømningsmaske. Se forøvrig pkt 8.

Annen informasjon  Beholdere i nærheten av brann flyttes straks eller kjøles med vann.

6. Tiltak ved utilsiktet utslipp


Sikkerhetsitiltak for å beskytte ytre miljø  Forhindre utslipp til kloakk, vassdrag eller grunn.

Metoder til opprydding og rengjøring  Spill tas opp med inert absorberende materiale. Spill samles opp i egnede beholdere og leveres som farlig avfall (se pkt. 13).

7. Håndtering og lagring


8. Eksponeringskontroll/personlig verneutstyr

Administrative normer

<table>
<thead>
<tr>
<th>Komponentnavn</th>
<th>Identifikasjon</th>
<th>enhet</th>
<th>Norm år</th>
</tr>
</thead>
<tbody>
<tr>
<td>hydrogenklorid</td>
<td>CAS-nr.: 7647-01-0</td>
<td>8 t.: 7 mg/m³ T</td>
<td>2003</td>
</tr>
</tbody>
</table>

Eksponeringskontroll

Annen informasjon  Det oppgitte verneutstyr er veiledende. Risikovurderingen (Faktisk risiko) kan føre til andre krav.

Begrensen av eksponering på arbeidsplassen  Sørg for tilstrekkelig ventilasjon. Vask hensene etter hvert skift, og før spising, røyking eller bruk av toalett.

Åndedrettsvern  Ved utstrekkelig ventilasjon: Bruk egnet åndedrettsvern med gassfilter, type B. eller type E.


Øyevern  Bruk godkjente vernebriller eller ansiktsskjerm.

Annen informasjon  Benytt hensiktsmessige verneklær for beskyttelse ved mulig hudkontakt.

Nødusj og mulighet for øyeskylling må finnes på arbeidsplassen.
9. Fysiske og kjemiske egenskaper

<table>
<thead>
<tr>
<th>Egenskap</th>
<th>Verdi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilstandsform</td>
<td>Væske</td>
</tr>
<tr>
<td>Lukt</td>
<td>Stikkende lukt</td>
</tr>
<tr>
<td>Farge</td>
<td>Fargeløs til lysegul</td>
</tr>
<tr>
<td>løselighet i vann</td>
<td>løselig</td>
</tr>
<tr>
<td>Relativ tetthet</td>
<td>Verdi: 1,18 g/cm³</td>
</tr>
<tr>
<td>smeltepunkt/smeltepunktsintervall</td>
<td>Verdi: -30 °C</td>
</tr>
<tr>
<td>kokepunkt/kokepunktsintervall</td>
<td>Verdi: 108 °C</td>
</tr>
<tr>
<td>pH (handelsvare)</td>
<td>Verdi: 0</td>
</tr>
<tr>
<td>pH (bruksløsning)</td>
<td>Verdi: ~ 0</td>
</tr>
<tr>
<td>Damptrykk</td>
<td>Verdi: 105,5 mmHg</td>
</tr>
<tr>
<td>dampjetthet</td>
<td>Verdi: 1,26</td>
</tr>
<tr>
<td>luktenense</td>
<td>7mg/m³</td>
</tr>
</tbody>
</table>

10. Stabilitet og reaktivitet


Farlige spaltningsprodukter: Hydrogenklorid, Klorgass.

Stabilitet: Stabil under normale temperaturforhold og anbefalt bruk.

11. Toxikologisk information

Toksikologisk informasjon

Verdi: 4701 ppm
Forsøksdyreart: Rotte
Eksponeringstid: 30 min

Andre toksikologiske data: LCL0 menneske: 1300 ppm 30 min.

Øvrige helsesfareropplysninger

Generelt: Ved bruk representerer de etsende egenskaper den største faren.
Svelging: Etsende ved svelging. Gir brennende smerter i munn, svelg og spiserør. Fare for store varige skader.
Kroniske effekter: Kortvarig kontakt kan gi varig revskade.
Allergi: Allergifremkallende egenskaper er ikke kjent.
Kreft: Kreftfremkallende egenskaper er ikke kjent.
Fosterskadelige egenskaper: Effekter på fosterutvikling er ikke kjent.
Reproduksjonsskader: Reproduksjonsskadelige egenskaper er ikke kjent.
Arvestoffskader: Arvestoffskadende (mutagene) egenskaper er ikke kjent.

12. Miljøopplysninger

Toksikologisk informasjon

Verdi: 100-1000mg/l
Testmetode: LC50
Varighet: 96h

Verdi: 49 mg/l
Testmetode: EC 50, NOEC: 40 mg/l
Alge art: Selenastrum capricornutum
### Øvrige miljøopplysninger

<table>
<thead>
<tr>
<th>Økotoksitet</th>
<th>Produktet er ikke klassifisert som miljøskadelig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilitet</td>
<td>Løselig i vann.</td>
</tr>
<tr>
<td>Persistens og nedbrytbarhet</td>
<td>Produktet består utelukkende av uorganiske forbindelser som ikke er bionedbrytbare.</td>
</tr>
<tr>
<td>Bioakkumulasjonspotensial</td>
<td>Bioakkumuleringer ikke.</td>
</tr>
<tr>
<td>Andre skadevirkninger / annen informasjon</td>
<td>Utslipp av produktet til vann kan lokalt gi lav pH med fare for fiskedød.</td>
</tr>
</tbody>
</table>

### 13. Fjerning av kjemikalieavfall

<table>
<thead>
<tr>
<th>Avfallskode EAL</th>
<th>EAL: 06 01 02 saltsyre</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORSAS</td>
<td>7131 Syrer, uorganiske</td>
</tr>
<tr>
<td>Produktet er klassifisert som farlig avfall</td>
<td>Ja</td>
</tr>
</tbody>
</table>

**Egnede metoder til fjerning av kjemikaliet**


### 14. Transportinformasjon

<table>
<thead>
<tr>
<th>Proper Shipping Name</th>
<th>HYDROCHLORIC ACID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varenavn (nasjonalt)</td>
<td>SALTSYRE</td>
</tr>
</tbody>
</table>
| Farlig gods ADR       | Status: Ja  
 UN-nr.: 1789  
 Klasse: 8  
 Fare nr.: 80  
 Emballasjegruppe: II |
| Farlig gods RID       | Status: Ja  
 UN-nr.: 1789  
 Klasse: 8  
 Emballasjegruppe: II |
| Farlig gods IMDG      | Status: Ja  
 UN-nr.: 1789  
 Klasse: 8  
 Emballasjegruppe: II  
 Marin forurensning: N  
 EmS: F-A, S-B |
| Farlig gods ICAO/IATA | Status: Ja  
 UN-nr.: 1789  
 Klasse: 8  
 Emballasjegruppe: II |

Fareseddel 8

### 15. Opplysninger om lover og forskrifter

#### Faresymbol

<table>
<thead>
<tr>
<th>Sammensetning på merkeetiketten</th>
<th>saltsyre: 25 - 35 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC-nr.</td>
<td>231-595-7</td>
</tr>
</tbody>
</table>
| R-setninger                     | R34 Etsende.  
 R37 Irriterer luftveiene |
| S-setninger                     | S1/2 Oppbevares innelåst og utilgjengelig for barn.  
 S26 Får man stoffet i øynene; skyll straks grundig med store mengder vann  
 og kontakt lege.  
 S36/37/39 Bruk egne verneklær, vernehansker og ve nebriller/ansiktsskjerm.  
 S38 Ved utstrekkelig ventilasjon, må det benyttes egnet åndedrettsvern. |
S45 Ved uhell eller illebefinnende er omgående legebehandling nødvendig; vis etiketten om mulig.

Administrative normer for forurensning i arbeidsatmosfæren 2003, Direktoratet for Arbeidstilsynet (Best.nr. 361), med siste endringer mai 2007.
Avfallsforskriften, FOR 2004-06-01 nr 930, fra Miljøverndepartementet.
ADR/RID veg-/jernbanetransport av farlig gods 2007, Direktoratet for samfunnssikkerhet og beredskap.

Databladet er utarbeidet med basis i opplysninger gitt av produsenten.

16. Andre opplysninger
Liste over relevante R-setninger (i seksjon 2 og 3).
R34 Etsende.
R37 Irriterer luftveiene

Opplysninger som er nye, slettet eller revidert

Leverandørens anmerkninger Informasjonen i dette dokument skal gjøres tilgjengelig til alle som håndterer produktet.


Ansvarlig for HMS-datablad SOLBERG INDUSTRI AS
Appendix F

Specifications on NaOH
1. Identifikasjon av stoffet / produktet og av selskapet / foretaket

Utgitt dato: 19.04.2005
Revisjon: 27.04.2009
Kjemikaliets navn: NATRONLUT 10-50%
Kjemisk navn: Natriumhydroksidløsning
Synonymer: Natronlut 10%. Natronlut 20%. Natronlut 25%. Natronlut 30%. Natronlut 32%. Natronlut 45-47%. Natronlut 50%.
Kjemikaliets bruksområde: Avfettingsmiddel Luting, metallbehandling.

Nødstrømsbruker

Firmanavn: SOLBERG INDUSTRI AS
Besøksadresse: Rosenlund Allé
Postadresse: Boks 628
Postnr.: 1616
Poststed: FREDRIKSTAD
Land: Norway
Telefon: +47 69382908
Telefaks: +47 69382901
E-post: cathrine.lillestrand@solbergindustri.no
Hjemmeside: http://www.solbergindustri.no/
Kontaktperson: Cathrine Lillestrand
Utarbeidet av: Teknologisk Institutt as v/ Monica Rustad
Nøttelefon: Giftinformasjonen: 22 59 13 00

2. Farlige egenskaper

Klassifisering: C; R35
Farebeskrivelse: Helse: Sterkt etsende.
Brann og eksplosjon: Produktet er ikke klassifisert som brannfarlig.
Miljø: Produktet er ikke klassifisert som miljøskadelig.

3. Sammensetning /opplysning om innholdsstoffer

<table>
<thead>
<tr>
<th>Komponentnavn</th>
<th>Identifikasjon</th>
<th>Merking/klassifisering</th>
<th>Innhold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natriumhydroksid</td>
<td>CAS-nr.: 1310-73-2</td>
<td>C; R35</td>
<td>10 - 50 %</td>
</tr>
<tr>
<td></td>
<td>EC-nr.: 215-185-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Indeksnr.: 011-002-00-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>vann</td>
<td>CAS-nr.: 7732-18-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EC-nr.: 231-791-2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Kolonneforklaring

<table>
<thead>
<tr>
<th>FH/FB/FM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>T+ = Meget giftig, T = Giftig, C = Etsende, Xn = Helseskadelig, Xi = Irriterende, E = Eksplosiv, O = Oksiderende, F+ = Ekstremt brannfarlig, F = Meget brannfarlig, N = Miljøskadelig.</td>
<td></td>
</tr>
</tbody>
</table>

| Komponentkommentarer | Se seksjon 16 for forklaring av risikosetninger. |

Dette Sikkerhetsdatablad er utarbeidet i ECO Publisher (ECOonline) Revisjon 27.04.2009
4. Førstehjelpstiltak

<table>
<thead>
<tr>
<th>Generelt</th>
<th>I tvilstilfelle bør lege kontaktes.</th>
</tr>
</thead>
</table>

Informasjon til helsepersonell: Behandles som lutskader/brannskader.

5. Tiltak ved brannslukning

<table>
<thead>
<tr>
<th>Passende brannslukningsmiddel</th>
<th>Velges i forhold til omgivende brann.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uegnet brannslukningsmiddel</td>
<td>Bruk ikke full vannstråle.</td>
</tr>
<tr>
<td>Brann- og eksplosjonsfarer</td>
<td>Produktet er ikke brennbart. Kan danne giftige eller eksplosive damper i kontakt med enkelte metaller.</td>
</tr>
<tr>
<td>Personlig verneutstyr</td>
<td>Bruk friskluftmaske når produktet er involvert i brann. Ved rømning brukes godkjent rømningsmaske. Se forøvrig pkt 8.</td>
</tr>
<tr>
<td>Annen informasjon</td>
<td>Beholdere i nærheten av brann flyttes straks eller kjøles med vann. Slokningsvannet kan være sterkt etsende.</td>
</tr>
</tbody>
</table>

6. Tiltak ved utilsiktet utslipp

| Sikkerhetsltiltak for å beskytte ytre miljø | Forhindre utslipp til kloakk, vassdrag eller grunn. Samle opp søl/spill i sand, jord eller annet egnet absorberende materiale. |
| Metoder til opprydding og rengjøring | Stopp lekkasje hvis mulig uten risiko. Spill tas opp med inert absorberende materiale. Spill samles opp i egnede beholdere og leveres som farlig avfall (se pkt. 13). |

7. Håndtering og lagring


8. Eksponeringskontroll / personlig verneutstyr

<table>
<thead>
<tr>
<th>Administrative normer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Komponentnavn</td>
</tr>
<tr>
<td>Natriumhydroksid</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Eksponeringsskjønnhet

Begrensning av eksponering på arbeidsplassen


Åndedrøttssvern


Håndvern

Benytt hansker av motstandsdyktig materiale, f.eks.: Neoprengummi. Polyvinylklorid (PVC). Gjennomtrengningstid > 8 timer.

Øyevern

Bruk godkjente vernebriller.

Annet hudvern enn håndvern

Annet hudvern enn håndvern


Annen informasjon

Nøddusj og mulighet for øyeskylling må finnes på arbeidsplassen. Det oppgitte verneutstyr er veiledende. Risikovurderingen (Faktisk risiko) kan føre til andre krav.

9. Fysiske og kjemiske egenskaper

Tilstandsform

Viskøs væske

Lukt

Svak. Karakteristisk

Farge

Vannklar

Løselighet i vann

Levemøkk i vann.

Relativ tetthet

Verdi: 1500 kg/m³

Smeltepunkt/smeltepunktsintervall

Kommentar: 5°C (46%)

Kokepunkt/ kokepunktintervall

Kommentar: ca.143 v/50%

pH (bruksløsning)

Verdi: > 14

Kommentar: (20%)

Damptrykk

Verdi: 0.9 mmHg (20°C)

10. Stabilitet og reaktivitet

Forhold som skal unngås

Hell aldri vann direkte i produktet - dette kan føre til kraftig reaksjon. Det samme kan skje ved kontakt med syrer.

Materialer som skal unngås


Farlige spaltningsprodukter


Stabilitet

Produktet er stabilt ved de angitte lagrings- og bruksbetingelsene.

11. Toksikologisk informasjon

Tokskologisk informasjon

LD50 oral

Verdi: 500 mg/kg

Forsøksdyreme: LD20 Hare

Kommentar: LD50 Mus (intraperitoneal) 40 mg/kg

LD50 dermal

Verdi: 500 mg/kg

Forsøksdyreme: Hare, Skinn

Varighet: 24 h

Kommentar: Hare, øye: 0,4 mg= mild.

Ape, øye 24 h: 1% alvorlig

Øvrige helsefareopplysninger

Generelt

Ved bruk representerer de etsende egenskaper den største faren. Sårene vil gro sent med betydelige arrdannelser.

Innånding

Damper virker etsende. I løpet av 24-36 timer kan den skadede utvikle
alvorlig åndenød og lungeødem. Damper og sprøytetåke kan irritere luftveiene og forårsake halsirritasjon og hoste.

**Hudkontakt**
Sterkt etsende.

**Øyekontakt**
Virker sterkt etsende og fremkaller store smerter og alvorlige øyeskader. Øyeblikkelig førstehjelp er nødvendig. Damp eller sprut kan gi øyeskade, nedsatt syn eller synstap.

**Svelging**
Virker sterkt etsende. Selv små mengder kan være livsfarlig. Symptomer er voldsomme brennende smerter i munn, hals og mage.

**Kroniske effekter**
Varige vevsskader kan bli resultatet ved akutt påvirkning.

**Allergi**
Produktet er ikke kjent for å ha allergifremkallende egenskaper.

**Kreft**
Kreftfremkallende egenskaper er ikke kjent.

**Fosterskadelige egenskaper**
Arvestoffskadende (mutagene) egenskaper er ikke kjent.

**Reproduksjonsskader**
Reproduksjonsskadelige egenskaper er ikke kjent.

**Arvestoffskader**
Arvestoffskadende (mutagene) egenskaper er ikke kjent.

### 12. Miljøopplysninger

**Toksikologisk informasjon**

<table>
<thead>
<tr>
<th>Akutt akvatisk, fisk</th>
<th>Verdi: 157-213 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Testmetode:</strong></td>
<td>LC50</td>
</tr>
<tr>
<td><strong>Fiske art:</strong></td>
<td>Leucisus idus melanotus</td>
</tr>
<tr>
<td><strong>Varighet:</strong></td>
<td>48h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Akutt akvatisk, alge</th>
<th>Verdi: 78 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Testmetode:</strong></td>
<td>EC50</td>
</tr>
<tr>
<td><strong>Alge art:</strong></td>
<td>Selenastrum Capricornutum</td>
</tr>
<tr>
<td><strong>Varighet:</strong></td>
<td>72h. NOEC &lt; 30 mg/l</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Akvatiske kommentarer</th>
<th>AKUTT TOKSISITET</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bletdyr LC50/48h 100 - 1000 mg/l Crustaceans</td>
</tr>
<tr>
<td></td>
<td>LC50/48h 33 - 100 mg/l Starfisk, saltvann</td>
</tr>
<tr>
<td></td>
<td>LC50/96h 100 - 1000 mg/l Fisk</td>
</tr>
</tbody>
</table>

**Øvrige miljøopplysninger**

- **Økotoksisitet**
  Produktet er ikke klassifisert som miljøskadelig.

- **Mobilitet**
  Løselig i vann.

- **Persistens og nedbrytbarhet**
  Produktet består utelukkende av uorganiske forbindelser som ikke er bionedbrytbare.

- **Bioakkumulasjonspotensial**
  Forventes ikke å bioakkumulere.

- **Andre skadevirkninger / annen informasjon**
  Utslipp av produktet til vann kan lokalt gi høy pH med fare for fiskedød.

### 13. Fjerning av kjemikalieavfall

<table>
<thead>
<tr>
<th>Avfallskode EAL</th>
<th>EAL: 06 02 04 natrium- og kaliumhydroksid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NORSAS</strong></td>
<td>7132 Uorganiske baser</td>
</tr>
<tr>
<td><strong>Produktet er klassifisert som farlig avfall</strong></td>
<td>Ja</td>
</tr>
<tr>
<td><strong>Egnede metoder til fjerning av kjemikallet</strong></td>
<td>Leveres som farlig avfall til godkjent behandler eller innsamler. Koden for farlig avfall (EAL-kode) er veiledende. Bruker må selv angi riktig EAL-kode hvis bruksområdet avvikler.</td>
</tr>
</tbody>
</table>

### 14. Transportinformasjon

<table>
<thead>
<tr>
<th>Varenavn (nasjonalt)</th>
<th>NATRIUMHYDROKSIDLØSNING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Status:</strong></td>
<td>Ja</td>
</tr>
<tr>
<td><strong>UN-nr.:</strong></td>
<td>1824</td>
</tr>
<tr>
<td><strong>Klasse:</strong></td>
<td>8</td>
</tr>
<tr>
<td><strong>Fare nr.:</strong></td>
<td>80</td>
</tr>
</tbody>
</table>
**15. Opplysninger om lover og forskrifter**

**Faresymbol**

<table>
<thead>
<tr>
<th>Faresymbol</th>
<th>Etsende</th>
</tr>
</thead>
</table>

**Sammensetning på merkeetiketten**
Natriumhydroksid: 10 - 50 %

**R-setninger**
R35 Sterkt etsende.

**S-setninger**

**Referanser (Lover/Forskrifter)**
Forskrift om registrering, vurdering, godkjenning og begrensning av kjemikalier (REACH) Vedlegg II: Sikkerhetsdatablad.
Veiledning om administrative normer for forurensning i arbeidsatmosfære fra Direktoratet for Arbeidstilsynet, den til enhver tid gjeldende utgave.
ADR/RID veg-/jernbanetransport av farlig gods 2007, Direktoratet for samfunnssikkerhet og beredskap.
Avfallsforskriften, FOR 2004-06-01 nr 930, fra Miljøverndepartementet.

**Deklarasjonsnr.**
20%: P-82529. 25 %: P-82530. 30%: P-82406. 32%: P-82531. 45-47%: P-33817. 50 %: P-82532

**16. Andre opplysninger**

**YL-tall**
0

**Liste over relevante R-setninger (i seksjon 2 og 3).**
R35 Sterkt etsende.

**Opplysninger som er nye, slettet**
<table>
<thead>
<tr>
<th>Leverandørens anmerkninger</th>
<th>Informasjonen i dette dokument skal gjøres tilgjengelig til alle som håndterer produktet.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kvalitetssikring av informasjon</td>
<td>Dette sikkerhetsdatabladet er kvalitetssikret av Teknologisk Institutt as, som er sertifisert iht. NS-EN ISO 9001:2000.</td>
</tr>
<tr>
<td>Ansvarlig for Sikkerhetsdatablad</td>
<td>SOLBERG INDUSTRI AS</td>
</tr>
</tbody>
</table>
Appendix G

Specifications on 75% $\text{H}_3\text{PO}_4$
# PRODUKTSPESIFIKASJON

## FOSFORSYRE 75%

<table>
<thead>
<tr>
<th>Cas.nr.: 7664-38-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref.: 60297/219</td>
</tr>
</tbody>
</table>

### Teknisk H₃PO₄

### KJEMISKE DATA:

<table>
<thead>
<tr>
<th></th>
<th>Spesifikasjon</th>
<th>Typiske analyser</th>
<th>enhet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fosforsyre H₃PO₄</td>
<td>75 +/- 1</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Fosforosid P₂O₅</td>
<td>54 +/- 1</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Uløselige substanser</td>
<td>&lt; 0,1</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Aluminum Al</td>
<td>&lt; 0,08</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Klorid Cl</td>
<td>&lt; 50</td>
<td>10</td>
<td>ppm</td>
</tr>
<tr>
<td>Fluor F</td>
<td>&lt; 0,15</td>
<td>0,1</td>
<td>%</td>
</tr>
<tr>
<td>Magnesium Mg</td>
<td>&lt; 0,8</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Jern Fe</td>
<td>&lt; 0,25</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Silisium Si</td>
<td>&lt; 200</td>
<td></td>
<td>ppm</td>
</tr>
<tr>
<td>Sulfat SO₄</td>
<td>&lt; 0,4</td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Arsen As</td>
<td>&lt; 1,0</td>
<td>0,5</td>
<td>ppm</td>
</tr>
<tr>
<td>Kadmium (Cd), Kvikksølv (Hg), Bly (Pb)</td>
<td>&lt; 2</td>
<td>1</td>
<td>ppm</td>
</tr>
</tbody>
</table>

### FYSIKALSKE DATA:

- **Frysepunkt (75%)**: -20°C
- **Utseende**: Brunaktig, luftløs, noe tregflytende væske.
- **Tetthet (15°C)**: 1,610-1,650 g/cm³

### LEVERANSEFORM:

- Bulk/IBC/fat/kanner
Appendix H

Specifications on micronutrients solution
APPENDIX H

Trace element solution

Nitriloacetic acid 1.5 g eller EDTA 0.5 g (Bruk EDTA viss tilgjengelig)

0.5 g MnSO$_4$·2H$_2$O

3 g MgSO$_4$·7H$_2$O

1 g NaCl

0.1 g FeSO$_4$·7H$_2$O

0.1 g CoCl$_2$·6H$_2$O

0.1 g CaCl$_2$·2H$_2$O

0.1 g ZnCl$_2$

0.01 g CuSO$_4$·5H$_2$O

0.02 g NiCl$_2$·6H$_2$O

0.001 g Na$_2$SeO$_3$

0.01 g AlK(SO$_4$)$_2$

0.01 g H$_3$BO$_3$

0.01 g Na$_2$MoO$_4$

0.01 g Na$_2$WO$_4$·2H$_2$O

All added in 1000 ml double distilled water