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Adsorption of Organic Pollutants in Peat and Carbon Filters: A Pilot Study of Landfill Leachates

Master of Science Thesis in the Master's Program Geo and Water Engineering and Master's program Industrial Ecology

Daniel Krewer and Nashita Moona

Department of Civil and Environmental Engineering
Water Environment Technology
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Examensarbete/Institutionen för bygg- och miljöteknik,
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ABSTRACT

In this thesis, a pilot plant to treat landfill leachate from contamination at Brudaremassen is designed, constructed and evaluated as preceding step before constructing a full scale plant on-site. Brudaremassen is a landfill site located near Lake Delsjön and leachates produced in this landfill are transferred to Göteborg's wastewater treatment plant. Since leachate contains large quantities of harmful pollutants, it may affect the performance of the wastewater treatment process and quality of the sludge, and thus the leachates could preferably be treated locally.

The organic pollutants of priority in the Brudaremassen landfill leachates are polycyclic aromatic hydrocarbons (PAHs), oxygenated PAHs (oxy-PAHs), phthalates, alkylphenols (APs) and alkylphenolethoxylates (APEOs), and various petroleum hydrocarbon (PHC) fractions. The treatment technique chosen to study is sorption filtration, and the filter materials selected were activated carbon and *Sphagnum* peat moss. Two combinations of filter materials were examined: a column packed with granulated activated carbon (GAC) in series with another GAC column, and a column packed with peat moss followed by a column with GAC. Equal flow rates of the leachate were running through both combinations and the best alternative were identified based on the adsorbent performance.

The plant was running for 120 days and influent and effluent concentrations to all the four filters were sampled weekly and selected samples analyzed for organic contaminants concentration. The result showed convincing performance in the adsorption of all the above mentioned organic pollutants. The GAC removed PHC fractions more efficiently (84-100%) than peat (31-52%), while peat was more efficiently adsorbing PAHs (14-61%). After two months of operation in field, both of the filters indicate that PAHs, alkylphenols as well as phthalates were adsorbed effectively. Oxy-PAHs were removed efficiently by both filters. The GAC filter removed dissolved organic carbon (DOC) (85-100%) more effectively than the peat filter (2-28%), and total organic carbon (TOC) was removed well (5-100%) by both filter materials. The peat alternative overall reduced metals with better efficiency. The only complication during the operational period of the plant was the technical difficulties related to clogging of the filters due to too high concentration of iron and suspended particles. Therefore a sand filter was constructed before the filters, and influent and effluent samples from this filter were also analyzed for contaminants concentration. The need for a further pre-treatment is desirable because the sand filter was getting clogged too often and needed to be backwashed. Suggestions were made based on a laboratory test to aerate the leachates with addition of CaCO_3 as a suitable pre-treatment for the construction of the final treatment plant.

Key words: leachate, adsorption, filter, activated carbon, peat, organic pollutants.

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SAMMANFATTNING

I denna studie har ett pilot projekt designats, konstruerats och utvärderats i form av en förundersökning för rening av lakvatten från Brudaremassens avfallsdeponi. Brudaremassen är en avfallsdeponi som är belagd i närheten av Delsjön i östra delen av Göteborg och lakvattnet från avfallsdeponin leds sedan vidare från deponin via rör till Göteborgs avloppsreningsverk. Lakvattnet innehåller stora mängder av farliga föroreningar vilket kan leda till störningar i processen vid avloppsrening och försämrad kvalitet på avloppsslammet. Därför är det av stor vikt att lakvattnet renas lokalt innan det når avloppsreningsverket.

Syftet med denna studie var att rena lakvattnet från organiska föroreningar som polycykliska aromatiska kolväten (PAH:er), oxygenerade PAH:er (oxy-PAH), ftalater, alkylfenoler och alkylfenoletoxilater, samt olika fraktioner av petroleumkolväten. Adsorptionsfiltrering med lämplig torv och aktivt kol som sorptionsmaterial valdes som reningsteknik. Två olika kombinationer av filterkolonner testades: en kolonn packades med aktivt kol följt av ytterligare en med aktivt kol och det andra alternativet var en kolonn packad med torv i serie med en kolonn med aktivt kol. Det bestämdes att flödena av lakvatten genom de båda serierna av kolonner skulle var lika stora.

Pilotanläggningen var i drift i 120 dagar och provtagning i kolonnernas ingående och utgående lakvatten utfördes varje vecka. Resultaten från de kemiska analyserna visade att de ovan nämnda organiska föroreningar sorberades effektivt i både kol- och torvkolonnerna. Det aktiva kolet avlägsnade fraktioner av petroleumkolväten i större utsträckning (84-100%) jämfört med torvfiltret (31-52%), medans torvfiltret mer effektivt renade PAH (14-61%). Efter två månaders driftstid adsorberades PAH:er, alkylfenoler samt ftalater fortfarande mycket effektivt. Oxy-PAH:er sorberades effektivt av båda filtervarianterna. Kolfiltret var ett bättre alternativ gällande rening av DOC (85-100%) jämfört med torvfiltret (2-28%) medans båda filtermaterialen fungerade effektivt för att rena TOC (5-100%). Torvfiltret sorberande metaller mer effektivt än kolfiltret. Det enda problem som uppkom under drifttiden av anläggningen var de tekniska svårigheterna relaterade till igensättning av filtrena p g a stora mängder av järn och partiklar i lakvattnet. För att åtgärda detta konstruerades ett sandfilter som placerades före kolonnerna. Prover för analys av föroreningar togs på både in- och utflödet till/från sandfiltret. Trots denna åtgärd föreslås ett ytterligare reningssteg för att undvika frekvent återkommande backsponing av filtren. Baserat på resultat från ett test i laboratorium föreslås att lakvattnet luftas under tillsättning av CaCO_3 .

Nyckelord: lakvatten, adsorption, filter, aktivt kol, torv, organiska föroreningar

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Preface

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This master's thesis was performed during spring and summer 2011 at Chalmers University of Technology in cooperation with Kretsloppskontoret in Gothenburg. Kretsloppskontoret is acknowledged for funding the construction of the pilot plant and necessary analyses to assess its performance.

We would like to especially express our gratitude's to Lars-Ove Sörman for his help and supervision during the construction and the operational period of the pilot plant. Mona Pålsson has been very helpful during the laboratory work. At the Geology laboratory we would like to thank Peter Hedberg for his assistance through providing us with transportation to the landfill pilot plant site and also for giving us a chance to use the Geology department's climate room to store the samples. Further we would also like to thank colleagues at Water Environment division for good coffee and refreshing discussions.

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Daniel Krewer and Nashita Moona

1 Introduction

Increasing industrialization and consumption of non-reusable products has resulted in a rapid increase in industrial and household waste production around the world. Not long ago landfilling was presumed to be the most desirable and cheapest solid waste management process, in terms of capital cost and exploitation (Baldasano, 2003). Thus landfill sites can be seen in every city around the world (Kurniawan, 2006). However, due to the increasing amount of waste and increasing environmental consciousness, there is now a strict regulation against landfilling of waste or building new landfills in Europe and awareness about waste minimization (European union, 1999). This regulation imparts a demand on existing landfills to reduce and prevent negative effects on surface water, ground water, soil, air and human health.

Leachate is the effluent that is produced from the biochemical reaction occurring inside the waste deposit with the moisture content of the wastes and penetrating rainwater. (Chiang & Chang, 1995; Renou S. G., 2008). The composition or the constituents of the leachate produced makes it quite harmful to the environment and human health. Most pollutants originating from leachates are generally persistent, carcinogenic and bio-accumulating pollutants as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) etc. (Kjeldsen, 2001).

The Swedish landfill owners are obliged to collect and treat landfill leachates. According to a 'performance requirement' the leachate must be treated or managed to a certain level of treatment performance. The second type of requirements is 'reduced emission requirements', which relate to obligations on emission levels of some chemical parameters in the leachate (Svenska miljöinstitutet, 2007). Therefore, the leachates from the landfill must receive some form of local treatment before it is conducted to receiving water or wastewater treatment plants. The most common pollutants that are treated by local leachate treatment facilities are nitrogen (as total-N or ammonium-N) and COD (chemical oxygen demand) and some of the organic pollutants like PAHs, PCBs, alcohol oxides (AOX), nonylphenols (NPs) and toluene. Most common arrangement is that landfill leachates are transferred to municipal sewage treatment plants either immediately or after a local treatment (Svenska miljöinstitutet, 2007).

Due to a voluntary agreement between REVAQ, Swedish Environmental Protection agency (Naturvårdsverket), Farmers Federation (Lantbrukarnas riksförbund, LRF) and Swedish Water (SvenskVatten), certain flows of contaminated water should not be accepted to the wastewater plants in Sweden. The purpose of REVAQ is to ensure cleaner and safer sludge so that it can be used for agriculture and it is possible to return nutrients and humus forming substances back to the agricultural land. This is due to the national goal to return at least 60% of the phosphorous compounds from wastewater to the farmland by 2015. This imparts a necessity of onsite treatment of leachate so that they cannot pose a risk on the sludge content (Naturvårdsverket, 2011).

Various treatment techniques are applied at landfill sites due to different composition and changes in composition of leachates (Christensen, Alberchtsen, & Heron, 1994). The most efficient treatment techniques are often more expensive and require energy (Svenska miljöinstitutet, 2007). Kretsloppskontoret together with Chalmers University of Technology has examined the characteristics of the leachate of Brudaremossen landfill and reviewed different treatment options to treat leachates. This review has found that treatment by using different types of adsorption materials by filtration could be selected as the best suited technique for Brudaremossen landfill (Kalmykova

Y. a.-M., 2010). A treatment method by using two types of sorption materials as filters has been proposed. The aim is to compare low-cost sorption material with conventional sorption materials in treating leachate pollutants. These low-cost sorption materials are naturally occurring or by-products and rest-products of some industrial or agricultural manufacturing process and they are also considered to be an environmentally friendly option. However there is still research going on regarding the capacity of low-cost sorption materials to treat different types of pollutants.

The studied leachate was pumped from a leachate pond at the Brudaremassen landfill site located near the area of Lake Delsjön, Gothenburg. The sorption materials that will be used in this study are peat moss and activated carbon, and organic pollutants such as nonylphenol, PAH, alkylphenols and phthalates are the main objectives for the adsorption study. A pilot plant was constructed with four filter beds in order to examine sorption capacity of the two materials under dynamic conditions.

1.1 Aim of the thesis

The overall aim of this thesis work is to design, construct and run a pilot scale leachate treatment plant, based on sorption filtration technique to remove persistent organic pollutants like polycyclic aromatic hydrocarbons (PAHs), oxygenated PAHs (oxy-PAHs), phthalates, alkylphenols (APs), alkylphenolethoxylates (APEOs) and petroleum hydrocarbon (PHC) fractions. The results will be used as a support for construction of a full scale leachate treatment facility at the Brudaremassen landfill. The specific goals are to:

- Investigate which sorption materials could be used in sorption filter for efficient removal of the organic contaminants,
- Propose how a pilot plant facility should be designed at the Brudaremassen landfill. Including calculations on contact time, leachate flow and amount of sorption materials required.
- Install the facility at site and solve the technical difficulties during construction and operation of the plant.
- Run the facility for at least 120 days and analyze the influent and treated effluent samples to determine the percentage removal of contaminants as a support for calculations and design of a full scale filter.
- From the analysis results, the need for pre-treatment before the filter beds will also be investigated.
- The effect of high level of humus content on the leachate water on the adsorption capacity of the activated carbon will also be analyzed by taking sample at different depths of the activated carbon filter bed.

1.2 Scope

The scope of this master thesis includes:

- Giving a brief overview of other leachate treatment techniques for organic pollutants.
- Literature reviews on related topics are included.
- Concentration of various pollutants in the leachate from different locations of the landfill site since 2007 and comparison with guideline values from Göteborg and Swedish EPA for protection of groundwater is added in the thesis.
- Design parameters and calculations for construction of the pilot plant are included.
- Calculation of efficiency of the pilot plant in adsorbing desired pollutants are added.
- The interrelationships between various contaminants as PAH and oxy-PAH is discussed

1.3 Limitations

Some of the limitations of the experimental work are:

- Grab sampling technique was used to measure the influent and effluent concentration. This grab sample is assumed to be representative of a range of time. Influent leachate concentrations changes with time, it was therefore difficult to decide a concentration upon which to base the design parameters like, contact time or flow.
- To design a pilot plant by sorption technique, the first step is to perform beaker test with the proposed adsorbents and then a column test. But in this case, due to limitations of time and economy, the pilot plant was constructed based on previous consistent and reliable results. The detailed literature review for *Filtrisorb 400* activated carbon and peat as filter to remove organic pollutants are given in chapter 4. Use of *Filtrisorb* by many municipalities has been reviewed by many researchers. (Flick, 1991; Valderrama, 2008).

1.4 Background of the study

The Brudaremassen landfill site is located close to the lake Delsjön which in turn is located in the south eastern part of Gothenburg, Sweden. The position of the landfill is shown in Figure 1-1.

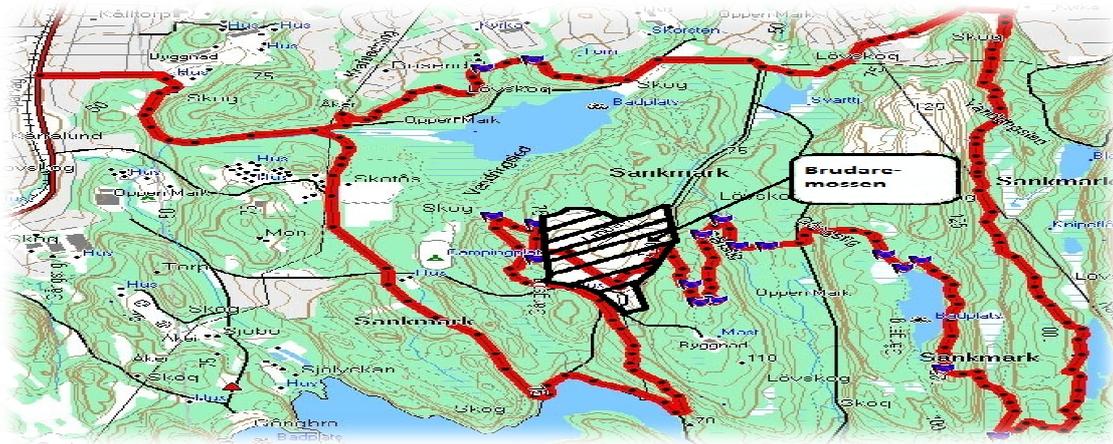


Figure 1-1: The Delsjö area, the stretched lines indicate the Brudaremossen landfill site

The surrounding area is built up by high ridges in the north-south direction and the now closed landfill is shaped as a hill with a height level of 130 meters above Gothenburg's height system. The landfill site was operating with an area of 25 hectare between the years 1938-1978 and was at that time the most important waste disposal site for the Göteborg region. Till now there is no documentation found on the waste type to this landfill. Various important improvements are presented in Table 1-1.

Table 1-1: Important improvements of the Brudaremossen landfill site

Brudaremossen Landfill		
Area	25 Hectare	
Operation period	1938-1978	
Improvements	1940	A concrete screen was constructed in the valley located south of the landfill in order to prevent leachate for reaching the lakes further south
	1960	A drainage system was constructed in order to collect the leachate and the run-off
	1991	Clay was spread on the top to improve the seal, decrease rainwater penetration and decrease the creation of landfill leachate
	2003-- 2008	Several improvements of the leachates treatment have been made

According to the yearly report 2007 by Kretsloppskontoret it can be found that throughout the year three crucial improvements has been made. New ditches have been created to divert surface water run-off to Stora Delsjön, old ditches in the northern part of the landfill site has been repaired. Both bentonite carpet as well as clay was used in the development of the ditches. An additional control spot for surface water had been developed. The leachate pipe between Brudaremassen and Robertshöjd had been sealed throughout the whole length, as well as 11 wells have also been sealed. A new oil and sludge separators as well as new pipelines have been installed (Kretsloppskontoret , 2007).

1.4.1 Water Quality

According to the study done by Chalmers University of Technology with Kretsloppskontoret, at Brudaremassen landfill site, four sample locations were chosen for assessment of the water quality. These locations are called:

- L1: inlet to the sludge/oil-separator,
- L1A: outlet from the sludge/oil-separator,
- L1B: downstream leachate pond connected to the local municipality sewage pipe.
- L2: an underground telecom tunnel located at the northern part of the landfill site and represents the leachate infiltrating into the tunnel through the bedrocks.

From the study it could be seen that in samples taken from the locations L1A and L1B, metal concentrations such as Cd, Cu and Pb were considerably higher than in the location L1 at that specific occasion. The sampling was performed after a long dry period and leachate may have become more concentrated due to the evaporation. A comparison with the guidelines from the Environmental Department for spillage of sewage water to storm-water and recipients in Gothenburg (Carlsrud, 2009) was also carried out and the results showed that only N_{tot} exceeded the guidelines. This problem can be solved by removal of the sediment in the sedimentation pond from time to time.

The concentrations of organic pollutants at the Brudaremassen landfill site are above the median level for leachates obtained for Swedish landfill sites in the RVF report 2000:7. For the metals, Pb could be found in high concentrations in all the flows, and Cd and Zn were found in high concentrations in the flows L1 and L1A. The maximum measured concentrations and their comparison to the guidelines can be found in Table 1-2.

Table 1-2: Maximum concentration from year 2007 to 2010 in ppm in comparison to the guidelines

Parameters	Unit	L1 inlet oil/sludge separator	L1A outlet oil/sludge separator	L1B outlet sedimentati on pond	L2 Tele chamber	Guide line values Gothenb urg ¹	Swedish EPA guideline values for protection of groundwat er
N _{tot}	mg/l	129	115	113	104	1.25	
TOC	mg/l	48.2	50.8	46	44.2	12	
Cadmium	µg/l	1.38	0.8	1.1	2.22	0.3	2.5
Nickel	µg/l	<u>16.1</u>	<u>13.3</u>	<u>13.4</u>	8.25	45	10
Copper	µg/l	4.09	19.6	16.1	13.7	9	50
Lead	µg/l	4.27	<u>7.23</u>	<u>5.82</u>	3.09	3	5
Benso(a)antracene	µg/l	<u>0.32</u>	<u>0.08</u>	<u>0.1</u>	< 0.01	0.01	0.05
Chrysene	µg/l	0.38	0.09	0.26	<0.01	0.01	0.05
Benso(b,k)fluorantene	µg/l	<u>0.36</u>	<u>0.08</u>	<u>0.41</u>	<0.01		0.05
Benso(a)pyrene	µg/l	<u>0.2</u>	0.03	<u>0.07</u>	<0.01		0.05
Indeno(1,2,3-cd)pyrene	µg/l	<u>0.06</u>	0.01	<u>0.09</u>	<0.01	0.03	0.05
Dibenso(a,h)anthracene	µg/l	0.01	<0.01	<u>0.19</u>	<0.01		0.05
Naphthalene	µg/l	0.12	3.8	1.3	0.05	2.2	10
Acenaphthylene	µg/l	0.09	0.05	0.03	<0.01	0.1	10
Fluorene	µg/l	1.2	1.5	0.81	<0.01	0.39	2
Acenaphthene	µg/l	0.76	1.1	0.66	<0.01	0.26	10

Parameters	Unit	L1 inlet oil/sludge separator	L1A outlet oil/sludge separator	L1B outlet sedimentati on pond	L2 Tele chamber	Guide line values Gothenb urg ¹	Swedish EPA guideline values for protection of groundwat er
Fenantrene	µg/l	0.8	1.4	0.2	0.01	0.52	2
Anthracene	µg/l	0.5	0.34	0.15	<0.01	0.04	2
Fluorantene	µg/l	1.1	0.35	0.2	0.01	0.09	2
Pyrene	µg/l	0.91	0.25	0.13	0.01	0.05	2
Benzo(g,h,i)p erylen	µg/l	0.02	0.01	<u>0.12</u>	<0.01	0.01	0.05
PCB	µg/l	<u>0.23</u>					0.0001

Bold italic values indicates concentrations above the Göteborg's guideline values and underlined font indicates higher than Swedish EPA report 5976 for protection of surface waters.

It can be seen that 15 of the 16 important PAH, has higher values than one or both guideline values. PCBs (polychlorinated biphenyls) are very high in concentration compared to the guideline values of Swedish EPA.

1.4.2 Treatment steps and their functions

A pipeline for the leachate was constructed at the Brudaremassen landfill site in 1996-1997, as well as a wetland for treatment of leachate and surface run-off. Even though the wetland exists at the site, it has not been applied as a treatment step for the leachate. The leachate pipeline was connected to the sludge/oil-separator and after the separator the leachate is transported via a sedimentation pond through the sewage pipe to the WWTP (waste water treatment plant) (Kretsloppskontoret , 2009). Today, also a sedimentation pond exists which works as a pretreatment step for the leachate. The purpose as well as treatment principles for the current treatment steps at Brudaremassen are: sedimentation ponds and sludge/oil-separators will be described below (Kretsloppskontoret , 2009).

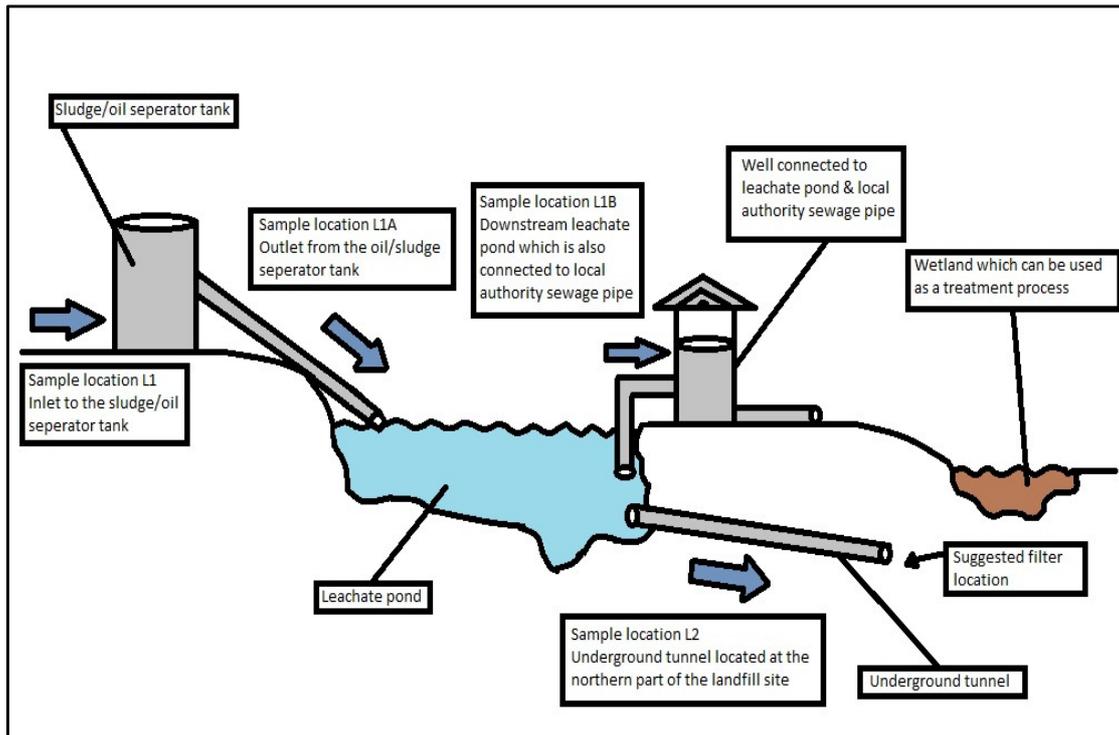


Figure 1-2: The treatment steps for leachates at the Brudaremossen landfill site and sample locations

Sludge/oil-separators: In a sludge/oil-separator heavier particles and sludge sinks to the bottom and got caught up in the sludge hopper. Lighter particles such as oil and oil-water mixtures travel upwards the sloped or inclined plates. Use of media packs will allow the smaller oil particles to attach to the media and produce larger flocs/bigger oil particles. These larger flocs of oil become lighter and get released from the media and start to float and then travel to the top of the separator. Once the oil has reached a certain level at the top of the tank an outflow pipe then collect the oil out from the tank for further treatment to an oil storage tank. The clean water then gets released to the sedimentation pond (Admin, 2010). From Table 1-2, it can be seen that for most pollutants the concentration is lower after the sludge and oil separator than before. This implies that the oil and sludge separator reduces pollutants to some extent.

Sedimentation ponds: In the sedimentation pond water is allowed to stay with a certain retention time, i.e. the time between the inflow and the outflow, so that particle-bound pollutants may sink to the bottom (Caldwell, 2006). From Table 1-2 it can be seen that the concentrations of contaminants after the sedimentation pond are even lower than the concentrations coming from the oil and sludge separator.

2 Literature review

In this chapter the main aim will be to describe:

- The various states a landfill will undergo throughout its lifetime
- The types of pollutants that one might find in Swedish leachate.
- The treatment techniques of landfill leachates.

2.1 Characteristics of Landfill Leachate

Volume and chemical composition of the liquid effluent are the main characteristics of the leachate (Renou, Givaudan, Poulain, Dirassouyan, & Moulin, 2008). These two parameters are in turn affected by a number of various factors for a landfill. Examples of such factors are the age of the landfill, precipitation or seasonal variation, composition of the waste inside the landfill, technique of landfilling (the waterproof covers, liners used etc). (Lema, Mendez, & Blazquez, 1988). Generally landfill leachate quality is represented by the COD, BOD, the ratio of BOD/COD, pH, suspended solid etc (Renou, Givaudan, Poulain, Dirassouyan, & Moulin, 2008).

The age of the landfill has a great influence on the quality of leachate produced. All landfills undergo the following stages of stabilization:

Initial Stage - In young landfills containing large quantity of easily bio-degradable organic material, fast fermentation occurs in the presence of air contained within the waste. This produces large quantity of volatile fatty acid (VFA) as the main fermentation product (Hoyer & Persson, Om filtrering och andra fysikalisk-kemiska separationsmetoder för lokal behandling av lakvatten; Welander, 1997).

Transitional phase—After the degradation of bio-degradable organic fraction of waste, oxygen in the landfill runs out and anaerobic conditions formed. Nitrate and sulphate acts as electron recipients of biochemical processes and reduces to nitrogen and hydrogen sulphites.

Acidogenic phase - When the redox potential drops below a certain lower level, microorganisms that are responsible for production of carbon dioxide and methane from organic material become active. Molecular material is broken down into smaller molecules by enzymes through hydrolysis and anaerobic bacteria break down the smaller molecules to volatile fatty acids, such as acetic acid. Carbon dioxide and hydrogen is formed and the pH drops, which resolves some heavy metals. Leachate from the acidic phase is characterized by high concentrations of organic acids and inorganic ions, high BOD (> 10000 mg / l), high BOD / COD (≥ 0.4) and low pH (5-6) (Uyguner C. a., 2005). Thus young landfill leachate typically has high BOD/COD ratio and low $\text{NH}_3\text{-N}$.

Methanogenic phase - In the next phase, called the methanogenic phase the VFA produced are converted to biogas (CH_4 , CO_2). The organic fraction is dominated by

non-biodegradable fraction in the methanogenic phase (Chian 1976). The bacteria are strictly anaerobic and pH increases to 6.8 to 8. Leachate from the methanogenic phase is characterized by low BOD / COD (≤ 0.2) and pH 6-8 (Stegmann, 2005).

Saturation phase - Saturation phase begins when all the easily biodegradable material is converted into methane and carbon dioxide (Hoyer & Persson, Om filtrering och andra fysikalisk-kemiska separationsmetoder för lokal behandling av lakvatten).

Thus the level of stabilization of the waste has a great influence on the landfill leachate and could give an idea of the type of treatment facility needed to be designed.

It is rather difficult to find references which provide the information in what state the Brudaremossen landfill is. But since Brudaremossen is a rather old landfill, it can be assumed that it is in one mature state of stabilization, considering the fact that it was more than 60 years ago since the landfill was started. However the fact that the Brudaremossen landfill is a rather old landfill is further proved by putting up the BOD/COD ratio. As already stated a young landfill has a high BOD/COD ratio. By taking the calculated COD and BOD concentrations that Kretsloppskontoret had analyzed throughout the months February, April, August and November/December for the years 2003 to 2006 and then taking a mean value for both the BOD and COD concentrations, it can be found that the BOD value to be 8.6 mg/L and the COD value to be 170 mg/L. The BOD/COD ratio thus resulted in $a\ ratio = \frac{8.62}{169.58} = 0.05$. This is a very low ratio which then indicates that the Brudaremossen landfill is in one of the later stages.

2.2 Pollutants in Leachate

At the presence there exists a quiet strong opposition against landfills in Europe and due to this opposition only non-combustible waste (such as glass, tiles etc.) and residues from municipal solid waste incineration plants (MSWI) such as fly ashes and bottom ashes is sent to the landfills. However, due to these organic pollutants in non-combustible wastes, new persistent organic pollutants (POP) have increased in concentration from active landfill leachates (Kim, 2002). Some other reasons to the changes in characteristics of a landfill are due to the facts that the landfilling technique changes over time due to changes in the costs and techniques of putting the waste at the landfill. New technologies for reducing the amounts of the various pollutants are developed over time thus increasing the percentage reduction of those types of pollutants (USEPA, 2005).

Since Brudaremossen is a quite old landfill (active from 1938-1978); most of the pollutants should be non-biodegradable, heterogeneous, microbially refractory and naturally occurring humic substances (Bae, Jung, Kim, & Shin, 1999) and as mentioned in chapter 2.1, with low BOD/COD ratio. The pollutants that are found in leachate could leach from everyday products which are disposed in the landfill. Therefore, it is quite difficult to assess the constituents of leachate since they may contain pollutants from originally disposed waste or may be produced from the

degradation process (Marttinen & Rintala, 2003). Since there is no documentation of the type of waste disposed in Brudaremossen, it is rather difficult to evaluate the composition of leachate with certainty. A report from the Swedish Environmental protection agency (SEPA) showed that there are 930 substances found in leachate and of which 334 substances are found in Swedish landfill leachates (Törneman, 2009). These substances were classified according to their persistency, bioaccumulation and toxicity. Some of those pollutants are (Thörneby, 2006):

- Aromatics,
- Benzene-sulfonamides,
- Biphenyls,
- Phenols,
- Phthalates

2.3 Treatment of landfill leachates

There are various ways leachate can be treated (Renou, Givaudan, Poulain, Dirassouyan, & Moulin, 2008) and some methods are quite conventional like:

- Transferring leachate (to treat with domestic waste water or recycling back to the landfill)
- Biological treatment, (aerobic and anaerobic degradation)
- Physical-chemical processes as (chemical oxidation, adsorption, chemical precipitation, coagulation/flocculation, sedimentation/flotation and air stripping)

Some are relatively new such as membrane techniques which consist of ultra-filtration; nanofiltration, reverse osmosis (RO), micro filtration and membrane reactors and the purpose of these techniques are all based on removal or separation of different pollutants. Depending on the component of the leachate, the effectiveness of each treatment technique varies.

For micro, ultra nanofiltration and reverse osmosis (RO) technique, four types of membrane filters can be used with unique properties for different application areas. The four membrane filters are spiral wound module, plate and frame module, tubular membrane and hollow fiber membrane. The choice of which of these four membrane filters to use depends on the type of water to treat (Lenntech, 1998).

Table 2-1 describes the effectiveness of different treatment techniques to remove different pollutants (Renhållningsverksföreningen, 2000). Expected effectiveness and suitability of various treatment methods, for Brudaremossen landfill leachate is indicated by scores of 1-5, where 5 is the technology best estimated based on weighted efficiency and appropriateness.

Table 2-1: Methods suitable for treatment of the Brudaremassens landfill leachates.

	Activated Carbon / Other sorbent	Oxidation UV	Reverse osmosis	Oxidation Fenton	Oxidation ozone	Wetlands	Evaporation
Suitability	5	4	3	2	2	1	1
Organic compounds	5	5	5	5	5	3	3
Organic pollutants colloidal	5	5	5	5	5	3	1
Metals	3	1	5	1	1	3	5
Metals in colloidal form	3	3 (With sorbents afterward)	5	3 (With sorbents afterward)	3 (With sorbents afterward)	3	5
N_{tot}, P_{tot}	1	1	5	1	1	5	5
Investment cost	1	1	5	1	1	3	5
Operating cost	1	1	3	3	3	1	3
Staff requirement	1	1	3	3	1	1	1
Footprint	1	1	1	1	1	5	1
Chemical requirement	1	1	5	5	1	1	5
Deposit requirement	1(combustion)	1	5	3	1	1	5
Energy requirement	1	5	3	1	5	1	5
Notes: "1" Low or No effects "2" Some effect or moderately low, "3" Moderately high, "4" Good effects, "5" Very good effects							

The comparison is based on a weighting system from 1 to 5 where 1 represents the worst and 5 the best.

The treatment techniques described in Table 2-1 will briefly be described in the following text:

Adsorption using activated carbon/other adsorbent: Adsorption is a physio-chemical process which is non-selective to dissolved organics and thereby could remove both biodegradable and non-biodegradable fractions. The usage of activated carbon or other adsorbent materials are especially useful when it comes to water treatment applications. The activated carbon can reduce COD and ammonium nitrogen by 50-70% efficiency (Bodzek M. a., 2004). This treatment technique is reviewed in details in following section.

Oxidation UV: This treatment technique is based on a destruction process which means that various types of organic contaminants are being destroyed. The destruction of these contaminants are due to that oxidizing agents such as ozone (O_3) or hydrogen peroxide (H_2O_2) and UV lights are added which results in that the contaminants becomes oxidized. The contaminated water is then led into a chamber where UV light from light bulbs is added (Bodzek M. a., 1992).

Reverse osmosis: It is a pressure driven membrane process where, pressure is used on the side where the contaminated water is placed to force the water molecules to go through the membrane filter and in to the side where pure water is placed. Reverse osmosis is usually applied at commercial and residential water filtration (Helmenstine, 2011; Bodzek M. a., 2004).

Oxidation Fenton: Contaminated water which contains organic contaminants can be treated by adding or injecting a strong chemical oxidizer which consists of a mixture of hydrogen peroxide (H_2O_2) and a catalyst of ferrous iron salts at a pH of 3 to 5. This oxidizer is achieved by also adding sulfuric acid. This mixture which consists of all these various reagents is called Fenton's reagent (FR) or in a more common name as Fenton's reagent oxidation process (FROP) since it was discovered by H.J.H Fenton at 1894 (Bodzek M. a., 1992).

Oxidation ozone: By using ozone in water treatment applications results in that the ozone reacts with various contaminants and then an oxidation process takes place. Odors, bacteria, viruses and mould are effectively removed due to the electrical charge within the ozone molecule causes a microscopic explosion and it removes these types of pollutants; thus an oxidation process takes place. Another reaction which occurs due to the ozone molecule that is oxidizes various types of metals and manages to decrease the level of toxicity for some types of toxic contaminants. Ozone is a toxic compound when it exists in the air, however, in water it is not toxic since the process for braking down the ozone molecule to water (H_2O) and oxygen O_2 happen very fast (LFS, 2001).

Wetlands: Wetlands are areas which consist of both soil and water, thus allowing a wide range of various vegetations to be able to grow at these places. The function of a wetland is that it pre treats water by filtration, settling and decomposes bacteria and other types of contaminants within the water. The treatment results vary however depending on the climate. Warmer climates lead to better performance while a colder climate leads to worse performance. Solids are removed due to filtration and settling within the rocks/gravel and sand as well as the roots at the bottom of the wetland. Organic matter is usually taken up by the various plants (biodegradation) which exist within the wetlands but it can also be removed due to the settling and filtration processes. The treatment procedure is usually based on anaerobic (without the

presence of air) or aerobic processes (with the presence of air) (Gustafson, Anderson, & Christopherson, 2002).

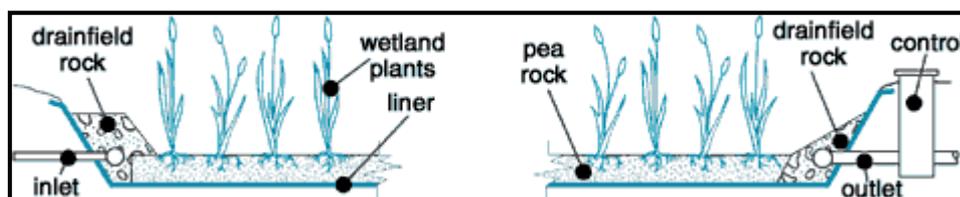


Figure 2-1: Wetland treatment process

Evaporation: The evaporation technique is a separation technique of various contaminants. By adding heat to the water which is going to be treated, the water is vaporized. The vapor is then cooled and condensed in order to get a precipitate. A common problem by using evaporation for landfill leachate is that the heat transfer surfaces are usually covered by various types of pollutants after a while. Another problem is that this technique is quiet energy demanding (Olsson, 2007).

From the results presented in Table 2-1, it can be seen that for the Brudaremossen landfill, the best technologically suitable option is filtration using activated carbon or other adsorbent media. It removes organic pollutants with great efficiency and metals to fairly good efficiency, with added advantages of low investment and operation cost. UV oxidation technique is closely competitive to this technique but it has the disadvantages of high energy requirements.

2.3.1 Physio-chemical treatment

As characteristics of the landfill leachates changes over the years, from easily biodegradable to non-biodegradable (Stegmann, 2005), for leachates with high concentrations of persistent and toxic pollutants, biological treatment is not the most effective treatment technique. Thus sorption or other physio-chemical treatment is becoming popular to treat landfill leachates. Physical-chemical treatment are processes that deals with wastewater, toxic compounds or other materials by combining both physical processes such as air stripping or filtration and chemical processes such as coagulation, chlorination and coronation (network, 2011). In a report of RVF, it is found that technologically most effective treatment technique for the Brudaremossen landfill is filtration using suitable adsorbent for organic pollutants. This treatment can be used alone or with combination of the conventional wastewater treatment system as post treatment (Hoyer, Om filtering och Andra fysikalisk-kemisk separationsmetoder för lokal behandling av lakvatten, 1998).

Filtration mainly removes particles based on their size. However, further separation based on the density, surface charge, hydrophobic or hydrophilic nature, ability to form complexes etc. could also be the reason for separation by filtration. Hydrophobic refers to compounds that does not easily get dissolved in water and usually are non-polar while hydrophilic compounds tend to dissolve in, mix with or be wetted by water due to that the compound has a strong affinity to water ((Lefers, 2006); (Farlex, 2009)). There are three phases through which adsorption of organic pollutants take place.

- First, the pollutants travel from the bulk liquid phase to the liquid film around the adsorbent.
- Second, pollutants travel through the liquid film around the adsorbent to the voids or interstitial voids.
- Third, they diffuse through the carbon voids in the adsorbents solid phase, and lastly, the pollutants get adsorbed onto the pores of the adsorbents (Department of US Army, 2001).

Compared to the biological treatment, sorption and physio-chemical processes are easier to automate and requires less time in order to treat the wastewater. These techniques are also less sensitive to temperature variations (Nilsson, 1991). Sorption in filter media can occur by three different ways. It can be either physical, chemical or exchange adsorption.

- Van der Waals force is the reason for physical adsorption and they have the weakest bond.
- Chemical bonding causes the chemical adsorption which has stronger bond than physical adsorption.
- Electrical attraction between the adsorbent and the surface causes the exchange adsorption which creates the strongest bond (Mckay, 1991).

Thus depending on the characteristics of the adsorbent and adsorbate, wide varieties of pollutants can be removed by filtration.

3 Concepts on adsorption technique

In the next section different characteristics of adsorbent and adsorbate/pollutant, which affect adsorption process, are described briefly.

3.1 Properties of sorbent material

The filter material or the material that is used to remove pollutants from wastewater is called adsorbent or sorbent material. All the properties which are described in Table 3-1 are important properties when it comes to sorbent materials. Each of these sorbent properties affects the adsorption capacity of any given sorbent material and a good and effective sorption material is one that fulfills all or most of the criteria which are described in Table 3-1.

Table 3-1: The various adsorption properties for adsorption materials are briefly described.

Properties of adsorbent	Description	Reference
Total Surface Area	The higher amount of effective surface area available the higher adsorption	(Brunauer & Emmett, 1938)
Particle Size	Adsorption rate depends inversely on particle size, which means that as the particle size decreases the adsorption ability increases	(Rodriguez-Reinoso, 2001; Department of US Army, 2001)
Sorption Capacity	The sorption capacity of an adsorbent for a specific solute can be defined as the value of the amount of pollutants that can be adsorbed in a saturated solution.	(IUPAC, 1972)
Mechanical Strength	Mechanical strength specifies the resistance to abrasion or attrition under operational conditions	(Rodriguez-Reinoso, 2001)
Apparent Density	The mass or weight of adsorbents per unit volume (including pore volume and interparticle voids by considering the moisture content) is called the apparent density	(Rodriguez-Reinoso, 2001; Department of US Army, 2001)
Real Density	It is the mass of adsorbent per unit volume (without the void space). Using the apparent density and the real density, the pore volume of an adsorbent can be calculated	(Rodriguez-Reinoso, 2001)
Empty Bed Contact Time	Empty bed contact time is used to describe the time of contact required between wastewater and adsorbent to remove pollutants. This parameter is related to the rate of adsorption of the organic pollutants on the adsorbent and varies for specific applications.	(Carbtrol Corporation, 1992; Department of US Army, 2001)

Properties of adsorbent	Description	Reference
Isotherm	Adsorption isotherm is a property that shows if a particular type of adsorbent is suitable for removing a particular pollutant. There are three types of models developed: Langmuir isotherm, the BET equation and the Freudlich isotherm	(IUPAC, 1972; Department of US Army, 2001)
Break-through Curve	Breakthrough curve (BTCs) are commonly used to characterize the physicochemical processes which take place in the transport of solutes in porous media. The x-axis shows the variation in time and the y-axis shows the variation in adsorbed concentrations of the pollutants. The resulting curve will then indicate when the sorption material has reached equilibrium between the inflow and the outflow concentrations and at that point the sorption material does not efficiently adsorb any more of the pollutants.	(Wang, 2002; Department of US Army, 2001)

Since it might be difficult to find a sorbent material that fulfills all of these criteria or have all of the properties required in order to be classified as a completely effective sorption material, it is now standard practice to find sorption materials that fulfill several of these criteria. Different types of sorption materials suits for different types of pollutants, it is usual to consider what types of pollutants that needs to be treated before the sorption material is chosen. After that, different types of sorption materials are considered based on these criteria.

3.2 Factors of pollutants that influence adsorption

All the factors which are stated in Table 3-2 determine how effective an adsorption material will adsorb various types of pollutants/adsorbate. In Figure 3-1, the adsorption process is described as illustrated in different literatures. The hydrophobic, non-polar and large molecules are better adsorbed on activated carbon like materials than the hydrophilic, polar, soluble and small molecules. Resulting in a much cleaner effluent through the system.

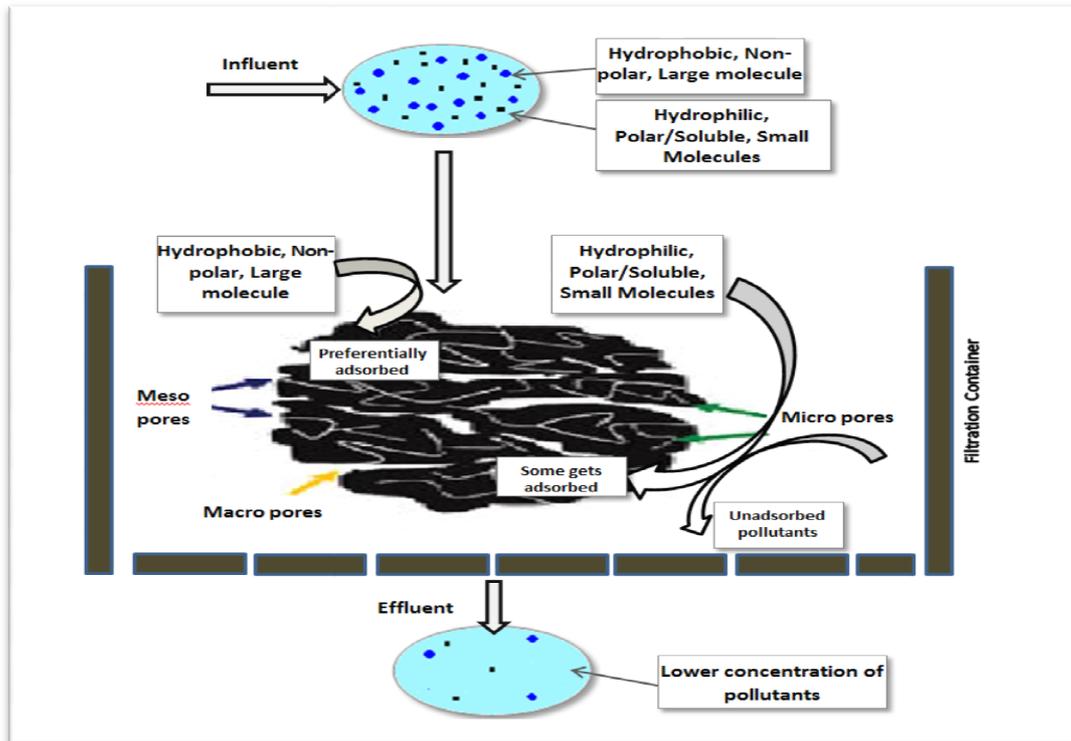


Figure 3-1: Illustration of adsorption process based on adsorbate characteristics for GAC

Brief description of the adsorption process based on pollutants properties are added in Table 3-2.

Table 3-2: Factors of the contaminated water that affect adsorption

Factors of wastewater which influence adsorption	Description	Reference
Molecular structure	<p>Molecular structure of the adsorbate is an important parameter that influences the sorption onto a sorbent material. Usually they follow the following trends for activated carbon:</p> <ul style="list-style-type: none"> — Straight chain compounds are less absorbable than the branched-chain compounds. — Less soluble or non -polar molecules are preferentially adsorbed. — Functional groups location and type affects adsorption capacity etc. 	(Perrich, 2000)
Solubility	Solubility i.e. hydrophobicity or hydrophilicity has an important effect on adsorption.	(Perrich, 2000)

Factors of wastewater which influence adsorption	Description	Reference
Ionization	Ionization has significant effect on adsorption. For activated carbon, strongly ionized materials are poorly adsorbed than non-ionized materials. Thus ionization negatively affects adsorption.	(Perrich, 2000)
Temperature	Lower temperature should improve adsorbability as adsorption reactions are generally exothermic. But in aqueous solutions is not that significant.	(Perrich, 2000)
Adsorption of mixed solutes	Both leachates and wastewater contains wide varieties of components. These components can improve, interfere or act independently in adsorption processes. Some of these factors are: <ul style="list-style-type: none"> ❖ Relative molecular structure ❖ Relative adsorption affinity ❖ Relative concentration in solutes 	(Perrich, 2000)

The filter media that will be used for the pilot plant are granular activated carbon (GAC) and peat moss.

3.3 Filter material

There are several materials that are suitable for wastewater treatment. Most common commercial adsorbent is activated carbon. Now-a-days, low-cost materials which are found in large quantity in nature or as byproducts of industrial process or as agricultural waste, are gaining popularity as alternative sorption material (Bailey, 1999). Some of these low cost materials that are suitable for treatment of organic pollutants include: nut shells, wood chips, bone, rice hulls and peat (Amuda, 2006; Robinson, McMullan, Marchant, & Nigam, 2001; Nawar, 1989). In the following section, a study on the chosen filters materials: peat and GAC for this pilot plant is presented.

3.3.1 Peat moss

Decaying sphagnum moss in water column, wetland sediment detritus and the dissolved colloidal material incorporated in the sediments are called peat moss. It is an organic soil which is formed at places that has high moisture content as well as where the growth of the peat moss exceeds the rate of residue decomposition. Due to this, an accumulation of organic matter takes place because decomposition is limited

by the lack of oxygen. Peat comes from a variety of different sources and the adsorption capacity of peat in removing various types of pollutants varies a lot depending on peat origin, degree of decomposition, particle size, metal concentration, ligand concentration and competing ions. Constituents such as decomposed organic matter and mineral particles are the main build up components of peat. (Brady, 2002) It contains mainly lignin and hemicelluloses, which produces humic substances once after it has been broken down (Brady, 2002). These substances contain a variety of polar functional groups such as alcohols, aldehydes, ketones, acids and phenolic hydroxides (Bailey, 1999; Brady, 2002). They create chemical bonds and perform ion exchange. These characteristics can be used to remove ionic pollutants like heavy metals and other nonionic hydrophobic compounds like PAHs by hydrophobic interactions. (Tang, Zhou, Xu, Zhao, & Lu, 2010).

Peat has an extensive capacity to absorb metals (Brown, Gill, & S.J Allen, 2000; Gosset, Trancart, & Thevenot, 1986; Couillard, 1994) (Kalmykova Y. , 2009), oils (Cojocaru, 2008; Cohen, Rollings, Zunic, & Durig, 1991), pesticides (Smith, 1978), detergents, dyes (Ho, 1998; Crini, 2006; Robinson, McMullan, Marchant, & Nigam, 2001; Nawar, 1989) , phosphorous and nitrogen. A study (Cohen, Rollings, Zunic, & Durig, 1991), showed that, peat has a capacity to remove petroleum hydrocarbons with an efficiency of 63-97%. Organic pollutants can be removed by humic substances which are present in the peat. The humic substances can be characterized as a group of heterogeneous, high molecular weight organic substances which originates from decomposed organic matter. Fractions of humic substances which also are water soluble are considered to be the main adsorption agents for metals because they have a high content of oxygen-containing groups. Examples of such groups are carboxyl (COOH), hydroxyl (OH), and carbonyl (C=O), which are scattered in water and then provides negatively charged adsorption sites. (Kalmykova Y. , 2009).

The benefit of using peat as an adsorbent lies in the fact that, peat is biodegradable and a natural renewable resource with an opportunity of waste recycling. Also peat is a low cost adsorbent having lower impact on the environment, if gets released in the environment during operation, has an environmental friendly public perception (Cojocaru, 2008). In Sweden, peat is used as a horticultural product and 15% of the land area of Sweden is covered with peat (Kalmykova Y. , 2009). Thus using peat as a low-cost sorption material for treatment of organics is a feasible selection for this pilot plant. Another added benefit of using peat is that the exhausted peat can be used as fuel as it has high calorific value with low ash content (Shao, o.a., 2011). Very little too almost no studies regarding peat moss as an sorbent for treating and removing organic pollutants in a pilot scale facility under dynamic condition have been made. Based on previous research on peat as a potential adsorbent for organic and petroleum based hydrocarbons and furthermore due to availability of peat in Sweden, peat has been selected as the low-cost adsorbent for this pilot plant.

Regeneration of spent Peat moss

One common way for disposal of peat after it has been used as a sorbent is by sending it to an incineration plant where the peat is being burnt and thus the various pollutants are destroyed. This type of disposal is however not very economic. In a study (Gossett, Trancart, & Thevenot, 1986) it was shown that by regulating or changing the pH, one can then regenerate the peat. However, in that study only removals of metals

were considered and the pH interval varied from 1.2-2.0 and at that specific pH range, only half of the maximum sorption capacity was attained.

3.3.2 Activated carbon

Carbon has been used to adsorb contaminants for many years. Its first documented usage is found for medical purpose in 1500 B.C. Activated carbon was first used as filter media in 1800 century. Understanding of the mechanism of carbon absorption progressed from 19th to early 20th centuries. Granular activated carbon was first used in Europe for water treatment in 1929. (Department of US Army, 2001)

Carbon from coal (bitumen, sub bitumen and lignite), peat wood or coconut shells can be carbonized and activated to produce activated carbon. In the carbonization phase, carbon sources are dried and heated to remove by-products like tars or other hydrocarbons and remove gases generated. This heating is done at temperature 400-600°C in absence of oxygen. Activation is done by exposing the carbonized material to an activating agent like steam at high temperature. Decomposition products are burned off by steam, developing porous lattice structure of graphite. Activated carbons are commercialized on powder or granular form. (Department of The Army 2001)

Activated carbons can be produced from many sources of carbons, and the properties of carbon depend on the raw materials used. This activated carbon can be produced in powder, granular, pellet, spherical and block forms. (Rhinehart, 1996). Powdered Activated Carbons (PAC) is usually defined as PAC and Granular Activated Carbon is usually defined as GAC. Other important parameters that determine the performance of activated carbon are: particle size, surface area, ash content, and abrasion resistance, backwashed and drained or bulk density.

Regeneration of spent carbon

When the properties of the GAC have decreased to a level that the GAC does not adsorb any more of the pollutants or very little, it is removed from the filter and then new GAC is added. The removed carbon will be regenerated, reactivated or disposed.

In the regeneration processes the adsorbed contaminants are removed from the carbon by using temperatures such as temperatures above 600-700°C or processes that remove the contaminants from the carbon without destroying the contaminants. The regenerated carbon is then mixed with new carbon and can then be used again in the filters.

In the reactivation process of spent carbon the adsorbed contaminants are removed from the spent activated carbon by using high temperatures occurring within the specially designed furnaces where the contaminants will be desorbed and destroyed. When reactivation processes takes place there will always be some carbon losses depending on the source of the carbon (Department of US Army, 2001).

In some occasions disposal of spent carbon might be the only option due to difficulties to send the carbon for regeneration or reactivation or the carbon might have adsorbed some pollutant that cannot be removed or destroyed. For carbon which treated and dealt with listed hazardous contaminants or which exhibit a RCRA hazardous characteristic (corrosive, reactive, ignitable or exceeds the toxicity level for leachate) it must be managed as a hazardous waste and then dealt with in an

appropriate place like for example a treatment storage or disposal facility (TSDF) (Department of US Army, 2001).

The carbon which has been used in this study was an activated carbon called '*Filtrisorb 400*' produced from a company called Chemviron Carbon. This activated carbon is an agglomerated coal based granular activated carbon. For the '*Filtrisorb 400*', once it has been saturated it can be reused by recycling through thermal reactivation. (Calgon Carbon Corporation, 2006)

4 Methodology for the design and construction of the pilot plant

Before constructing a full scale pilot plant for leachates of Brudaremossen a small scale pilot plant will be built to test the performance of the proposed adsorbent materials to remove organic pollutants and also to check the feasibility of the proposed technique for a large scale treatment plant. After evaluating the historical concentration a basic idea about the change of concentration with time is obtained. This is important to design the full-scale treatment plant so that it can handle any rapid change in concentration of pollutants.

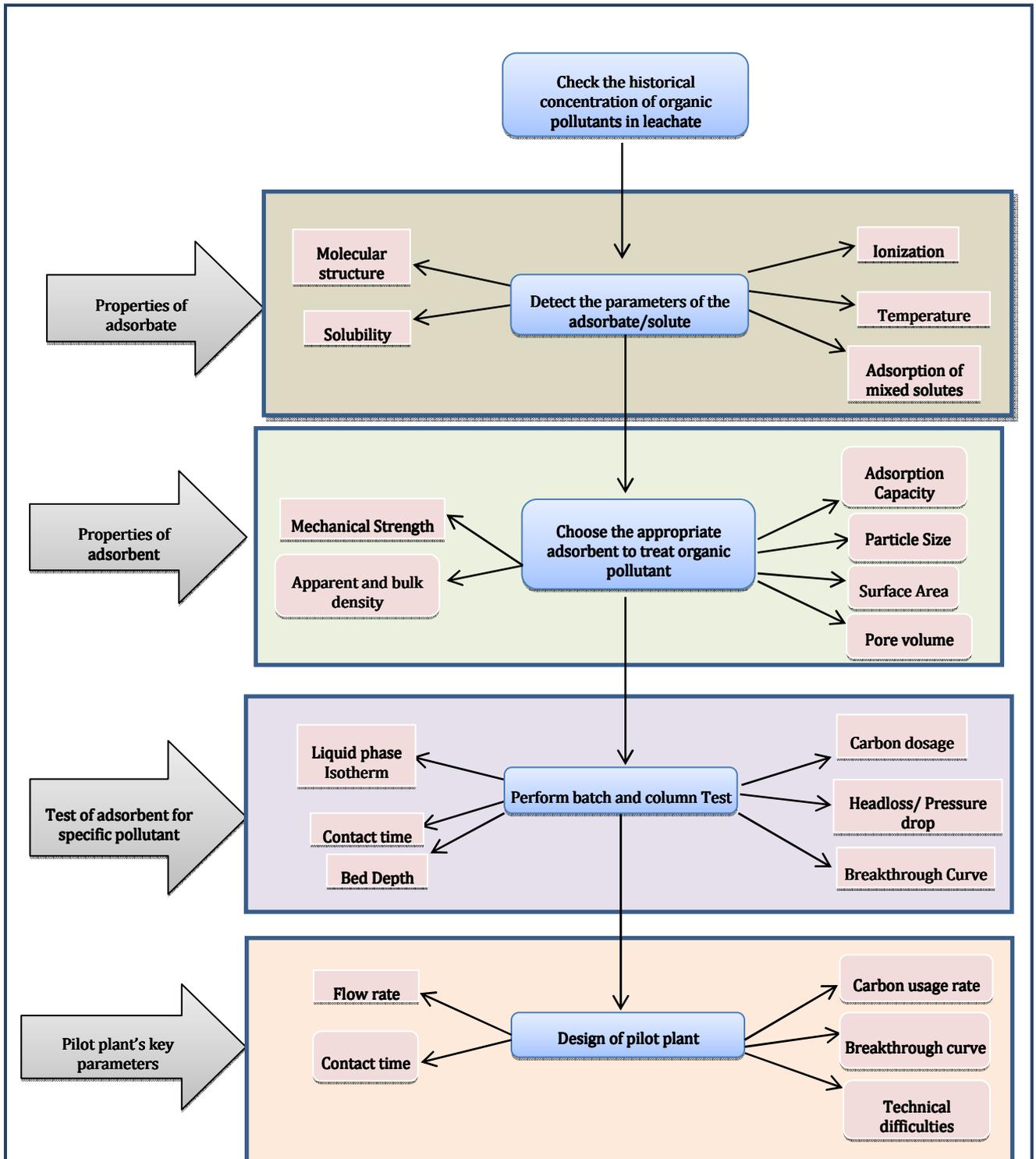


Figure 4-1: The steps to design a pilot plant using adsorption as treatment

In Figure 4-1, the steps in designing a pilot plant based on adsorption process is illustrated.

4.1 Design of the pilot plant

The first step in designing the pilot plant is to choose appropriate adsorbent material. As mentioned in Chapter 3.3, peat moss and granular activated carbons 'Filtrisorb 400' are the two adsorbent chosen for this plant. The validation of choice is also added in those chapters. To treat the leachate of Brudaremossen, two adsorbent column options were suggested. First two columns in series filled with activated carbon. The second with sequenced adsorption in a peat moss column in and activated carbon column in. In Figure 4-2, a graphic representation of the treatment alternatives are added. It will be investigated which of these two alternatives that remove organic pollutants most effectively, with respect to breakthrough time, cost, efficiency, maintenance and technical difficulty.

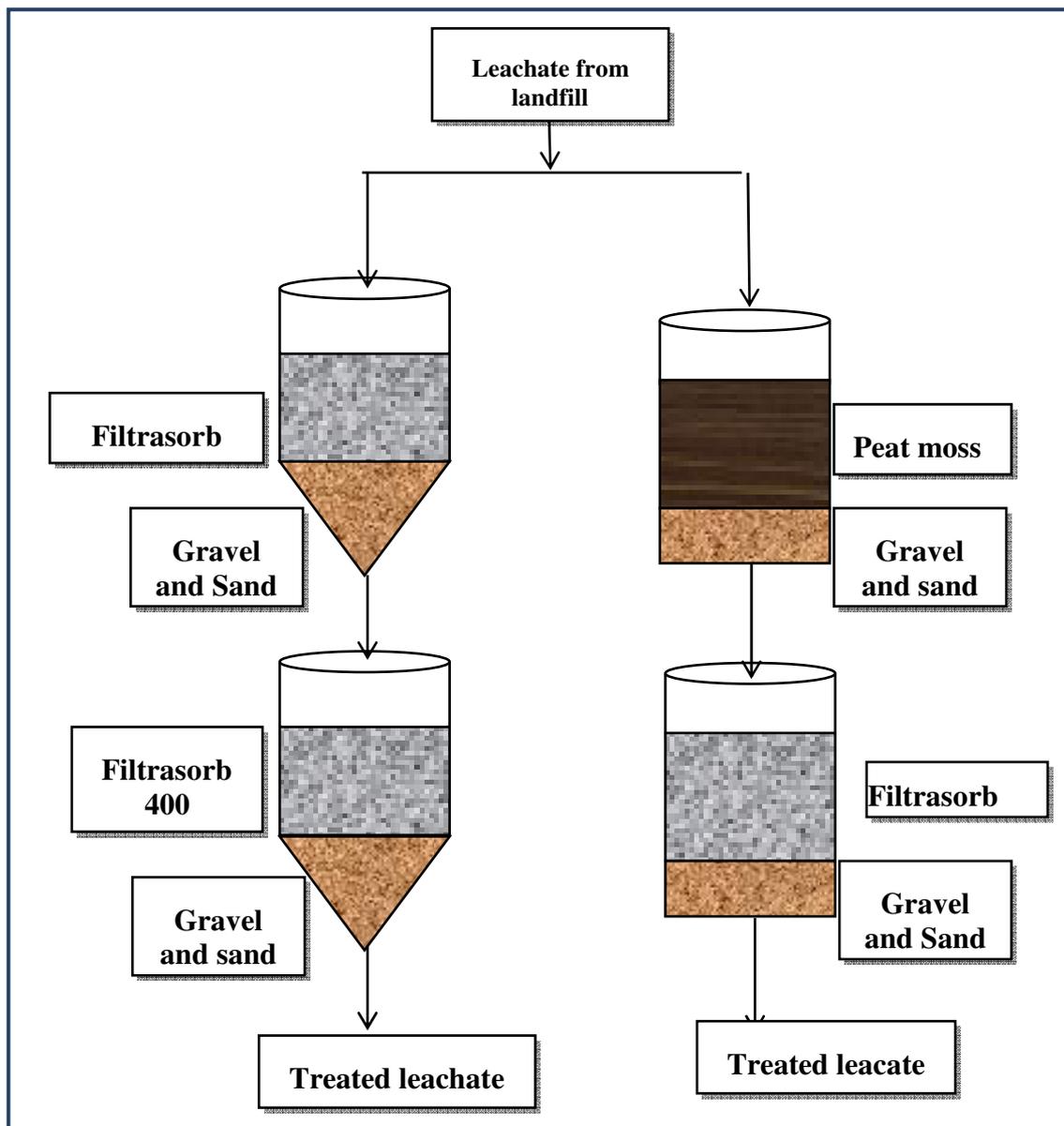


Figure 4-2: Pilot plant treatment alternatives

To begin the construction process of the pilot plant, the column tanks available were measured and dimensions are recorded. The dimensions of the columns are added in Appendix I. There were four columns available for the pilot plant of two different kinds. One pair is cylindrical in shape and the other pair is cylindrical at the top with a cone part at the bottom and three legs. Figure 4-3 shows the proportions of the columns. As peat has a tendency to swell when comes in contact with water, the column with longer length was chosen for peat alternative.

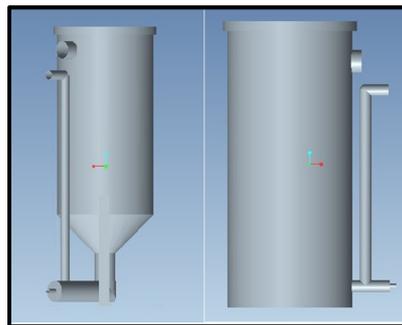


Figure 4-3: On left, columns that are used for GAC in a series and on right columns that are used for peat and GAC in series.

The functional parameters like flow rate was calculated based on the contact time required by each adsorbent to remove multiple pollutants. This calculation was done from the equation of ‘Empty bed contact time’.

$$EBCT = \frac{V}{A} = \frac{LA}{Q}$$

Where,

V= bulk volume of sorbent material in contactor, m³ (ft³)

A=Cross-sectional bed area, m² (ft²)

L= Bed depth, m (Ft)

Q=Volumetric flow rate, L/s (ft³/min)

For GAC, the carbon producer suggested a contact time of 15 min to 20 min from isotherms for multiple pollutant like naphthalene, fluorene, acenaphthene and phenanthrene in solutions and with average concentrations found in the leachate from the landfill. The isotherm is added in Appendix II. The multi- component isotherm added here was obtained from the computer program called ‘Waterads’ used and copyright protected by the Chemviron Carbon production company. These models predict the effects of competitive adsorption among all components present in the water or gas phase. It should be noted that usually isotherms obtained are obtained from batch tests done with GAC and for only one group or one specific pollutant. The

same range of contact time was also selected for peat in the beginning so that the effluent results can be comparable.

The calculation of the flow rate from the data of contact time for the GAC columns are added in Appendix III. For the given dimensions of the GAC columns, the flow rate was calculated to be around 4 l/min. With the presumption that peat will allow less water through-the peat columns, the flow rate was decided to be half of the carbon column.

4.2 Characterization of GAC and peat

To characterize the GAC, dry weight test was performed by drying at 105°C for 24 hours. One crucible was used to test the dry weight of the GAC slurry. The results of the analysis are presented in Appendix IV. The test was run according to the Swedish standard test 'SS 02 81 13'. From this test it can be seen that the dry weight of the GAC slurry is 158 mg/kg.

To characterize the peat, two parameters were chosen, i.e. the sieve analysis test and the Loss of ignition test. Standard methods are used for these two analyses. Three crucibles were used for this analysis to improve of the accuracy of the analyses. The result of this test is added in Appendix V. Average organic content of peat was found to be 20.7%.

4.3 Construction procedure of the pilot plant

In this chapter the construction procedure for the plant is described. After the dimensions of the columns where obtained, a preliminary idea on the amount of carbon needed for three columns along with the amount of peat required was estimated. The activated carbon required was 250 L and peat around 138 L. The activated carbon producers sell carbons in 25 kg bags which gives around 58 L of carbon, 5bags of 'Filtrisorb 400' was ordered from Chemviron. The peat for the pilot plant was obtained from a horticultural firm.

4.3.1 Placement of the columns

The two types of columns were placed in the same way for both of the alternatives. The first column was placed in an elevated height above the second container. This was done to allow water to flow by gravity from the first column to the second one through a pipe.

4.3.2 Sand and Gravel at the bottom

Sand and gravel was added at the bottom of all four columns to provide clean effluent from suspended solids and also to eliminate the possibilities of activated carbon and peat being washed out with effluent water. Three different types of sands were used based on their size distribution. Each bag of gravel weighted 25 kilo and a total amount of 9 bags were ordered. The size range of these bags of gravel were

- 5-10 mm,
- 3.0-5.0 mm and
- 1.2-2.0 mm

The bag of gravel that contained 5.0-10.0 mm sand was sieved to divide in coarser and finer fraction in order to improve their performance. So they were further divided in two fractions of 8-10mm and 5-8mm size gravels.

The gravels were added in sequence of coarser to finer gravel from bottom to top. This is done till all four fractions of gravel had been placed on top of each other. The amount of gravel which was used in the tanks differed between the two different dimensioned tanks. The amount of different size fractions used for four columns are added in Appendix VI.

4.3.3 Soaking the GAC

Six bags of granular activated carbon (GAC) was bought and used in this study. The total weight of all the dry GAC was 150 kilo. These bags of GAC were soaked with pure and clean water in columns. The reason to use clean water is to make sure that the GAC did not adsorb any types of pollutants and in that way decrease its sorption capacity before it is implemented in the field. The soaking process has to be at least twenty-four hours to make sure that the GAC has enough time to swallow and ensure that there are no air bubbles left in the carbon slurry. In this study, the total amount of 150 kg of GAC was left in the water over a time period of eighty-four hours to make sure that it had swallowed enough.

4.3.3.1 Amount of soaked GAC into the columns

In the smaller columns a total amount of 98 kilo of soaked GAC slurry was used for each tank. This resulted in a carbon bed depth of 40 cm and remaining empty distance of 23 cm from top of the column to the top of GAC or. For the bigger container, a total amount of approximately 58 kilo of GAC slurry was used. After filling the columns with this amount of soaked GAC a remaining distance of 45 cm remained with a GAC depth of 35.

4.3.4 Soaking the peat

Four bags of peat were available in this study and each bag of peat had different weight. Around 2.5 bags of peat were used for the peat column.

First one bag of peat weighing 32 kg was soaked for 24 hours. When this peat was added on the adsorbent column, the finer and coarser fraction of the peat separated and made like 'clay' sediment at the bottom of the column and floating fraction of peat on top with water with big chunks of peat which had not soaked completely having a dry core. Then there became a part filled with water between the floating chunks and sedimented fines of peat. When the column was tested by adding water on top, to check the throughput of water, the fine particles of the peat clogged the outlet of the tank and prevented water from going out. The peat was removed and the tank was cleaned.

The dry peat that was left in the remaining peat bags was sieved in order to remove the big peat chunks as well as the fine peat particles which contributed to the clogging of the tank. In total an amount of 57 kilo of dry weight peat was sieved which resulted in an amount of 17 kilo of useful peat which lay within the right interval. The mesh sizes of the sieving machine which gave the right particle interval were: 5.6 mm, 4.0 mm and 2.0 mm. A mesh grid of 8.0 mm was also used in order to remove the big peat chunks and the bottom bin of the sieving machine gave the finer peat particles

which then also were removed. The 17 kilo of sieved peat was then soaked for about 24 hours.

In the first stop, the previous fraction of soaked peat from the bag of 32 kilo was then added in to the big column and a peat column height of approximately 40 cm was attained. As already mentioned a total dry weight of 17 kilo of peat was gained after the sieving. Once mixed with water this peat slurry was then mixed together with the old peat slurry which had been removed from the tank during the first performance. All of this mixed peat slurry was then added into the tank and a total peat height column of 52 cm was achieved.

4.4 Operational Time line of the pilot plant

In order to ensure a proper interpretation of the analysis results for various organic pollutants, a calendar was maintained. Below in Table 4-1, the calendar of the pilot plant is presented.

Table 4-1: Calendar of the pilot plant

	On site		On Lab	
April	24th April	Pilot plant starts to work		
	27th April	1st sampling day		
May			4th May to 9th May	Column test on lab
	6th May	2nd Sampling day		
	12th to 20th May	Acid wash of columns		
	24th May	Sand filter installation		
	26th May	3rd sampling day		
	30th May	Sand filter clogged		
June	31st May	Sand filter Backwashed		
	1st June	4th Sampling day		
	7th June	Sand filter backwashed		
	9th June	5th Sampling day		
	13th June	Acid washing of sand filter	13th June to 15th June	Beaker test on Lab
	16th June	6th Sampling day + Sand filter backwashed with clean water		
	22nd June	Sand filter Backwashed with clean water		
	23rd June	7th Sampling day		
	30th June	8th Sampling day + acid wash of sand filter afterwards		

4.5 Operation of the plant on field

From the height of adsorbent bed and the bulk density of carbon, a flow rate of 3.94 l/min for the GAC column, and for peat a 2.0 l/min of flow rate was fixed. The plant started to run from 24th of April. After applying the calculated flow rate on site in the first day, it was found that not GAC and neither peat could let through these high flows, and excess of water was overflowing through the overflow outlet. The first activated carbon filter had an outflow of 0.84 l/min and the first peat column was letting through only 0.5 l/min to the next GAC column. It was also noticed that, from the peat column, the flow to the next GAC column depended on the water level above peat. If the water level was high enough to flow through the overflow pipe, then the flow to the next series GAC column raised to 0.7 l/min. It was decided to change the inflow rate from 4 l/min to 0.70 l/min for both the GAC and peat column. The pilot plant was left running with this flow rate for one week. The sampling frequency was decided to be once every week.

The plant was operating from the 24th April 2011 until the 10th May 2011 and between these dates, two sampling occasions took place. The first was at 27th April 2011 and the second was at 06th May 2011. The reason to temporarily stop the plant after 10th May 2011 was because the columns had been clogged with various pollutants from the leachate such as iron and petroleum products etc., which resulted in almost no flow, coming out from the columns. On the sampling day (6th of May) it was found that, the inflow to first GAC was still 1 l/min but the outflow to second GAC column was around 0.6 l/min. The excess water was overflowing from the first GAC column. From peat to the next GAC column in series the flow was higher than GAC + GAC.

As both filters appear to be clogged with the suspended particle and/or iron in influent water, a sand filter was proposed to be built before the inflow to both columns. It was decided to backwash the columns with acidic water of pH 1 for at least 4 days.

4.6 Backwashing of columns with acidic water

In order to backwash the columns with acidic water 30-37% hydrochloric acid (HCl) was used. Only 40 ml of acid in 25 litre of tap water produced a water of pH 1. The backwashing was done from 12th May to 20th May with total 250l of water. The pump used did not have too high power, which resulted in only 20 litres water through the column overnight. This gives around 0.03 ml/min of flow. For the first GAC column and the peat column approximately 90 liters of water was used since those columns were the ones that were most clogged. This resulted in that approximately 150 ml of hydrochloric acid was used for each of those columns. For the other two columns which were not clogged that much, 75 liters of water was used for each of them, which resulted in that approximately 120 ml of hydrochloric acid was used for each column.

An interesting outcome of the pH drop from 7 down to 3 was that when the pH level had decreased below 6, the iron particles on top of the GAC bed started to dissolve in the water and when the pH level had decreased even further down to 4.5 the oil products started to float on the top of the water surface. Once the columns had been

cleaned with acid water, 25 liters of pure tap water for each column was pumped into the columns for two days just to make sure that the majority of the clogging contributing particles were removed.

After backwashing the columns with acidic water, the suspended particles on the upper layer dissolved with the acidic water. This cleared the columns quite well, and when a powerful pumped was used to backwash the columns, the inflow was equal to the outflow. Thus it was believed that the block of the columns was removed.

4.7 Small scale column test on laboratory

Since the columns on the site, designed to treat the leachate of Brudaremossen seemed to be clogged with iron and suspended particles, it was decided to run a small scale column test with sand and 40 litres of leachate on the laboratory. The column was filled with 1 kg of sand of size fraction 1.2-3.0 mm. The diameter of the column was 7 cm and the sand column height was 30 cm. The leachate was inserted in down flow mode. It was discussed to regulate the flow to meet the condition on the site. Both the field columns require around 2_L/min inflow and they have a diameter of 50 cm. The required flow to the small scale column should be 280_ml/min. But due to low capacity of the available pump, 280 ml/min flow was not possible to use for the column. The flow was measured to be 13_ml/min, which is 20 times less than desired. To assure constant quality of leachate entering the column and to reduce the sedimentation effect, the leachates where poured into a 12_L glass column and then placed on a magnetic stirrer so that the leachates were constantly stirred and thus will have uniform concentration all over the column. The column was left with this inflow conditions overnight. The flow into the column and out of the column was analyzed for total iron concentration using a HACH spectrophotometer. As the results obtained from the HACH method may have considerable variations, all tests were done in triplicates.



Figure 4-4: Small scale column test on Laboratory

The mechanical stirred stopped some time during the night, and this resulted in a sedimented and heavily concentrated leachate at the bottom of the glass container. More leachates where added on the glass container and the magnetic stirrer was changed to a better-quality one, with higher power. For the sand column, the total iron was continuously analyzed on the incoming and outgoing. The results are shown in the table in Appendix VII.

4.8 Construction of sand filter on site

A container with five fractions of various sizes of sand was also installed on top of the pilot plant as a pretreatment step to prevent future clogging. The sand range that was used was:

- 0.6-0.8 mm,
- 1.2-2 mm,
- 3-5 mm,
- 5-8 mm and
- 8-13.5 mm.

The courser sand/gravel was used in the bottom of the tank ending with the finest sand fraction on the top. The height of different fractions are 2cm of 0.6-0.8 mm sand fraction, 8cm of 1.2-2 mm fraction, 3cm of 3-5 mm fraction, 3cm of 5-8 mm fraction and 2cm of 8-16 mm fractions were used.

4.9 Operation of the plant with sand filter

Two days after the pure tap water had been pumped into the containers (24/05/2011) the pilot plant was put into operation once again and the flow that went into the sand filter was measured to be 2 l/min. The flow that went into the first GAC column was regulated to be 0.7 l/min and the flow that went into the peat column was regulated to be approximately 0.7 l/min.

A regular technical problem that seems to happen quite often is when the pump is turned off and afterwards when it starts up again, air bubbles get stuck inside the pipes that go from the sand filter to the filter columns which then creates uneven to no flows at all to the columns. To solve this problem, the pipes had to be shaken vigorously to let the air bubble come out. This step is quite time consuming as well as unnecessary. The recommendation is to try to avoid shutting down the plant too often or ensure that all the pipes have vent to allow excess air through.

After installing the sand filter, on 25th May 2011 the in/outflow to the various columns as well as the inflow to the sand filter was checked again. The regulated flows that had been used and regulated the day before had changed. Therefore new measurement of these flows was calculated until one had reached sufficient flows for the various columns as well as the sand filter. The value of these flows can be found in Appendix VIII as well as the calculated mean flow for the time period of these two days for each column. The reason for why the mean flow was calculated for each column was to get an idea about the average value of the flows between the various changes in flow rate.

4.10 Beaker test

As the sand filter was also getting clogged due to what was presumed to be high amount of iron in the water it was decided to run beaker test in the laboratory to precipitate the excess metals from the solution. By precipitation metals are removed by formation of solids within the solution. This step is usually followed by a sedimentation and filtration step, in which the formed solids are allowed to settle and thereby is removed from the solution (Ayres, Davis, & Gietka, 1994; Benjes, 2001). The main mechanism behind the precipitation technique is to convert the soluble materials into insoluble ones. The precipitation region of the solubility diagram is an important parameter that specifies the appropriate pH and concentration values when a specific metal forms solid (Ayres, Davis, & Gietka, 1994). For iron, aeration is the simplest technique to convert ferrous bicarbonate to ferrous hydroxides. Usually the pH needs to be increased in order to form metal solids and to oxidize iron. At lower pH the rate of conversion of ferrous hydroxide is low (Benjes, 2001). Thus in order to find the best alternative to remove iron from leachate by physio-chemical process, three alternatives were decided to test. The first was simple aeration, which will indicate the applicability of precipitating iron by only aeration. Second, caustic soda (NaOH) was added to increase the pH till 9 and then to aerate the leachate to see if this gives accelerate the process. The pH has to be within the range 7-9 for iron solids to form. At elevated pH, due to addition of NaOH, metals forms metal hydroxides and thus precipitate from solution. In Figure 4-5, the process of metal precipitation is added.

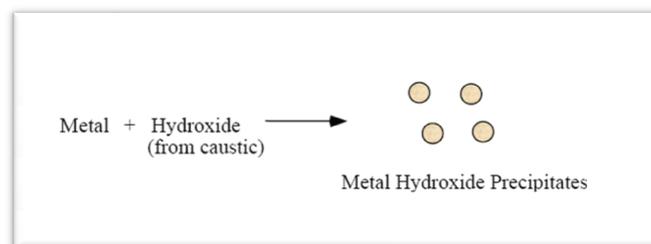


Figure 4-5: Steps of metal hydroxide formation by addition of NaOH.

The third option was to use lime (CaCO_3) as an adsorbent during aeration to remove iron. Research work done to treat landfill leachate using limestone filter was used as a reference for this option (Aziz, Yusoff, Adlan, Adnan, & Alias, 2004). In the beginning it was decided to aerate the beakers for 1 hour and then test the 5 parameters. After that, the beakers will be sediment the iron flocs formed for 20 hours and then test again the 5 parameters to observe the difference in solution. After this, it was decided again to aerate for 2 more hours and let the solution to settle for another 24 hours to see if further aeration reduces the iron content even lower. As the ferrous iron content was fairly low in raw leachate, only results found from total iron test was added in Appendix VIII.

5 Experimental Section

The basic aim of this pilot plant was to adsorb the persistent organic pollutants in column filters to reduce the pollutants load to GRYAAB wastewater treatment plant. In order to evaluate the performance of the pilot plant, the following chemical analysis where decided to be done:

Table 5-1: Analyses done for the pilot plant

Pollutants	Analyses site
TOC (Total organic carbon)	Chalmers Environmental Lab
DOC (Dissolved organic carbon)	
Total Nitrogen, Dissolved N	
Colour, pH, Alkalinity, Conductivity, Redox, Oxygen	Field measurement
Iron, Aluminium, Manganese and other metals and UV test	Chalmers Environmental lab using ICP-MS machine
Alkylphenols	Analysed by an commercial laboratory
PAH (16)	
Phthalates	
Oil products (C10-C40)	
Oxy-PAH	

It was decided that the oil-products or different fractions of hydrocarbons should be analyzed on a regular basis, because the analysis cost was reasonable and they give guidance on how the plant adsorbs the oils in the leachate water. The oxy-PAH analysis was done to find the relationship with PAH. As oxy-PAH is the degradation by-products of PAH and which is also toxic and harmful for nature (references?), it was decided to see if there exists any oxy-PAH in the leachate and on other locations of the pilot plant. For the oil-fractions, four different fractions of hydrocarbon chains are analyzed from the sample collected from the Brudaremossen site. These are: C₁₀-C₁₂, C₁₂-C₁₆, C₁₆-C₃₅ and C₃₅-C₄₀. The sum of these entire hydrocarbon fractions gives the oil index for the water sample.

The landfill is old, and the easily biodegradable fraction is low and the non-degradable fraction is high in the leachates. Thus the oil products and petroleum hydrocarbons that exist in the leachates are hard to degrade. For this reason the oil index and various fractions of petroleum hydrocarbons from C₁₀ to C₄₀ was chosen as

indicator pollutants to evaluate the efficiency of the pilot plant. The aim was to obtain the breakthrough curve or a pattern for breakthrough for these pollutants.

Both UV and color are two parameters that are closely related to each other as they both can be analyzed at different wavelengths. UV is usually measured at wave length 254 nm while color is measured at a wave length of 434 nm. The reason behind the use of the wavelength 254 nm is because it is a standard wavelength for UV analyses (binder) but also aromatics can be analyzed (Uyguner C. a., 2005). By using the wavelength of 436 nm both de-colorization related to the color and the removal amount of humic substances is measured (Uyguner C. a., 2005). Therefore during this study both UV and color were measured at the same time and with the same analysis method. The UV analysis is a fast and non-interfering method which allows analyzes of the contents of a multi component sample (Technologies, 2000-2011). However, in this study the reason behind performing this analysis is to analyze how different types of pollutants are adsorbed at different wavelengths. Thus during this study four pipes were put down in the first GAC filter (that is the GAC filter between the sampling spots L1 and L2) at different depths in order to analyze how the change in adsorption of various types of pollutants changes over the depths of the GAC filter. The four pipe depths were 7 cm, 17 cm, 27 cm and 37 cm.

In order to get result values which were as representative as possible, three analyses for each depth and for each sampling occasion as well as for both of the two wavelengths were carried out. Once all of these three analyzes had been carried out a mean value for each wavelength, each sampling occasion and depth was calculated. Once these mean values for the two different wavelengths were calculated the specific UV adsorption (SUVA) for each date and depth were calculated.

Specific UV adsorption (SUVA) is calculated mainly in order to determine the disinfection by-product (DBT) formation potential. By calculating the SUVA values it is possible to normalize the measured UV wavelength over the overall organic load in the water thus leading to a characterization of the pollutant level in the water. The SUVA calculation is defined as:

$$SUVA = \frac{\text{UV wavelength nm(m}^{-1}\text{)}}{\text{DOC } (\frac{\text{mg}}{\text{L}})}$$

For a wavelength of 254 nm a high SUVA value indicates that most of the organics present in the water are aromatics. The same goes for the wavelength of 436 nm but then a large SUVA value indicates that the majority of the organics present in the water are represented by humic substances instead.

5.1 Sampling locations

Because the pilot plant is performed with four tanks, the two tanks in series will work as one treatment alternative. Thus there will be two treatment options to evaluate, and five sampling locations. The reason was because the columns contained different types of sorption materials and was connected in series of two (as can be seen in Figure 5-1) and therefore it was assumed that different concentration of leachate will be achieved depending on efficiency of the adsorbent used.

The first sampling location was determined to be in the inlet to the first tank of both alternatives since the water has not passed any tank containing any of the sorption material.

The second and the third sampling locations are in the middle pipes between the tanks. At that moment the water has passed through the first tank for both of the alternative treatment options and thereby gets treated to some extent due to the sorption materials that has been used (in this case, activated carbon and peat respectively). The fourth and fifth sample locations will be at the outlets from the last tank in both of the lanes (the adsorbent is activated carbon for both alternatives).

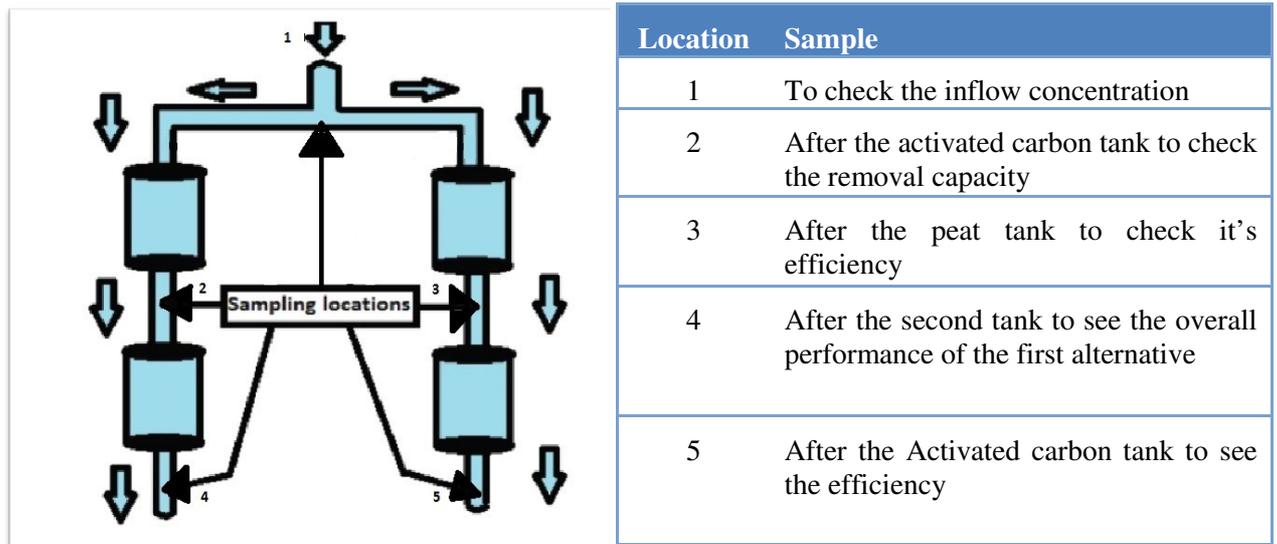


Figure 5-1: A simplified sketch over the pilot plant and the various sampling locations. The arrows indicate the flow direction.

5.2 Frequency of sampling

It was decided to take samples every week for the first two month and then take samples every other week for next 2 month. But due to clogging of the columns and other technical interruptions, it was possible to take sample only the first two week on a regular schedule. After that, the flow was stopped from 10th May to 24th May to backwash and to install the sand filter. After that the regular sampling plan was attempted to follow. More importance was given to the samples taken after the first two columns (L2 and L3) and also on the inflow sample (L1). This is because there might not be anything present after the last two columns in the beginning of the operation phase. This assumption was also validated from analyses results obtained. All the samples were stored on a cool dark room until they were sent for analysis.

5.3 Field measurements

The parameters that were measured during the field measurements are: conductivity, pH, temperature, oxygen level and redox potential. It was assumed that,

- There will be changes in color and TOC/DOC level with sampling locations along the plant
- There will be lower pH after the peat column

6 Results and Discussion

6.1 Removal of Oil products

The leachate from Brudaremossen contains high concentrations of oil and various lengths of petroleum hydrocarbons (PHC) fractions. Even though an oil separator exists after the sedimentation pond, various oil fractions are still present in the leachate. The efficiency of the filters on different dates is presented in the Table 6-1. Detailed results for these dates are added in Appendix IX. For values below the detection limits it was assumed that they were adsorbed efficiently.

Table 6-1: The efficiency of the pilot plant columns in adsorbing oil and PHC fractions

Date	27/04/2011		06/05/2011		26/05/2011			01/06/2011		
	After 1 st GAC	After Peat	After 1 st GAC	After Peat	After SF	After 1 st GAC	After Peat	After SF	After 1 st GAC	After Peat
Oil-index (µg/l)	T	T	T	T	L	T	36.3	30.0	T	51.5
fraction >C10-C12, µg/l	T	T	T	T	L	T	42.4	29.4	T	46.3
fraction >C12-C16, µg/l	T	T	T	T	L	T	35.0	26.4	T	60.8
fraction >C16-C35, µg/l	T	T	T	T	L	T	37.0	31.7	T	48.5
fraction >C35-C40, µg/l	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

*All concentrations are in µg/l level. SF represents sand filter, T represents 100% adsorbed, ND represents-not detected concentrations. L represents Leached.

The samples sent for analyses were the inlet and outlet waters from the first columns of the two combinations.

From the result it can be seen that

- In the first sampling day (27th April), there was no hydrocarbon fractions found in incoming leachate or after the columns.
- On the next sampling occasion (after a week and on 6th May), there was some PHC fractions found in the inlet water, but it was not detected after the carbon or peat column. Thus both peat and carbon adsorbed these fractions efficiently.
- On the third sampling day on 26th May (nine days after the sand filter were installed), it seems as the sand filter is leaching out hydrocarbons. For all PHC fractions, the concentrations are higher after the sand filter than in the incoming water and even higher than the incoming leachates for any other

date. A possible explanation may be that the sand filter has reached its breakthrough within nine days. Thus the accumulated hydrocarbons are leaching out of the filter. The first carbon filter had an adsorbent efficiency of 100% for oil and all PHCs. From the peat column, oil and some of the PHC fractions were still observed in the outgoing water, and the adsorbent efficiency was on an average 75%.

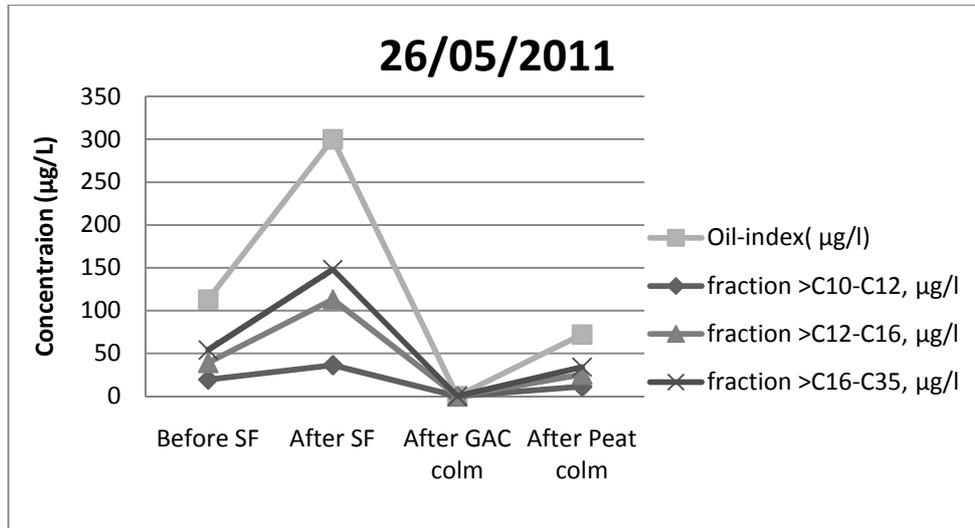


Figure 6-1: Concentration oil and PHC fractions in inlet and outlet water to/from the sand filter and adsorption columns 26/05/2011.

- The sand filter was backwashed with water one day before the sampling day on 1st of June. From the analyses result it can be seen that the sand filter is adsorbing some of the hydrocarbons with an average efficiency of 29%. Similarly to the results of the sampling from 26th May none of the PHC fractions were found in the water after the first carbon column. However, the adsorbent efficiency for oil and PHCs of the peat column was on an average 52%.

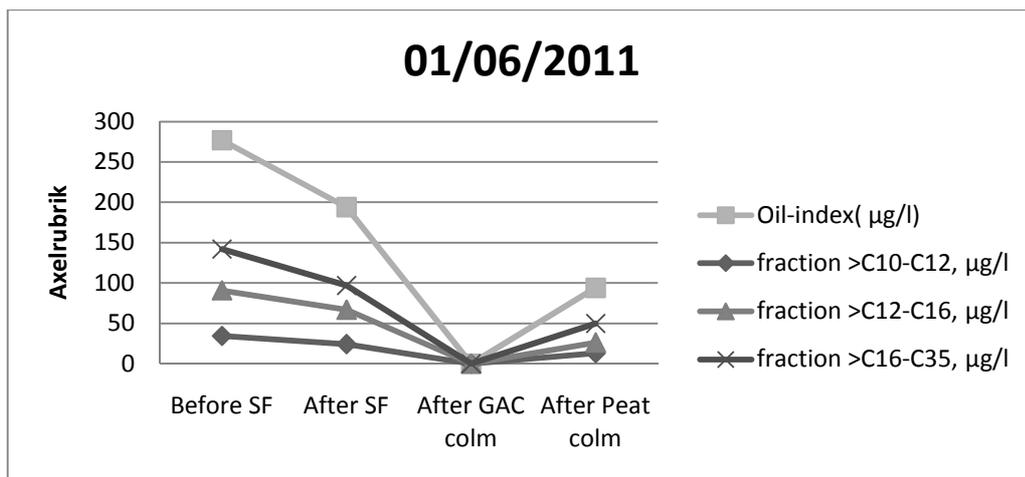


Figure 6-2: Concentration oil and PHC fractions in inlet and outlet water to/from the sand filter and adsorption columns 01/06/2011.

Observing the next one and a half month of performance of the filters, it can be seen that from 1st June till the following month both peat and carbon columns were adsorbing oil and various PHC fractions. Peat was adsorbing from 1st June till 30th July with an efficiency ranging between 52-31%. Carbon adsorbed fractions C₁₀-C₃₅ with 84-100% efficiency. For some reason, on 30th June, the carbon column was leaching out the highest fractions C₃₅-C₄₀. As mentioned before, a possible reason could be that the carbon filter was storing C₃₅-C₄₀ from the previous periods, during which period these fraction was below detection limit. In Figure, 6-3 the concentration changes of oil and PHC fractions on 30th June are presented.

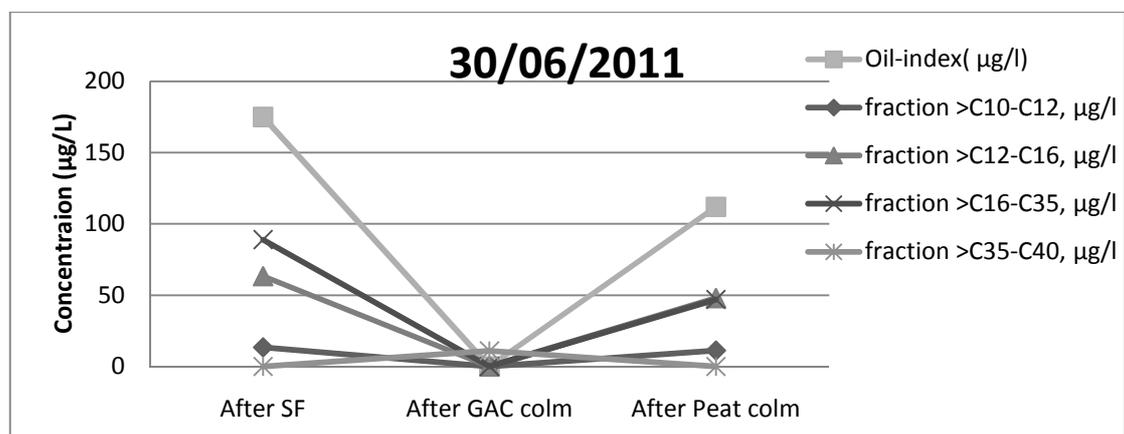


Figure 6-3: Concentration oil and PHC fractions in inlet and outlet water to/from the sand filter and adsorption columns 30/06/2011.

After observing a consistent performance from the carbon filter, it was decided that for the next analyzed sample only the peat effluent were sent for analysis. It was found that the peat filter was leaching C₁₀-C₃₅ fractions on that date. Thus peat might have reached its breakthrough for oil and PHCs after operating for 3.5 month.

Overall it can be concluded that, the carbon columns were adsorbing the hydrocarbon fractions with 100% efficiency for these first four sampling occasions, but the peat column was adsorbing the hydrocarbons in less and varying efficiencies. From Figure 6-3, the variation of adsorbent efficiencies of peat for different fractions of hydrocarbon is presented for the sampling occasions. When the concentration was high in the inflow to the peat column, the adsorbent efficiency increased to 75% and when the incoming concentration is not too high, and the adsorbent efficiency decreases. The performance of the peat column was most efficient on the 26th May and decreases uniformly for the fractions C₁₀-C₁₆. For fraction C₁₆-C₃₅ the adsorption efficiency was better on 16th June. There was no significant variation around these dates. But on 16th June, the sand filter was backwashed with acidic water, which might induce a better performance for the peat filter.

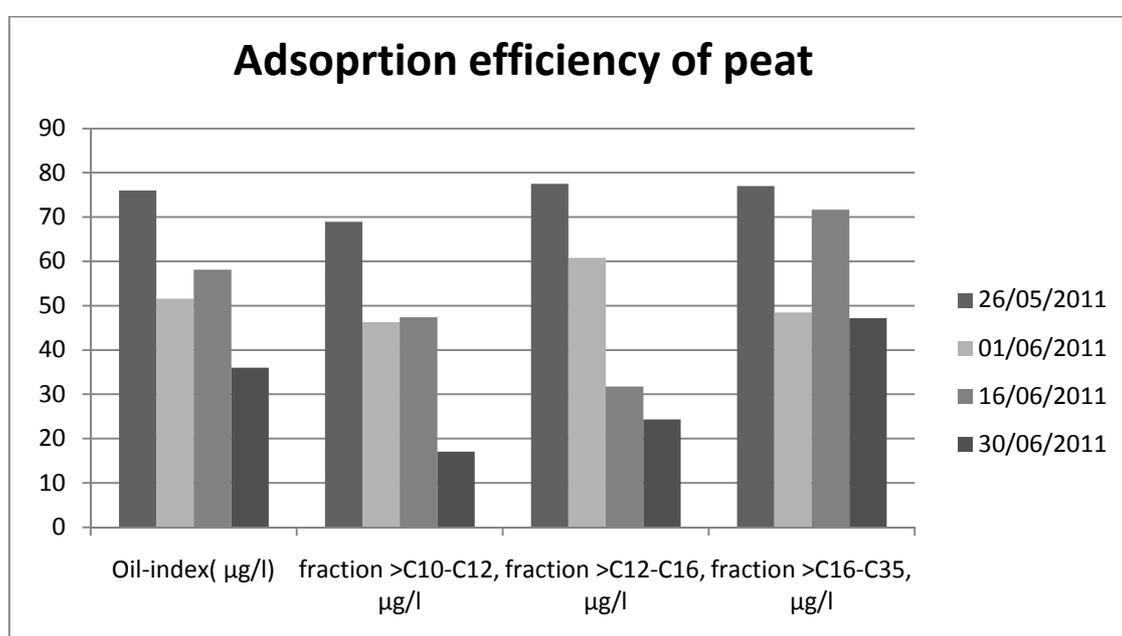


Figure 6-4: Adsorption efficiency of peat for oil and PHCs 26th May to 30th of June.

These phenomena can be explained in two ways. One could be that peat works better for high concentrations of hydrocarbons than lower concentrations. It requires a certain concentration level to adsorb the water efficiently for hydrocarbons. The second explanation could be, since on 26th May, the sand filter was leaching very high concentration of oil fraction in very low flow, the contact time was longer in that sampling day in peat. This resulted in a better removal of oils than 1st of June.

6.2 Removal of PAH

As mentioned before PAHs, alkyl phenols (APs) and phthalates are chosen as pollutant parameter to observe the efficiency of the filters. Only the inlet samples has been analyzed at first in order to check whether pollutants can be detected. The analysis results are presented in Appendix X. The graphical representation of the PAH concentration changes with various dates are presented in Figure 6-5:

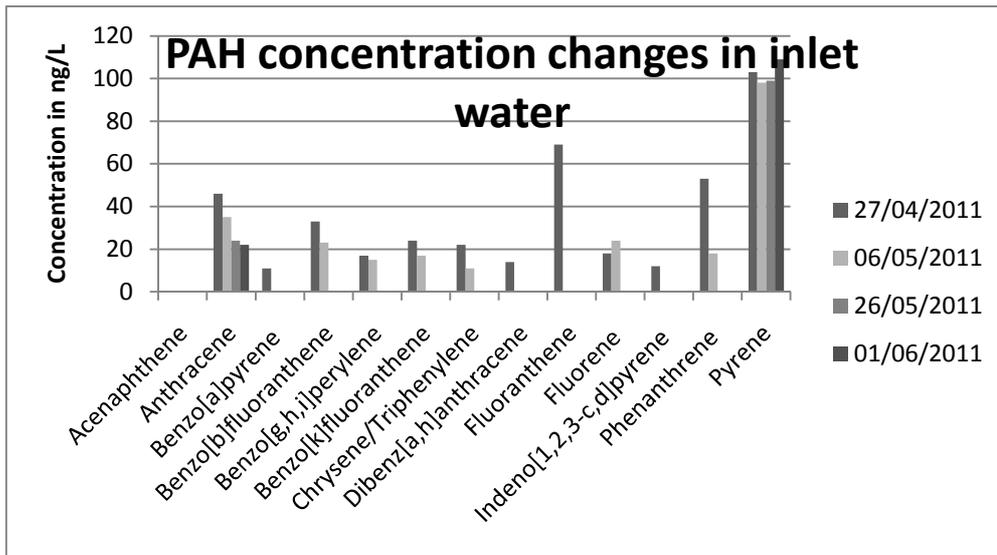


Figure 6-5: Changes in PAH concentrations with time in inlet leachate

It appears that the first sampling date, most of the PAH was found in the inlet water, and specially pyrene was present in all the samples. No other pattern for the PAH concentrations was found. However, after the backwashing of the filters and installation of sand column, high concentrations of acenaphthene and fluoranthene after the sand filter have been detected. This can also be seen from Figure 6-6.

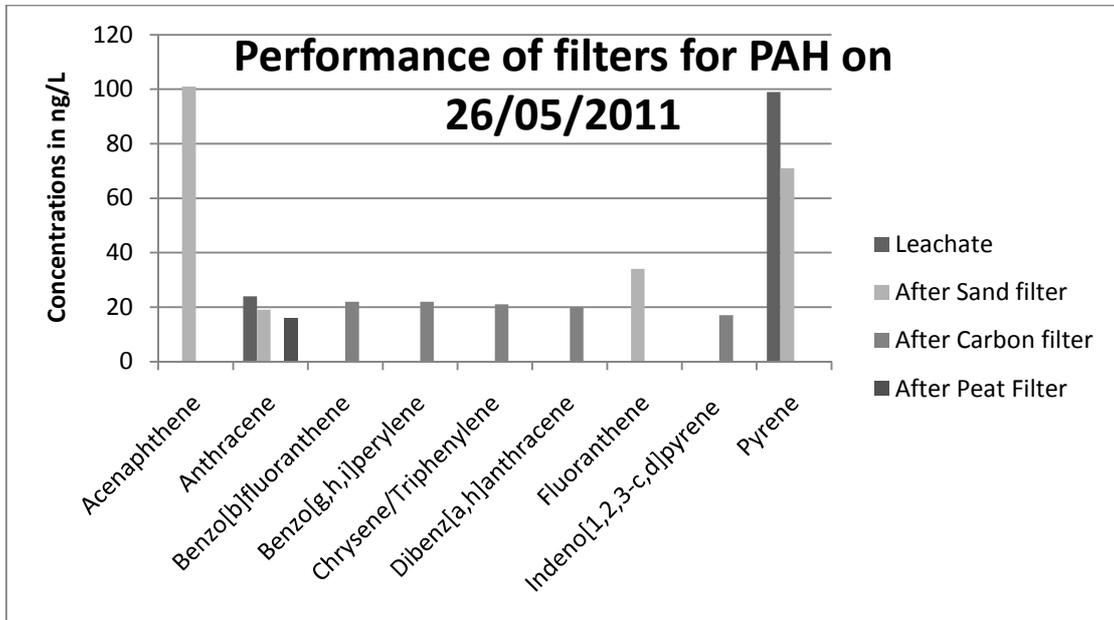


Figure 6-6: Performance of the filters to adsorb PAHs on 26th May

Acenaphthene was not detected in the inlet leachate on the other sampling dates before 26th May. It is probable that the sand filter was accumulating and leaching acenaphthene and fluoranthene when sand reached its breakthrough level for these pollutants. No leaching of acenaphthene and fluoranthene from the sand filter was observed after backwashing on 31st of May, and the removal efficiency was 9% for acenaphthene and 40% for fluoranthene.

From Figure 6-6, it can also be seen that benzo-[b]-fluoranthene, benzo-[g,h,i]-perylene, chrysene, dibenzo-[a,h]-anthracene and indeno-[1,2,3-c,d]-pyrene are leaching from the first carbon column, but not detected after the peat column. Peat is performing better than activated carbon to adsorb all of the PAH's except anthracene. Anthracene seems to be leaching out of the peat column for this specific date.

One month after 26th May, collected samples on 23rd June were analyzed to observe the same pattern. It was observed that both peat and carbon columns were removing all of the PAH below detection limit. Only difference between this date and the date before is the performance of the sand column. On 26th May, a sand filter was installed and was running for sorption of suspended solids and other pollutants. On this date, the sand filter was not backwashed. On the contrary, on 23rd June, the sand filter was backwashed the day before. Also 2 weeks before 26th May, the columns were backwashed with acidic water, and the sand filter was installed after backwashing of the columns. All of these factors somehow allowed a better performance on 23rd June than 26th June. The concentration of the PAH in effluent from the sand filter is shown in Figure 6-7. Overall, the concentration is higher in the influent to the columns on 23rd June than on 26th of May.

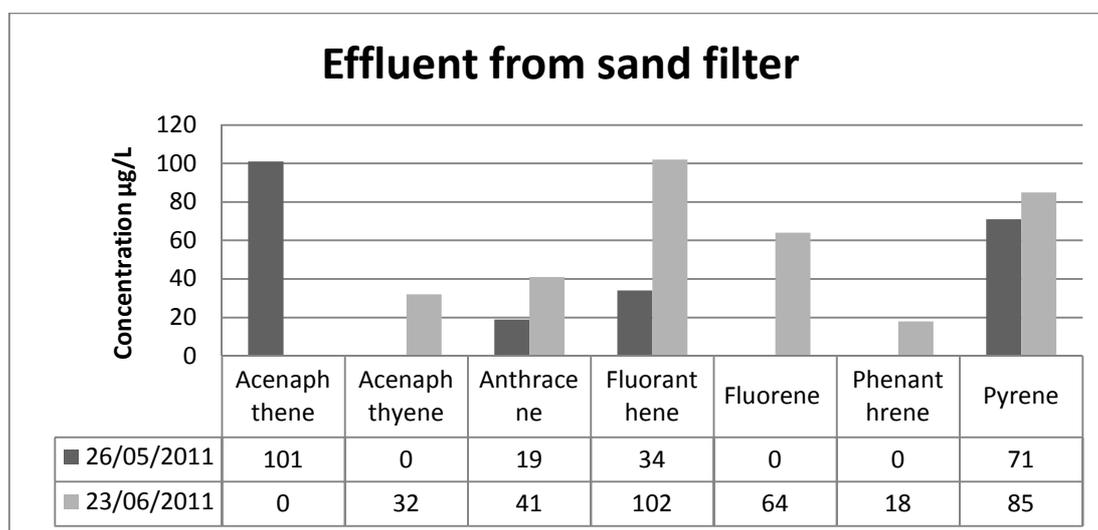


Figure 6-7 : Concentration of PAHs in influent to the adsorption columns on 26th of May and 23rd of June.

Precipitation data from the Swedish Meteorological and Hydrological Institute (SMHI) for those dates are added in Table 6-2 (Swedish Meteorological and Hydrological Institute 2011).

Table 6-2: Precipitation data in Göteborg during the sampling period

Date	Precipitation values (mm) between these dates
26/04/2011	0-1
06/05/2011	0-5
27/05/2011	0-15
01/06/2011	3-20

If the PAHs inlet concentration values are compared with the precipitation data, it can be seen that, when the precipitation is 20 mm around date 01st June, the PAH concentration increased in leachate. This is reasonable, since higher precipitation on the area will indicate that more pollutants will be washed out with the precipitated water and thus will increase in the inlet concentration.

6.3 Removal of alkylphenols and alkylphenoethoxylate

The results obtained from the alkylphenols (APs) and alkylphenoethoxylates (APEOs) analyses are presented in Appendix XI. There is a distinct presence of APs in the inlet leachate for all analyzed sampling dates. The 4-t-octylphenolmonoethoxylate (OP-EO1) and iso-nonylphenolmonoethoxylate (NP-EO1) are present above detection limit in almost all the analyzed samples. The sand filter leached out some 4-t-Octylphenoldiethoxylate (OP-EO2) and (NP-EO1) both 26th may and 1st of June and some of APs as 4-tert-Octylphenol (OP), iso-Nonylphenol (NP), 4-tert-Butylphenol (BP) and 4-tert-Pentylphenol (PP) on 1st June. It should be noted that 26th may was the first day of running of the sand filter, and 1st June is one day after backwashing of the sand filter. Backwashing did not alter the concentrations of the three APEOs after the sand filter. Thus the sand filter might have reached its breakthrough point for these APEOs and leached the stored pollutants. Backwashing with only water did not make any difference in the case of APEOs. In Figure 6-8, the changes in APEOs can be seen.

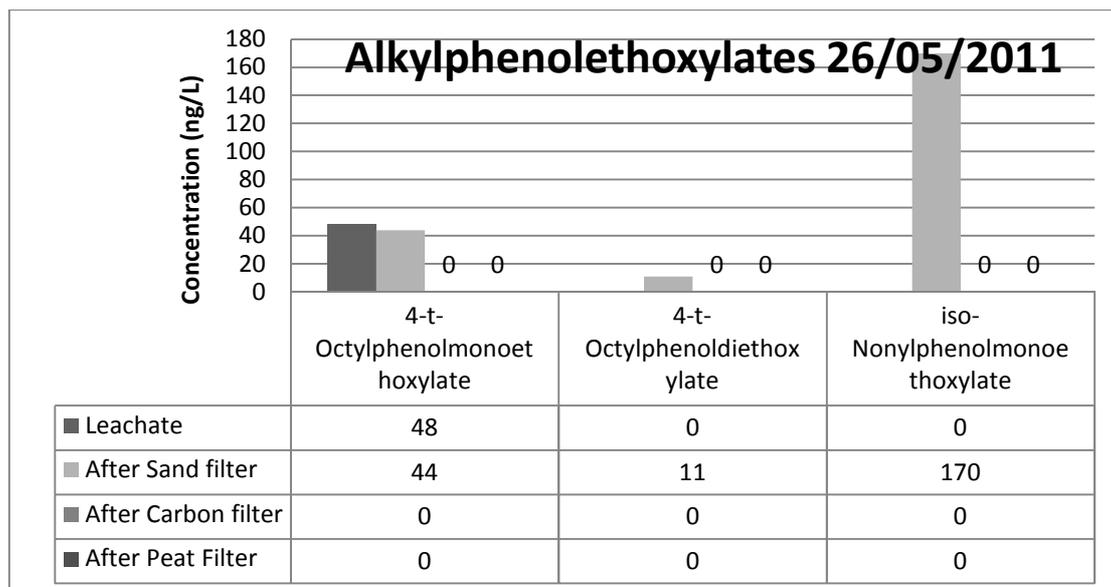


Figure 6-8: Concentrations of some selected APEOs in the leachates and after the filters at 26th May

From Figure 6-10, it can be seen that the first GAC columns removed all of the APs below detection limit, but peat does not remove out 4-tert-OP, 4-tert-BP and 4-tert-PP. In case 4-tert-BP, the concentration is even higher than the influent concentration to that column. Thus there is a possibility that peat might have reached its breakthrough point for 4-tert-BP and thus release this AP.

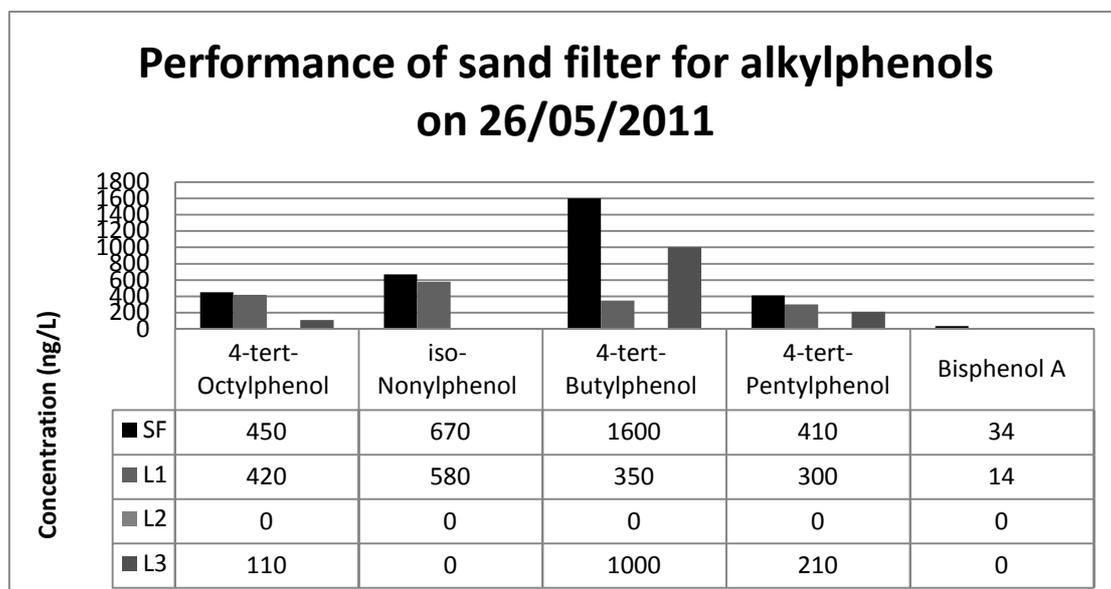


Figure 6-9: Changes in concentrations after the first columns (SF=leachate, L1= after sand filter, L2=after first carbon filter, L3=after peat filter)

For APs, from Appendix XII, it can be seen that they were adsorbed efficiently on 26th May, but after backwashing the sand filter on 31st of May, the concentration was higher after the sand filter. Backwashing might have desorbed these pollutants from the sand particles and they are then leached on 1st June after backwashing. In Figure 6-9, the changes in concentration before and after the sand filter for 1st June are presented.

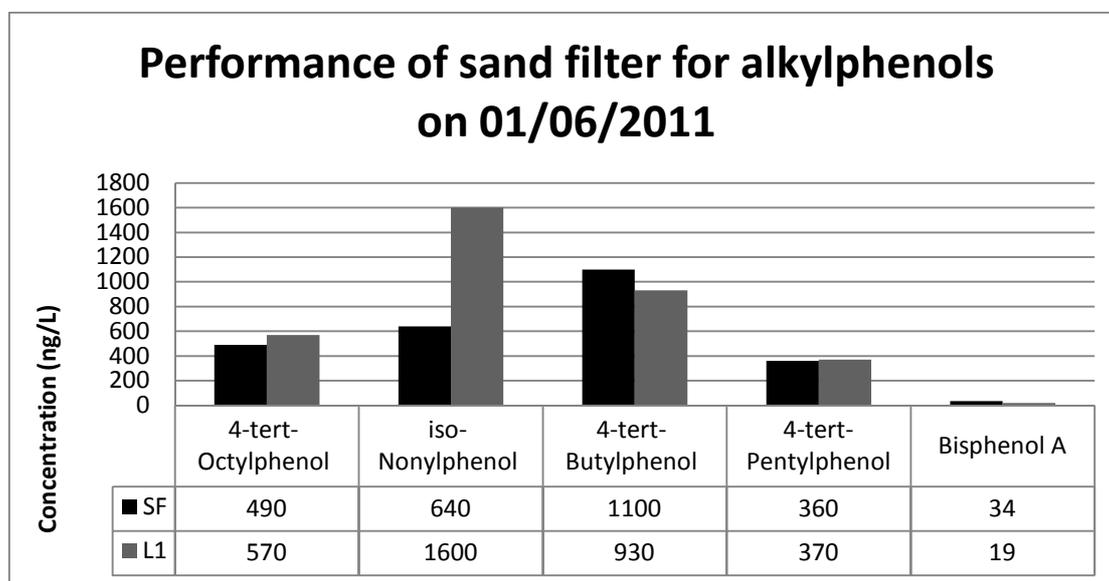


Figure 6-10: Changes in alkylphenol concentrations on 1st June along the filters (SF=leachate, L1= after sand filter)

On 23rd June, none of the APEOs were found after the columns. In the case of APs, it was observed that both the peat and carbon filters reduced APs very efficiently. Detailed results are added in Appendix XII.

6.4 Removal of phthalates

The results of phthalates are added in Appendix XII. Almost all specific phthalates (except Di-n-octyl phthalate, DOP) are present in the inlet samples for the first two sampling dates. After that, on the third sampling day (26th May) the concentration in the inlet seems to decrease below the detection limit. On that day, the sand filter was almost clogged and the flow to the filters was low. These concentration changes are presented in Figure 6-11. On the fourth sampling day on 1st of June only Di-2-ethylhexyl phthalate (DEHP) was found in the inlet water. Compared with the rainfall data along these dates shows that elevated rainfall occurred around 26th May and 1st of June. Thus higher precipitation might dilute the concentration of phthalates below the detection limit.

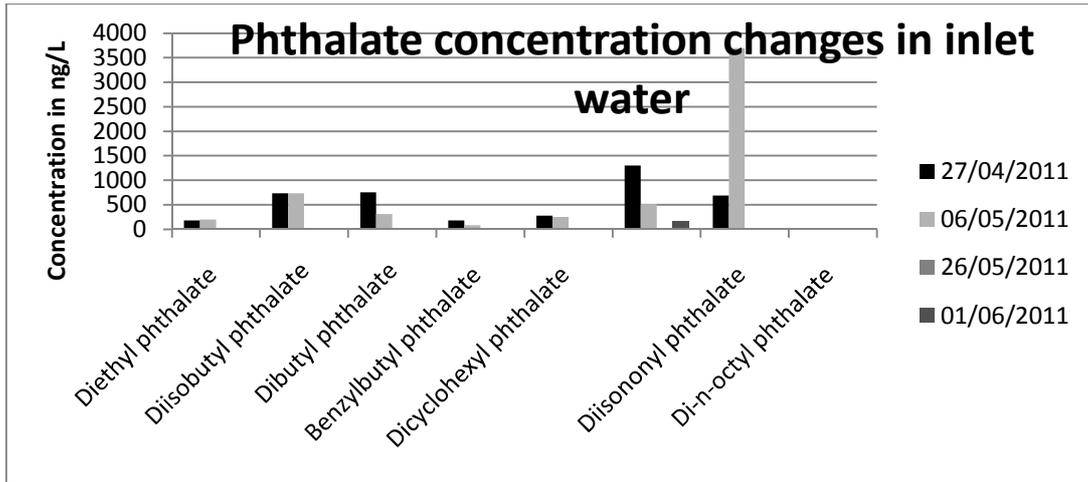


Figure 6-11: The changes in inlet concentrations for Phthalates

When observing the changes in concentration of phthalates in Figure 6-12, it can be seen that, none of the Phthalates were found in samples before and after sand filter and after peat filter. But di-isobutyl phthalate (DIBP), Di-2-ethylhexyl phthalate (DEHP), di-isononyl phthalate (DINP) are leaching from the carbon filter on this date. Thus it can be concluded that peat performs better to adsorb Phthalates for 26th May than carbon.

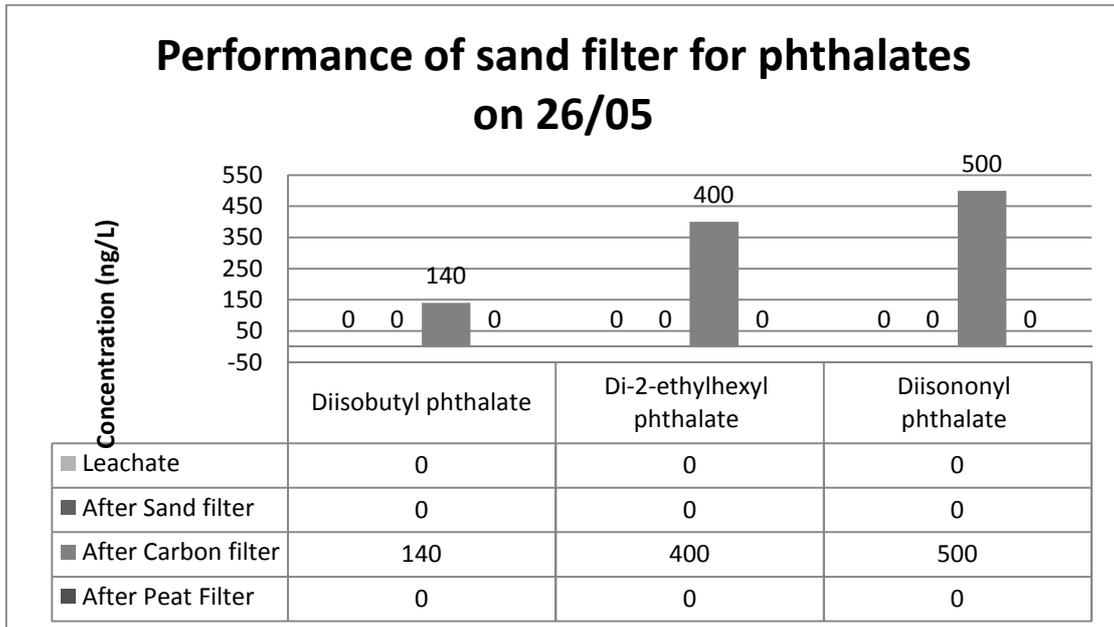


Figure 6-12: Concentrations of selected phthalates in leachates and after the first filters on 26th May.

To observe the performance on 23rd June, it can be seen that the phthalates are adsorbed efficiently by both columns except for DINP, which was released from both columns on this date.

6.5 Removal of oxy-PAH

Analyses result obtained from oxy-PAH analyses are added in Appendix XIII, and 9-fluorenon, 9,10-antrakinon, 2-metylantracen-9,10-dion and 4H-cyklopenta(def)fenantrenon are found in the leachate in various dates. Because the concentration of PAHs decreases after the sand filter, it is reasonable that the concentration of oxy-PAH increases as well as oxy-PAH may form from the degradation of PAHs in nature or might be exhausted from the same source as PAHs (Mackay, 1992; Johnston, 1993; Wild, 1995). The oxy-PAH 9-fluorenon is an oxidation by-product of fluorene (Cerniglia, 1997); 9, 10- antrakinon is biodegradation of anthracene (Cerniglia, 1997). The oxy-PAHs 2-metylantraceneb 9,10-dion and 4-H cyklopenta (def) fenantrenon are produced from phenanthrene (Lundstedt, 2007).

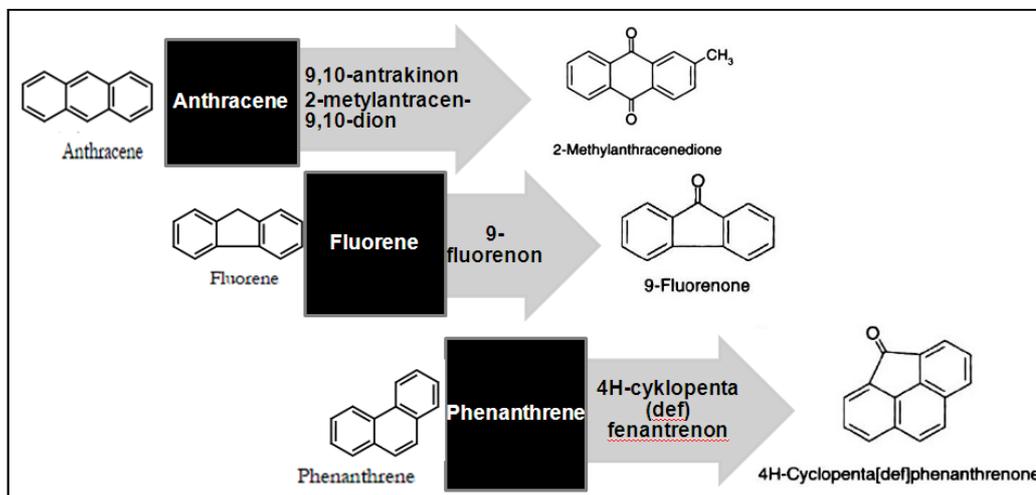


Figure 6-13: Source PAH and degradation oxy-PAH

On 26th of May, the leachate from the landfill had 9-fluorenon, 9, 10-antrakinon, 2-metylantracen 9, 10-dion and 4H- cyklopenta (def) fenantrenon in very low concentration. But after the sand filter, it seems that the concentration of these oxy-PAH increased. This pattern is also visible on 1st of June as shown in figure 6-15.

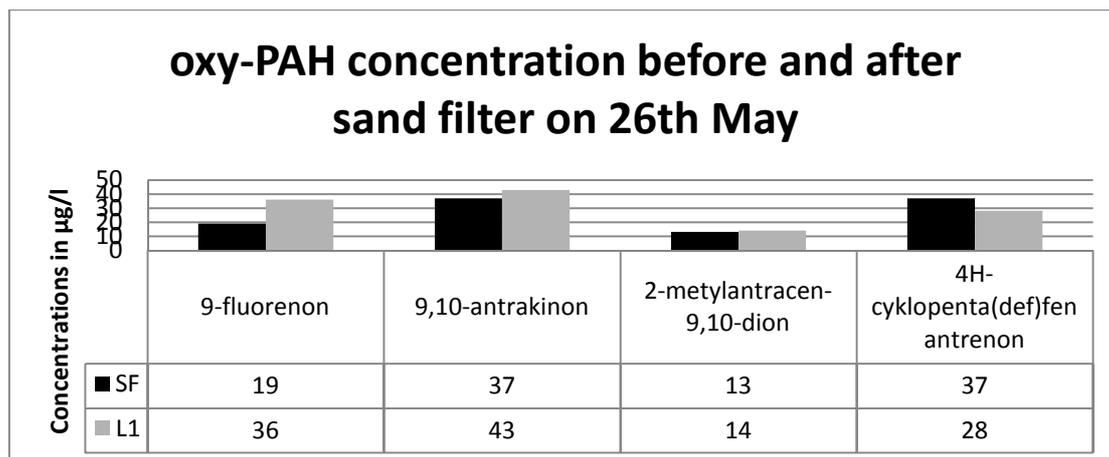


Figure 6-14: Changes in oxy-PAH concentrations on 26th May along the filters

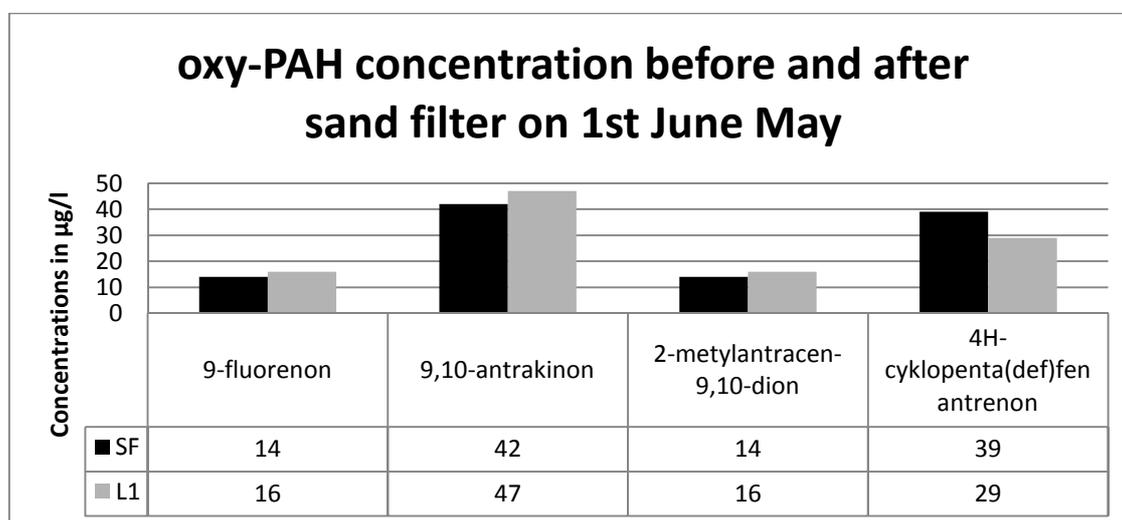


Figure 6-15: Changes in oxy-PAH concentrations on 1st June along the filters

It can be concluded that either the sand filter has reached its breakthrough point for these oxy-PAH or they are degraded by parent PAH inside the sand filter and increased in concentration after the sand filter.

6.5.1 Correlation between PAHs and oxy-PAHs

As mentioned earlier, there is a distinct presence of oxy-PAHs at sites where PAHs is found in nature. Oxy-PAHs might be considered even more harmful and toxic than PAHs because they are the degraded or converted fraction of PAHs. Oxy-PAH's widespread abundance in nature proves that they are more persistent than PAHs. They are more polar and more water soluble than the PAHs, making them mobile in soil with increasing risk to enter ground-water and the environment. In Table 6-3, the consecutive concentration of PAH and oxy-PAH are presented. It can be seen, for all the dates, oxy-PAH concentration is much lower than the parent PAH. There is

pattern found in oxy-PAH: 2-metylantracen-9,10-dion has a lower concentration than 9,10-antrakinon which might be an indication that anthracene is more easily converted to 9,10-antrakinon than to 2-metylantracen-9,-10-dion. In case of, 4H-cyklopenta (def)-fenantrenon, the concentration is low compared to the parent PAH–phenanthrene for the first two sampling date in the inlet. After wards, there is no phenanthrene found on the influent and effluent from the sand filter, but still the 4H-cyklopenta (def) fenantrenon is quite high. Thus the possible explanation could be that phenanthrene is converted to 4H-cyklopenta-(def)-fenantrenon in the sand column and thus their concentration increases after the columns.

Table 6-3: Concentration of PAH and oxy-PAH

Date		27/04	06/05	26/05		01/06	
Location		L1	L1	SF	L1	SF	L1
PAH (µg/L)	Anthracene	46	35	24	19	22	20
	Fluorene	18	24	<10	<10	<0.1	<10
	Phenanthrene	53	18	<10	<10	<10	<10
Oxy-PAH (µg/L)	9,10-antrakinon	0.59	0.51	0.42	0.47	0.37	0.43
	9-fluorenon	0.47	0.44	0.14	0.16	0.19	0.36
	4H-cyklopenta(def)fenantrenon	0.35	0.10	0.39	0.29	0.37	0.28
	2-metylantracen-9,10-dion	<0.1	0.20	0.14	0.16	0.13	0.14

The correlation between PAH and oxy-PAH, is presented in Table 6-4. This correlation is obtained between oxy-PAH and corresponding PAH for the first four sampling date and for the available concentrations. It can be seen that

- Anthracene and 2-metylantracen-9,10-dion;
- Phenanthrene and 4H-cyklopenta(def)fenantrenon;
- Anthracene and 9,10-antrakinon

They all have a strong positive correlation between concentrations for these samples. This implies, as these PAH concentration increases, the consecutive oxy-PAH concentration also increases. For fluorene and 9-fluorenoneurene has strong negative correlation. Thus fluorene’s concentrations changes have opposite effect on the oxy-PAH concentration.

Table 6-4: Correlation in PAH and oxy-PAH concentration changes along the plant

Correlating elements	Correlation
Fluorene and 9-Fluorenoneurene	-1
Anthracene and 2-metylantracen-9,10-dion	0.81
Phenanthrene and 4H-cyklopenta(def)fenantrenon	1
Anthracene and 9,10-antrakinon	0.86

6.6 Removal of metals

Leachate samples from the site for the first six sampling occasion were analyzed by ICP-MS which stands for Inductively Coupled Plasma Mass Spectrometry (Science) to observe the trend in metal removal by the columns. Cu, Ni, Al, Cr, Zn, Cd, Pb are mentioned here to monitor the sorbent efficiency and trends in sorbent within columns to sorb these heavy metals.

From the ICP-MS analysis result, it can be seen that the first alternative of GAC and GAC columns in series, the sorbent of these metals do not show any consistent pattern in their sorbent efficiency. Overall the average sorbent efficiency of all three GAC columns is in the following order: Cu>Al>Pb>Cr>Ni and they leach out Zn and Cd. These efficiency results are added in Figure 6-16. Detailed result of metals concentrations are added in Appendix XIV.

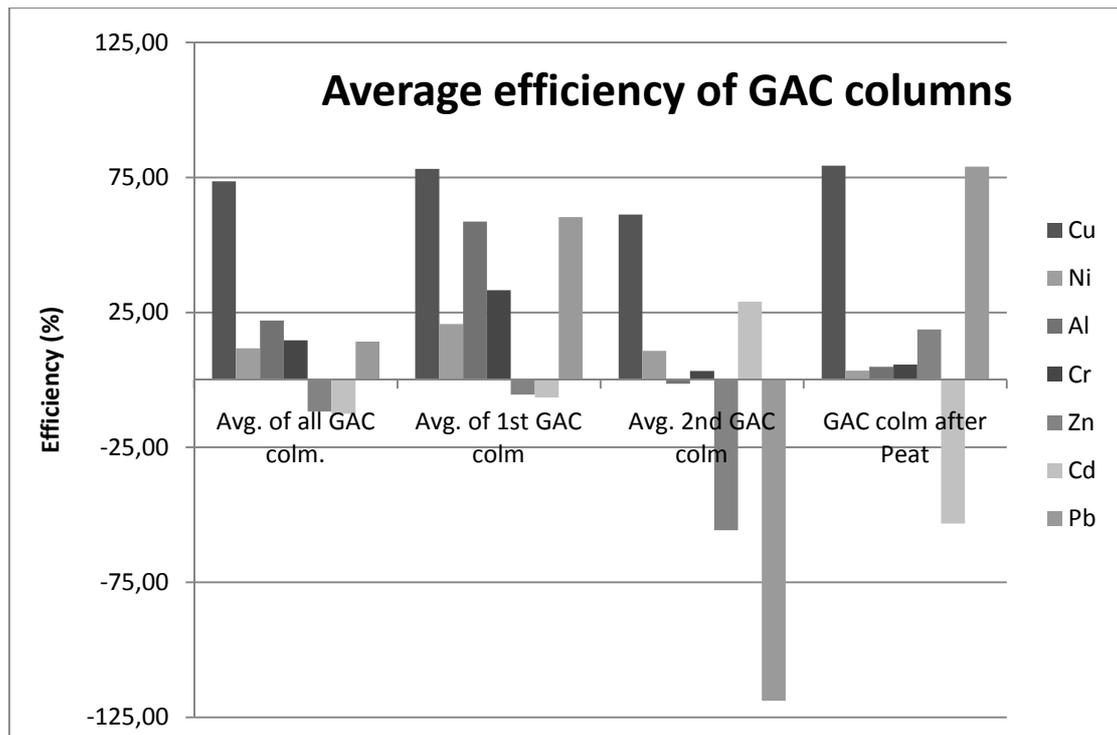


Figure 6-16: Average efficiencies of GAC columns

Overall this result seems quite convincing. But when looking at each of the columns separately it is noticed that, they have wide variations in their efficiencies and thus the average value has quite high standard deviations. The first alternatives GAC column sorbs these metals in the following order: Cu>Pb>Al>Cr, but their average results have high standard deviations, and the performance is not consistent over time. For example, Cu has a consistent removal for the first two sampling date which was around 92%. Also Al are sorbed well but other metals like Ni, Cr, Zn, Cd and Pd are sorbed in a moderate manner for the first two sampling dates.

The second GAC column sorbs in the order of: Cu>Cd>Ni>Cr and leaches out Pb and Zn in quite high concentration, and the column after peat sorbs metals in following order: Cu>Pb>Zn>Cr>Al>Ni and leaches out Cd in high concentrations. Overall it can be seen that, GAC removes Cu very well, Ni and Cr to some extent, but for Zn, Pb, Cd and Al removal do not show any regular pattern.

After the sand filter was installed, the first GAC column shows lower removal efficiencies for Al, Cr, and Cd. But the efficiency for Cu, Ni and Pb removal increased much after the sand filter installation. Some possible explanations could be:

The sand filter was leaching Cu, Ni, Zn, Cr and Pb in five out of six sampling times in high concentrations. These metals might be constituents of the sand that is used in the sand filter and thus gets leached after the filter. Another explanation could be that, the sand filter needed some time in the same way as the activated carbon filters before it

could start working efficiently once it had been installed. This theory was proven to be correct which can be seen in the 1st June since the sand filter removes large quantities of the various metals compared to what is entering the various columns. A solution to this repeatable scenario might be that the sand filter accumulates large quantities of the various metals up to a specific level before it releases these high concentrations into the columns but at the same time it appears rather strange since the sand filter is backwashed once in a week which should prevent the built up of these various concentrations. However, several studies have been carried out regarding sand filters and their treatment capacity to adsorb various types of heavy metals and the treatment capacity of sand filters is commonly attributed to the action of biological layer within the sand filter which in turn greatly improves the microbiological quality (Biosandfilter.org, 2004). Thus it can be assumed that the action of the biological layer in the sand filter used throughout this study was not great enough and thus these various metals were leached out.

Another observation from the result is that, the sand filter always reduces the concentrations of iron and aluminum and never reduces the concentrations of copper. A probable reason to this might be that the copper is dissolved in the leachate and thus just passes by the various fractions of sand and gravel while the iron and aluminum are sorbed to the sand/gravel. The elevated concentration of Cu, Ni and Pb after the sand filter can be sorbed by GAC columns but not the Cd and Cr. Figure 6-16, shows the efficiency of metal removal before and after the sand filter for the first GAC column in first alternative.

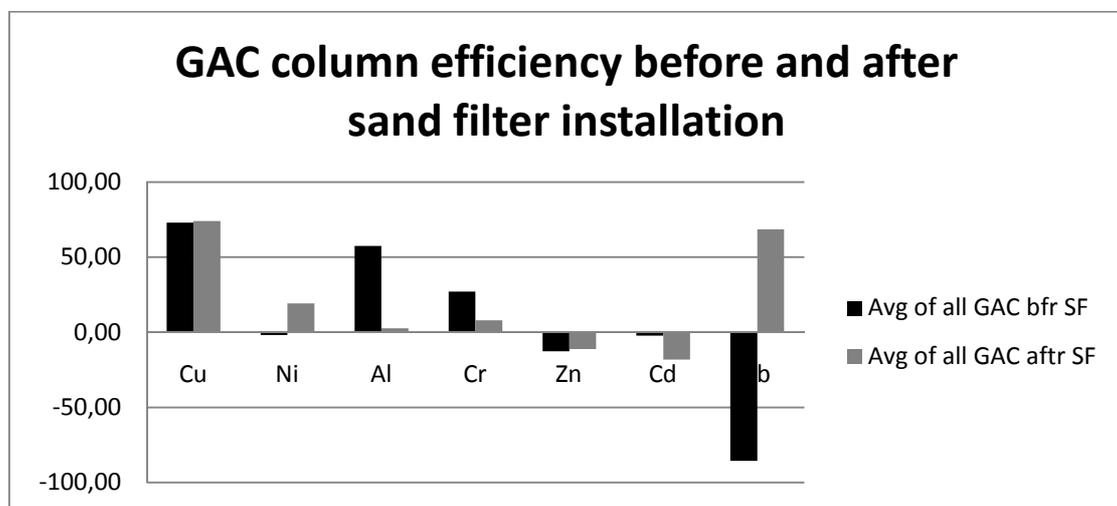


Figure 6-17: Efficiency of GAC columns before and after the sand filter installation

When comparing the GAC column with peat column in reducing the metal concentration in leachate, it can be seen that the first GAC column sorbs Cu, Ni, Al, Cr, and Pb more effectively than peat column. In Figure 6-17, it can be seen that the peat has reduced metal to a level that allows the consequent GAC filter to perform better. Only Cd is leached out in final effluent for the peat alternative whereas for

GAC alternative, Zn and Pb are leached in high concentration. Thus the peat alternative might be a good option for sorbent of metals from the leachate.

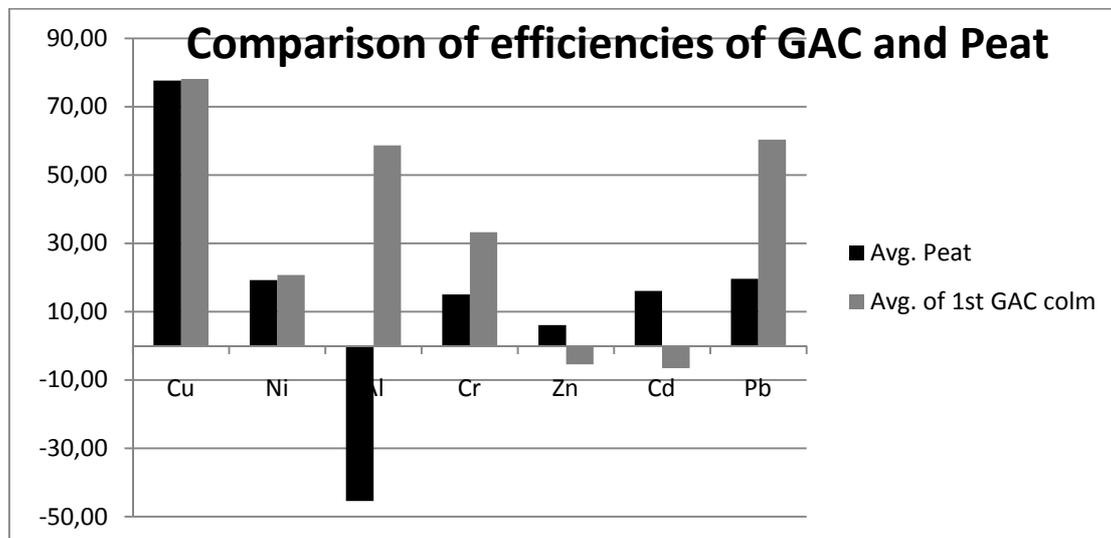


Figure 6-18: Comparison of removal efficiencies of metal for GAC and Peat columns.

6.7 Removal of TOC and DOC

From Table 6-5 it can clearly be seen that the concentrations before the inlet to both of the column series, is higher compared to the concentrations after these two first columns filters. The only exception is the DOC concentrations for the peat filter which shows that in three of the cases the concentrations are higher before the filter and in three of the other cases the concentrations are lower before the filter.

The two next following filters after the two first filters are GAC filters. It can be seen that at almost all of the sampling dates the concentrations decreases after the GAC alternative while for the peat alternative the concentrations does not decrease that much. After that the sand filter has been installed it can be seen that the inlet to the sand filter contains less concentrations compared to after the sand filter.

A theory to this strange phenomenon might be that the sand filter accumulates concentrations up to a certain level and then releases this high load into the columns. This indicates that GAC removes both DOC and TOC quite efficiently while the peat filter manages to remove/decrease some of it. GAC manage to remove quite a lot of the DOC concentrations indicates that GAC might be an efficient sorption material when it comes to the removal of DOC (Velten, 2007). The fact that peat is not efficient in removing DOC has been described (Worrall, 2007). The release of carbon from peat is often considered to be largely controlled by water table depth and aerobic decomposition of peat which then produces CO₂ and DOC.

Since it was more interesting to see the differences between peat and granular activated carbon (GAC) in removal of DOC/TOC, the peat and the first GAC filters in series 1 and series 2 were considered. The results can be found in Table 6-5.

Table 6-5: A description of the various sampling dates the reduction/increase in DOC/TOC concentrations for the peat / GAC filters.

Date	DOC reduction/ increase % peat. alternative 2	DOC reduction/ increase % GAC 1st. alternative	TOC reduction/ increase % peat. alternative 2	TOC reduction/ increase % GAC 1st. alternative
27-apr	+17	-84.6	Not analyzed	Not analyzed
06-maj	+7900	+69.6	+22.7	-100
26-maj	-27.6	-94.5	-16.6	-100
01-jun	+8	-93	-9	Data error N/A
09-jun	-2	-100	-23.5	Data error N/A
16-jun	-10	-98.4	-4.7	-98.8
Negative values or ('-') values indicates that the concentration decreases after the filter. Positive values or ('+') values indicates that the concentration increases				

By then comparing the removal efficiency of DOC for GAC and peat it can be seen that peat removes DOC concentrations in a range from 2 – 28 % for some sampling dates. The DOC concentrations also increase after the peat filter for some of the sampling dates. The range then goes from 8% up to 7900%. This great increase indicates that an error has occurred during sampling or analysis and some organic matter has ended up in the sample during the sample analysis and thus contributed to this severe increase in that sample. Another reason might be that there has been some internal error within the analysis machine at the lab. The increase after the peat filter might be due to that the filter accumulates DOC concentrations up to a specific level and then these levels are being released.

The DOC and TOC concentration after the GAC column and TOC for the peat column reduces for 5 out of 6 sampling occasions. The only time these concentrations increases are on 6th May. At this time, some error might have happened during sampling and some external organic matter would have entered all three of these samples at the sampling occasion and thus causing an increase in concentrations. Another probable reason might be that at that sampling date it had recently rained and before the rain event, a longer dry period had occurred. This would result in the “first flush effect” which leads to these high concentrations of organic matter in the inflows

to the two first filters (IRC, 2006). This results in high concentrations for the filters to deal with due to low retention time for the pollutants.

For the TOC in the 1st GAC filter all too almost all the TOC concentrations at the various sampling dates are removed. There are three occasions where no data were obtained.

Overall it can be seen from Table 6-5 that the GAC filter is better at removing DOC compared to the peat filter. When it comes to the reduction/removal of TOC, it can be seen that both of the two sorption materials are quite efficient in reducing/removing concentrations of TOC even though the GAC filter is clearly better.

6.8 Removal of Total Nitrogen (TN)

From the TN analysis, it can be seen that, four out of six sampling occasion, the peat alternative works with better efficiency in removing TN from the leachate. The variations in TN concentrations are presented in Figure 6-19 to 6-21. From various dates these three dates are chosen. It can be seen that on 27th April and 26th May, the peat alternative was reducing TN with better efficiency.

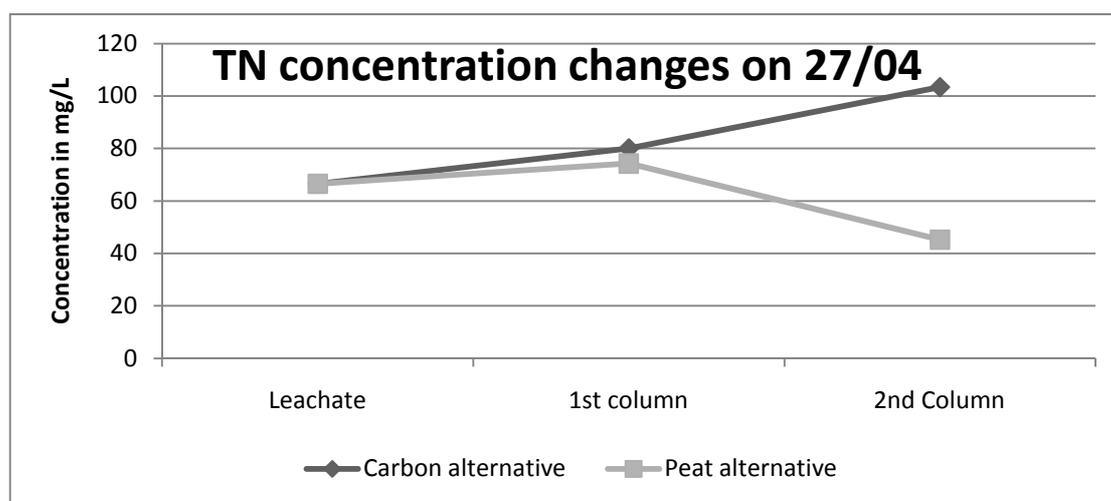


Figure 6-19: Concentration changes of total N in the peat+GAC and GAC+GAC filter combinations on 27th April

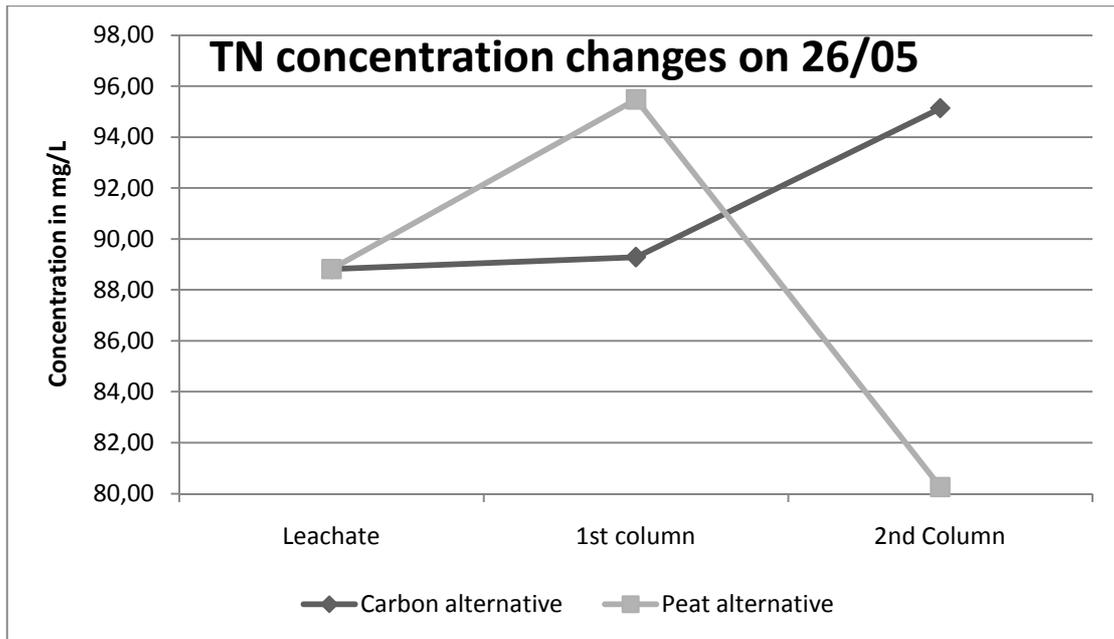


Figure 6-20: Concentration changes of total N in the peat+GAC and GAC+GAC filter combinations on 26th May

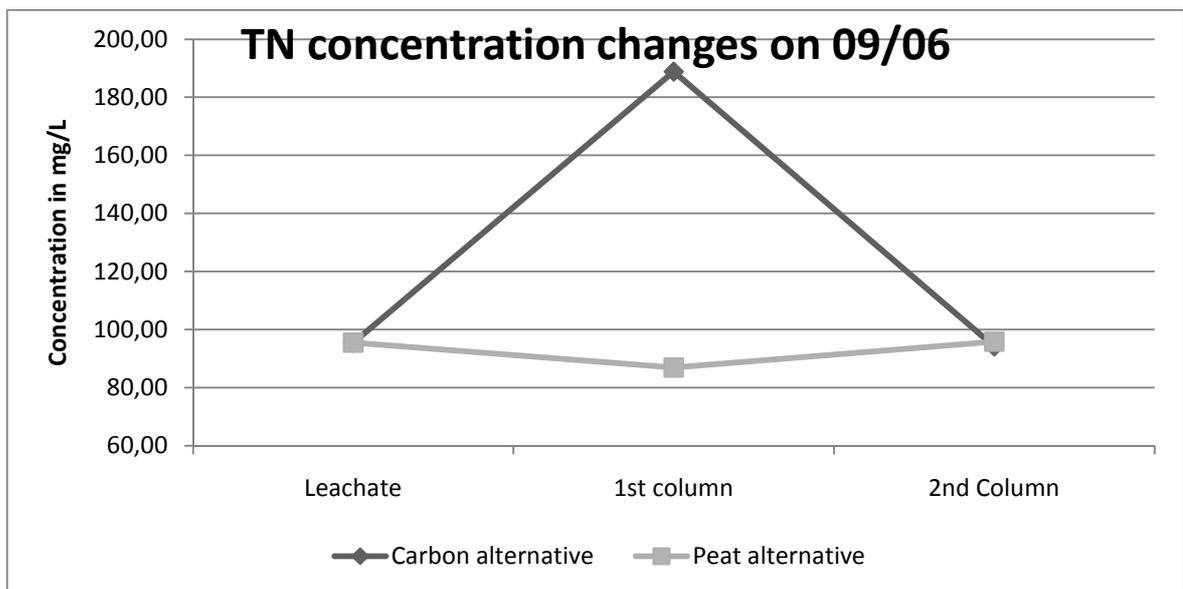


Figure 6-21: Concentration changes of total N in the peat+GAC and GAC+GAC filter combinations on 9th June

From Figure 6-20, it can be seen that on 9th of June, the first GAC column was emitting a high concentration of TN. From Table 4-1, it can be observed that before this date the sand filter was backwashed and maybe this is the reason for high concentration of TN emission from first GAC column. The TN analysis results are

added in Appendix XIX. Thus this plant using filtration technique in peat media will be able to remove TN.

6.9 Results from the beaker test

The highest removal was obtained by addition of limestone (CaCO_3) powder and about 82%. The second highest removal was obtained in beaker 3 (by only aeration in raw leachate) which was 81%. The color of the water was the clearest in beaker 1. As only iron was tested in solution, it might be possible that other metals are also removed by through absorption which resulted in a clearer solution. Figure 6-22, shows the distinct nature of the leachate after each alternative test.

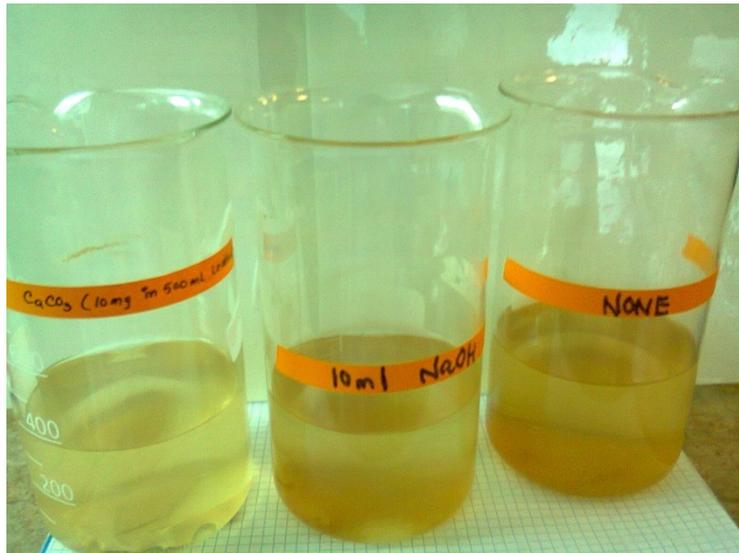


Figure 6-22: Observation of sedimentation after the Beaker test

The overall changes in total iron concentration can be presented by the following graph:

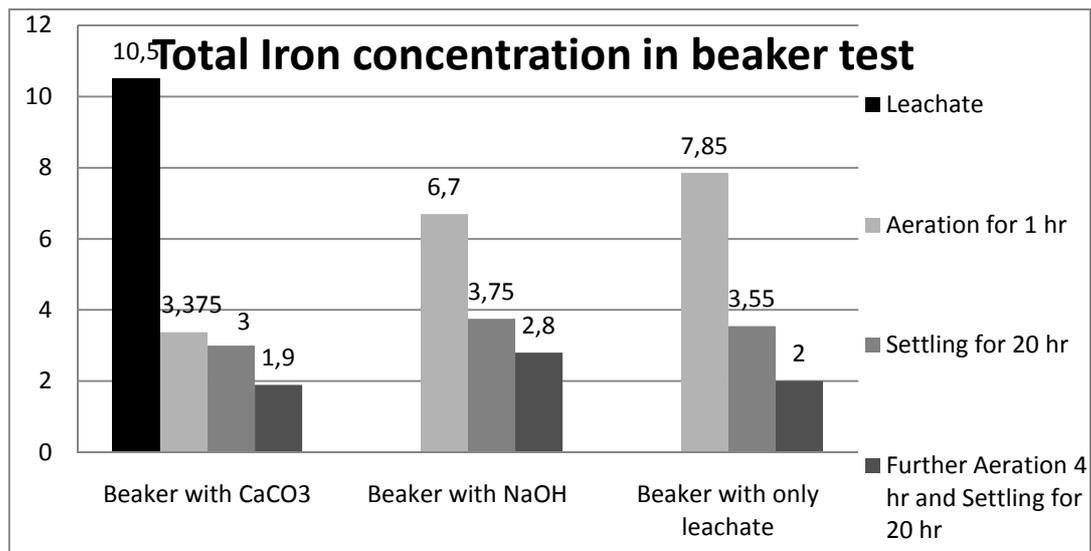


Figure 6-23 Experimental result of removal of iron by beaker test

Thus aeration is a possible pre-treatment solution for the pilot plant to reduce pollutant load. Since simple aeration reduces total iron quite as much as the beaker with CaCO_3 , only aerating the leachate from the pond in a container could reduce pollutant load to the pilot plant.

6.10 Results from the Column test

This laboratory test was done as an assessment step before constructing a sand filter on site. The changes in concentration of total iron after the sand column on the first day of experiment can be seen on Figure 6-24. The average removal efficiency was 96% on the first day. During the second day, after the leachate condition was supposed to be uniform the efficiency was around 87%, and after 5th day of running the column the efficiency was around 90%.

Overall it showed very good result in case of sorbing iron from leachate water. Also the water coming out of the sand column had fewer colors, suggesting a decrease in TOC level also. The results are added in Appendix XVII. It can be seen from the table that the removal efficiencies for TOC and Total Nitrogen (TN) vary widely in two different dates. Also the removal efficiency for isolated test on same day has wide variations. For TOC the efficiency values ranges from 9-55% and for TN it is between 20-60%. Overall, it is observed that TN removal efficiency is higher than TOC in three out of four tests.

From the ICP-MS analysis done on the inflow and outflow water from the sand column, it can be seen that, the sand column does not sorb aluminium (Al) at all. Somehow the sand column even leaches out Al. For Na, Mg, K, Cu, Li, Cr, Co, Pb, and Mo the sorbent efficiencies range from 5-25%, and Ba and Ni, were removed moderately well. The sand filter works the best in the order of degree for following metals: $\text{Mn} > \text{Fe} > \text{Zn} > \text{Ca} > \text{Cd} > \text{Ba} > \text{Ni}$. Thus the results obtained from the sand column shows that, the sand column has the ability to sorb some of the metals quite well and somehow it leaches out Al. Thus, adding a sand filter for the main pilot plant as a pre-treatment step will assist the activated carbon and peat filter to perform well.

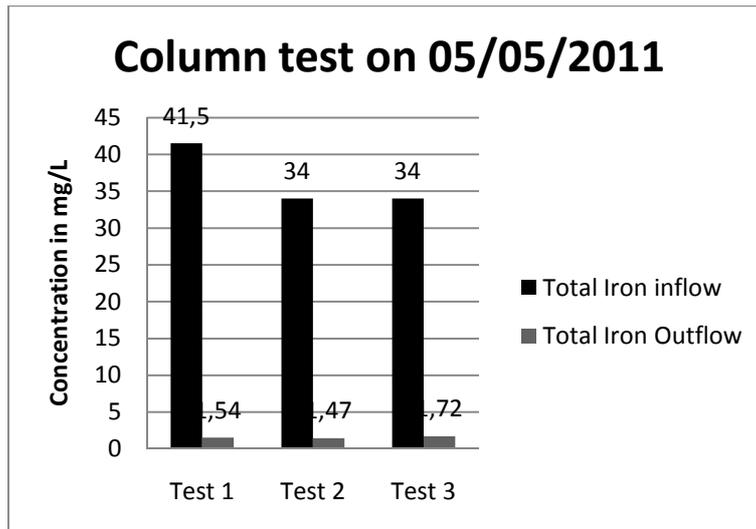


Figure 6-24: Changes in total iron concentration during the first day of running the sand column

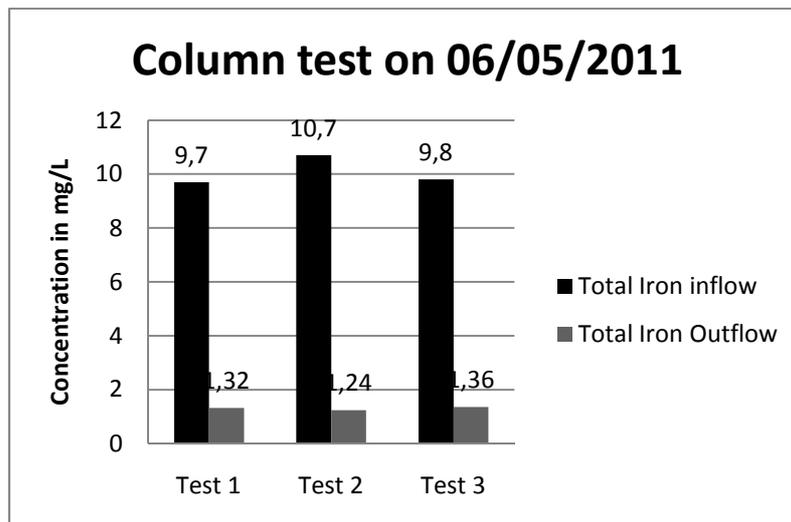


Figure 6-25: Changes in total iron concentration during the second day of running the sand column

Some inflow and out flow samples were analyzed by ICP-MS for metals and also TOC test was done on it. The results are shown in Appendix XVII.

6.11 UV analysis results

From Table 6-6, it can be seen that for the SUVA values for the wavelength of 254 nm a trend seems to exist. By considering the various calculated SUVA values at different depths for wavelength 254 nm, the trend is that the SUVA values increases with depths and this implies that more of the organics present in the water consist of aromatics (US EPA, 2005; Karanfil, 2002). The unit which SUVA values are measured is in $L/mgC \cdot m$ (Jonathan A, 2010) High $SUVA_{254}$ values, e.g., ≥ 4

L/(mgC*m) indicates that the leachate has high hydrophobic, aromatic and high molecular weight natural organic matter (NOM) fraction. A SUVA₂₅₄ of ≤ 3 L/(mgC*m) indicates the presence of high non-humic, hydrophilic and low molecular weight fractions. (Karanfil, 2002; Edzwald, 1999)

Overall from Table 6-6, the SUVA₂₅₄ values are lower than 3 and increases with depth. This implies that the non-humic, hydrophilic and low molecular weight fractions of organic carbons are better adsorbed at the upper layer than the lower layers of the carbon filter. On the lower layers more aromatics, hydrophobic and high molecular weight fractions are found. This result is completely contradictory to the characteristics of activated carbon, which is known to be very efficient in removing hydrophobic, high molecular weight aromatics (Rodriguez-Reinoso, 2001; Perrich, 2000). A possible explanation could be that the lower molecular weight, hydrophilic and non-humic organics were bound with the suspended particles existing in the leachate thus they are removed better by filtration through carbon filter rather than adsorption through the filter.

Analyzing the SUVA₄₃₆ values did not show a similar trend. The only pattern which can be drawn from these results is that the SUVA values are quite high no matter the depths. This pattern continues throughout all of the various dates. This high SUVA values indicates that the GAC is not that efficient in removing the humic substances. It is known that humic substances are very resistant degradation (Worrall, 2007) thus these constant high SUVA values for the wavelength of 436 nm independent of the depths indicates that GAC might have difficulties in adsorbing the humic substances. This leads to that high concentrations of humic substances are left untreated in the water.

Overall it appears that GAC might be a good adsorption material when it comes to double bonded substances or aromatics while for humic substances it is not such a good choice since humic substances are not that easily degraded.

Table 6-6: UV test values after recalculated and converted to mean values and the SUVA values for the 254 nm and the 436 nm

Wavelengths		$\lambda_1=254$ nm	$\lambda_2=436$ nm			
Date	Location	Mean value	Mean value	DOC	SUVA 254 nm	SUVA 436 nm
27-apr	7 cm	52,00	95,27	33,38	1,56	2,85
	17 cm	95,00	96,63	33,38	2,85	2,89
	27 cm	95,53	96,70	33,38	2,86	2,90
	37 cm	96,67	97,70	33,38	2,90	2,93

Wavelengths		$\lambda_1=254$ nm	$\lambda_2=436$ nm			
Date	Location	Mean value	Mean value	DOC	SUVA 254 nm	SUVA 436 nm
26-maj	7 cm	63,00	95,50	43,13	1,46	2,21
	17 cm	69,13	92,90	43,13	1,60	2,15
	27 cm	97,23	98,20	43,13	2,25	2,28
	37 cm	96,27	98,10	43,13	2,23	2,27
01-jun	7 cm	73,23	95,30	32,21	2,27	2,96
	17 cm	89,43	97,10	32,21	2,78	3,01
	27 cm	89,93	96,50	32,21	2,79	3,00
	37 cm	97,60	98,13	32,21	3,03	3,05
09-jun	7 cm	66,37	96,00	45109,78	0,0015	0,0021
	17 cm	78,07	93,07	45109,78	0,0017	0,0021
	27 cm	93,60	97,60	45109,78	0,0021	0,0022
	37 cm	92,57	95,00	45109,78	0,0021	0,0021
16-jun	7 cm	40,03	94,73	49,07	0,82	1,93
	17 cm	66,33	96,80	49,07	1,35	1,97
	27 cm	83,63	97,27	49,07	1,70	1,98
	37 cm	87,50	90,10	49,07	1,78	1,84

7 Conclusion and Future Recommendation

In this study it was found out that the level of the various organic pollutants which occurs within the leachate at the Brudaremassen landfill are far too high if compared to the SEPA guidelines for groundwater. Thus it is very important that the pollutant levels at the landfill are decreased so that they will fall below guideline limit. This will in turn lead to that the treatment processes at GRYAAB waste water treatment plant can maintain the desired level of treated water easily as there will not be that high loads of POPs pollutants reaching the GRYAAB wastewater plant.

In this thesis work, a pilot plant using different adsorbent materials is constructed to adsorb organic pollutants from the Brudaremassen landfill. The adsorbent materials which were used were activated carbon and peat moss.

In order to treat the leachate, two different adsorbent options were decided and evaluated. Alternative one was a series of two columns of carbon filter and alternative two was a series of one peat filter column and one carbon filter column. Different operating parameters were calculated like the contact time, flow rate etc. During operation in field, the calculated contact time and flow rate changed due to operational difficulties. After taking samples and analyzing them for organic pollutants and various oils fractions, the performance of the filters to treat the leachates were monitored.

From the analysis result it can be seen that, oil and PHC fractions are adsorbed well with carbon filters but the peat filters are adsorbing them in a moderate to low efficiency with an average value of 44%. On the other hand, the effluent from the filters showed that, peat works better for PAH (except for anthracene), but not that efficiently for APs on 26th May. After one month both of the filters work very well for PAH and AP sand phthalates (except for DINP). Both filters are effectively for APEOs. Oils are adsorbed well by the GAC columns, but not by peat. For metals, peat allows the following GAC filter to adsorb metals better.

Overall it can be seen that the GAC filter is better at removing DOC compared to the peat filter. When it comes to the reduction/removal of TOC, it can be seen that both of the two sorption materials are quite efficient in reducing/removing concentrations of TOC even though the GAC filter is slightly better.

It also appears that overall GAC might not be a good adsorption material when it comes to double bonded substances or aromatics or for humic substances. Thus the UV analyses results showed that both filters are reducing the organic pollutants from moderate to good efficiency. Both can be used for treating the Brudaremassen leachate on-site.

When it comes to future recommendations, one alternative can be a pre-treatment step like sedimentation with addition of CaCO_3 to speed up the rate of sedimentation. Another alternative is to add oxygen and thus aerate the leachate before entering the sand filter and in that way reduce the high quantities of iron particles which in turn lead to clogging of the filters. A third option is that by adding precipitants before the leachate reaches the sand filter one can then particles which contribute to clogging will be precipitated. A last future recommendation is to install air ventilations along the pipes between the sand filter and the columns and by doing so one can avoid air pockets or air bubbles within the pipes since this air bubbles prevents the leachate from reaching the filters.

However as some pre-treatment steps are already implemented at the Brudaremossen landfill, such as an oil separator and a leachate pond, the most beneficial future improvement would be to instead of leading the water directly after these two already implemented pretreatment steps to GRYAAB, the leachate from the pond will be lead from the leachate pond into the proposed treatment plant. Then the leachate will receive one of the mentioned pre-treatments to reduce pollutant loads to the plant and then will run through the sand filter and after that through the GAC or peat alternative and finally to GRYAAB. The whole proposed plan for the on-site treatment plant is presented in Figure 7-1.

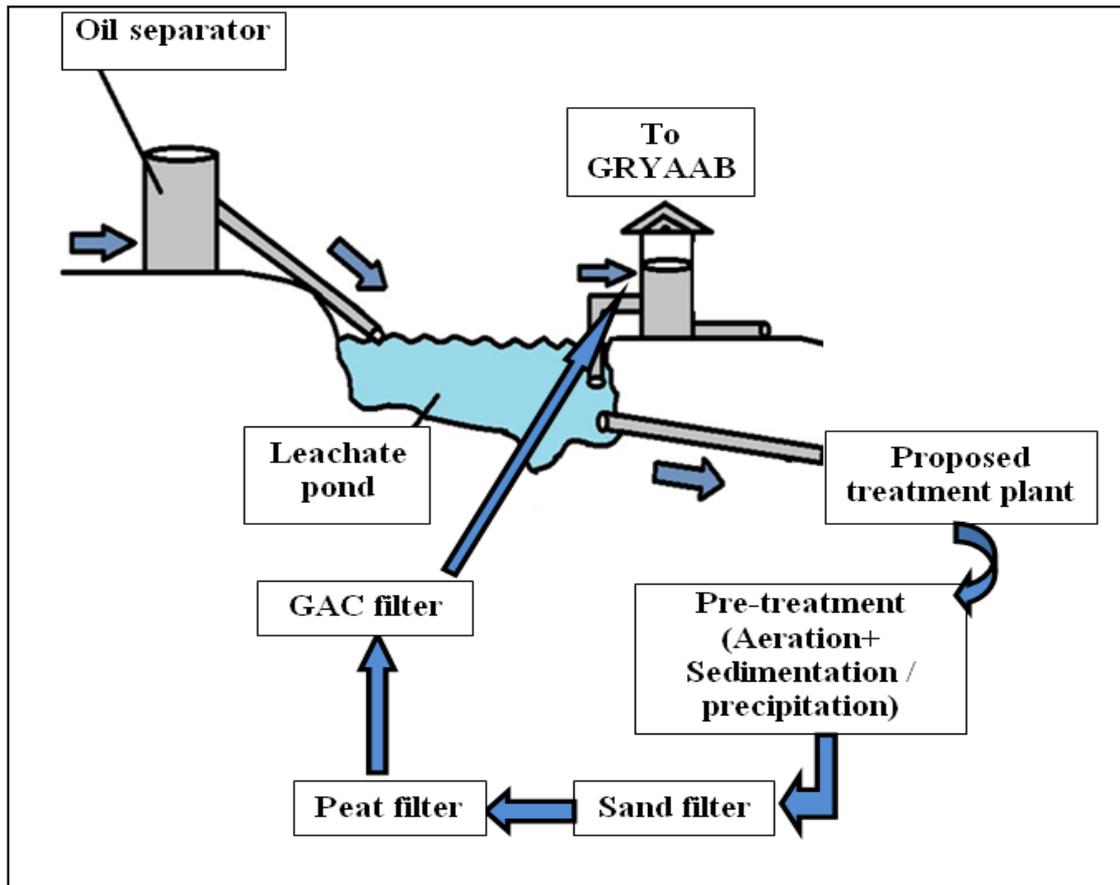


Figure 7-1: The proposed treatment process at the Brudaremossen landfill by both using the already existing pre treatment steps together with the proposed processes

However, in order to have a clearer understanding on the performance of the treatment plant more samples are needed to be analyzed and also a multicriteria analysis is needed for making further decision regarding the future treatment plant.

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Appendix

Appendix I: Design of pilot plant:

Design of pilot plant 1:	
Height (cm)	35
Diameter (cm)	50
Volume of tank (L)	68.72
Total Volume of 2 tanks in series (L)	137.44
Contact time(min)	20.00
Flow, Q (l/min)= Volm/time	3.4
Flow, Q (l/h)=Volm/time	206.16
Calculation of Activated carbon requirement	
Backwashed and drained density of GAC = Bulk density of GAC (kg/m ³)	425
1 bag of 25 kg GAC gives volume	60 L
Total number of bags required for alt 1	2.34

Design for peat and GAC plant	
Height in cm of GAC in alt 2	35.0
diameter (cm)	50.0
Area (cm ²)	1963.5
Volume of peat (L) [Assuming peat is filled up to 60 cm]	117.8
Volume of activated carbon (L) [Assuming peat is filled up to 35 cm]	68.7
1 bag of 25 kg of Filtrasorb 400 gives approx. volume of	60 L
Total number of bags required for alt 2	1.2
Overall requirement of GAC for alt 1 and 2	4.2
Weight of GAC	104.3
Contact time (min)	20.0
Flow, Q (L/min)	5.9

Appendix II: Isotherm for Filtrasorb 400 for 15 minutes

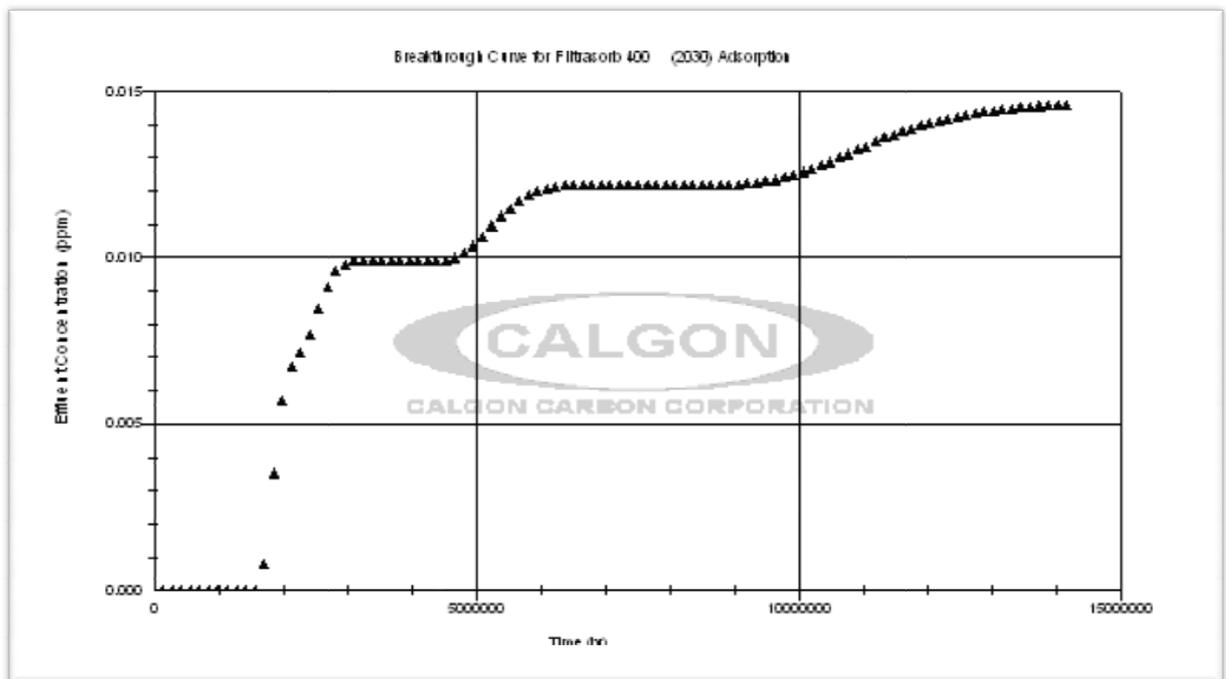


Figure A- 1: Isotherm for Filtrasorb 400 for 15 minutes

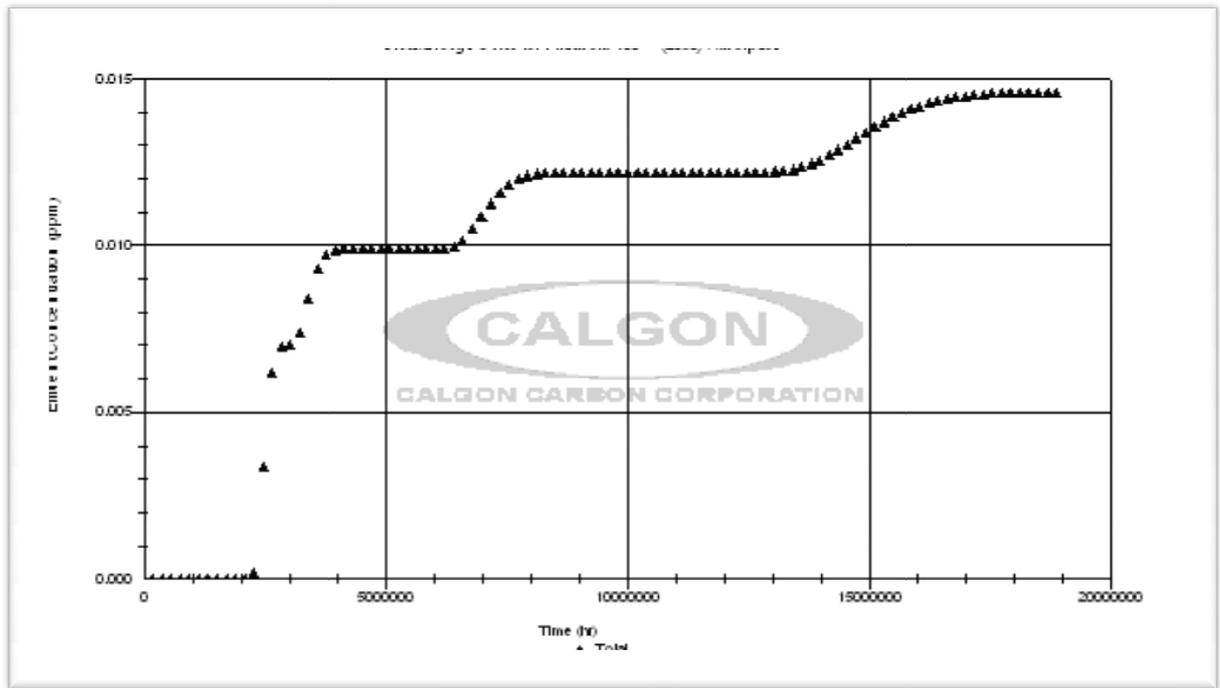


Figure A- 2: Isotherm for Filtrasorb 400 for 20 minutes

Appendix III: Calculation of contact time

Cross-sectional area of the bed,

$$A = \pi r^2 = \pi \cdot \left(\frac{50}{2}\right)^2 = 1963.495 \text{ cm}^2$$

Bed Depth, L=50 cm

Contact time from company, EBCT= 20minutes

$$EBCT = \frac{V}{Q} = \frac{LA}{Q}$$

$$\text{Or, } Q = \frac{LA}{EBCT} = \frac{50 \times 1963.495 \times 0.90}{20 \times 60 \times 60} = 0,06626797 \text{ L/s} = 3,97 \text{ L/min}$$

Here, Volume of the tank is multiplied with 0.9 as the equation is for bulk volume of adsorbents and that is 80-95% of the apparent volume (or the column volume).

Design of pilot plant:	
Height (cm)	45
Diameter (cm)	50
Area (cm ²)	1963,495408
Volume of tank (L)	88,35729338
Total Volume of 2 tank (L)	176,7145868
Contact time(min)	20
Flow, Q (l/s)=Volm/time	0,06626797
Flow, Q (l/min)=Volm/time	3,976078202

Appendix IV: Characterization of GAC

Dry weight test of GAC	Units		
Beaker/content		Dates	Weight/size
Empty beaker	gm	04-maj	9.370
GAC height on beaker	cm	04-maj	3.700
Diameter of beaker	cm	04-maj	4.200

Volume of GAC in beaker	cm3		51.261
Weight of beaker with GAC	gm	04- maj	56.250
Weight of porcelain with GAC	gm	04- maj	68.153
Weight of empty porcelain bowl	gm	04- maj	21.470
Weight of aluminium bowl	gm	04- maj	1.778
Weight of aluminium bowl+ porcelain bowl +GAC	gm	04- maj	69.931
Weight of aluminium bowl+ porcelain bowl +GAC at 105°C after 1 day	gm	05- maj	42.568
Weight of GAC before over dried on 105°C	gm	04- maj	46.683
Weight of GAC before after dried on 105°C	gm	05- maj	19.320
Thus 19.32 gm of dry weight of GAC gives 51.26 cm3 volume			

Appendix V: Characterization of peat

No.	Weight of empty container (gm)	Peat+ container (gm)	weight of peat(gm)	Fraction on 5,6 mm sieve(gm)	Fraction on 4,0 mm sieve(gm)	Fraction on 2,0 mm sieve(gm)
1	144.7	633.7	489	26.4	21	57
2	144.7	658.7	514	24.2	20.9	54.6
3	144.7	544.3	399.6	20.1	19	47.6
4	144.7	633	488.3	26.1	21.7	63.1
5	144.7	591.1	446.4	20.3	16.5	53.2
			AVERAGE	23.42	19.82	55.1
			STANDARD DEVIATION	2.73	1.88	5.054

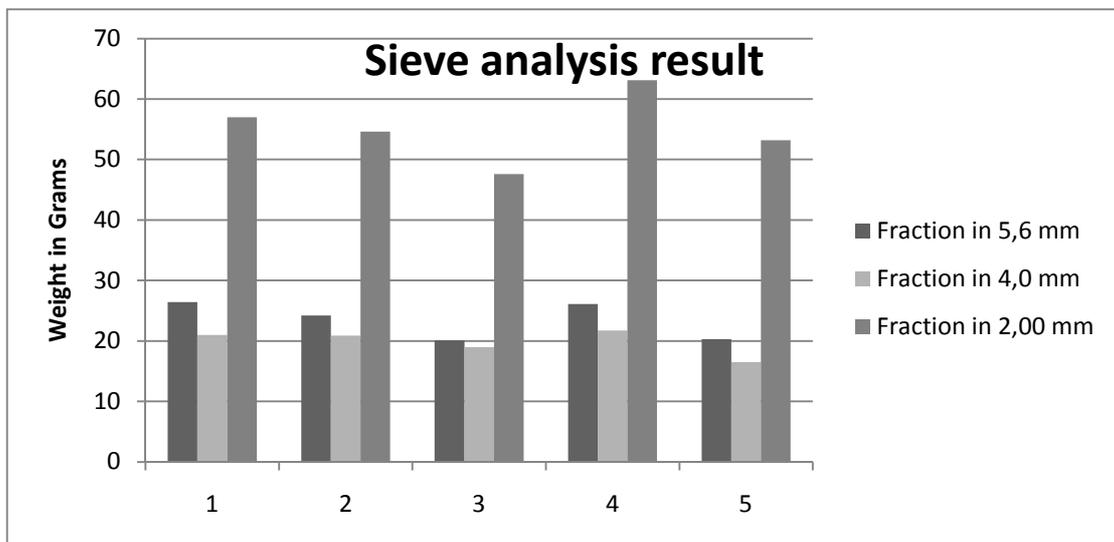


Figure A- 3: Sieve test result of Peat

Loss of ignition and solid content of peat

No	Weight of empty containers (gm)	Weight of container after 2 hr in oven at 105°C	Wt. With peat (gm)	Wt. After 20hr at 105°C	Wt. After 2h at 550°C	LOI % =100* (W4-W5)/(W3-W2)	Solid content=1000 * (W4-W2)/(W3-W2)
	W1	W2	W3	W4	W5		
102/45	29.1	29.0	38.6	31.5	29.3	22.5	253.8
No number	11.8	11.8	17.7	13.3	11.9	23.6	259.2
No. 79c-2	25.7	25.7	38.8	28.4	26.3	16.1	205.0
					Average	20.7	239.3
					Std dev	3.3	24.4

Appendix VI: Amount of sand used in pilot plant

For GAC and GAC alternative:

We used the following fractions of sand and gravel at the bottom for smaller columns in GAC and GAC series.

A- 1: Amount of Sand used at the bottom

Sizes of Sand and Gravel	Weight for 1 st columns	Weight for 2 nd columns
10-25 mm of size divided in coarser fractions	3 kilo	3 kilo
10-25 mm of size divided in finer fractions	6 kilo	9 kilo
5,0-10,0 mm	14 kilo	11 kilo
1,2-2,0 mm	22 kilo	15 kilo

The amount GAC added to each columns with water = 98,21 kilo

For Peat + GAC alternative

Amount of sand and gravel filled in the plant

A- 2: Amount of Sand used at the bottom

Sizes of Sand and Gravel	Weight for peat column	Weight for GAC column
10-25 mm of size divided in coarser fractions	9 kilo	9 kilo
10-25 mm of size divided in finer fractions	10,5 kilo	10,5 kilo
5,0-10,0 mm	20,7 kilo	20,7 kilo
1,2-2,0 mm	24 kilo	24 kilo

Appendix VII: Result from small scale column test

A- 3: Total iron concentration to and from the small scale column

Date	Location		Conc. (mg/L)	Location	Conc. (mg/L)	Removal efficiency of sand column	Average Efficiency (%)
05/05	Total Iron inflow	Test 1	41.5	Total Iron Outflow	1.54	96.3	95.6
		Test 2	34		1.47	95.7	
		Test 3	34		1.72	94.9	
06/05	Total Iron inflow	Test 1	9.7	Total Iron Outflow	1.32	86.4	87.0
		Test 2	10.7		1.24	88.4	
		Test 3	9.8		1.36	86.1	
09/05	Total Iron inflow	Test 1	11.5	Total Iron Outflow	1.36	88.2	89.8
		Test 2	11		1.34	87.8	
		Test 3	12		0.79	93.4	

A- 4: ICP-MS results of column samples

location	Unit	Inlet	Outlet	Removal (%)	Inlet	Outlet	Removal (%)
Na	mg/L	262.01	248.55	5	223.9	212.29	5
Mg	mg/L	39.15	35.23	10	33.13	29.82	10
K	mg/L	95.92	90.31	6	81.66	75.96	7
Ca	mg/L	100.53	23.68	76	47.77	20.11	58
Fe	mg/L	12.59	1.93	85	9.01	1.65	82
Mn	ug/L	1.21	0.04	97	0.46	0.03	93
Ba	ug/L	544.93	173.39	68	335.8	143.44	57
Cu	ug/L	17.93	18.48	-3	15.43	14.73	5
Ni	ug/L	141.60	36.24	74	70.51	30.17	57
Al	ug/L	39.40	68.78	-75	29.78	69.92	-135
Li	ug/L	46.38	44.27	5	39.99	38.28	4
Cr	ug/L	20.17	17.22	15	16.73	15.07	10
Co	ug/L	6.32	5.50	13	5.13	4.56	11
Zn	ug/L	25.98	5.84	78	22.46	6.90	69
Ag	ug/L	0.04	0.05	-5	0.05	0.02	53
Cd	ug/L	0.19	0.05	75	0.12	0.03	73
Pb	ug/L	1.00	0.74	25	0.76	0.74	1
Mo	ug/L	3.96	3.59	10	2.98	3.53	-18

*The color highlight shows the range of values, red represents worse removal and Green as the best removal efficiency.

Appendix VIII: Inflow to the pilot plant

A- 5: shows the various flows for each regulation and for each tank and for the sand filter in order to gain the desired flows.

Regulation of the flow for columns and sand filter						
Locations	Date	Desired flow (L/min)	Test 1 (L/min)	Test 2 (L/min)	Test 3 (L/min)	Mean flow (L/min)
Out/inlet peat/GAC	23/05/2011	0.7	0.7	N/A	N/A	0.7
Out/inlet GAC/GAC	23/05/2011	0.7	0.7	N/A	N/A	0.7
Inlet sand filter	23/05/2011	2	2	N/A	N/A	2
Out/inlet peat/GAC	24/05/2011	0.7	1.2	1.135	0.94	1.092
Out/inlet GAC/GAC	24/05/2011	0.7	0.26	0.253	0.7	0.404
Inlet sand filter	24/05/2011	2	1.018	1.96	N/A	1.489

Appendix IX: Oil index detailed result

Date	Location	Oil-index (µg/l)	fraction >C10-C12, µg/l	fraction >C12-C16, µg/l	fraction >C16-C35, µg/l
27/04/2011	L1	<50	<5	<5	<30
	L2	<50	<5	<5	<30
	L3	<55	<5	<5	<30
06/05/2011	L1	77	9.4	10.4	52
	L2	<50	<5.0	<5.0	<30
	L3	<50	<5.0	<5.0	<30
26/05/2011	SF	113	19.6	39.1	54
	L1	300	36.4	113	148
	L2	<50	<5.0	<5.0	<30
	L3	72	11.3	25.4	34
	Efficiency of peat	76	69.0	77.5	77.0
01/06/2011	SF	277	34.3	90.8	142
	L1	194	24.2	66.8	97
	Efficiency of sand	29.96	29.45	26.43	31.69
	L2	<50	<5.0	<5.0	<30
	L3	94	13	26.2	50
	Efficiency of peat	51.54639	46.28099	60.77844	48.45361

Appendix X: PAH detailed result

Date	27/04	06/05	26/05						
Location	L1	L1	SF	L1	SF-L1	L2	L1-L2	L3	L1-L3
Acenaphthene	<10	<10	<10	101	L	<10	T	<10	T
Acenaphthylene	<10	<10	<10	<10	T	<10	T	<10	T
Anthracene	46	35	24	19	20.8	<10	T	16	L
Benzo[a]pyrene	11	<10	<10	<10	T	<10	T	<10	T
Benzo[b]fluoranthene	33	23	<10	<10	T	22	L	<10	T
Benzo[g,h,i]perylene	17	15	<10	<10	T	22	L	<10	T

Benzo[k]fluoranthene	24	17	<10	<10	T	<10	T	<10	T
Chrysene/Triphenylene	22	11	<10	<10	T	21	L	<10	T
Dibenzo[a,h]anthracene	14	<10	<10	<10	T	20	L	<10	T
Fluoranthene	69	<10	<10	34	L	<10	T	<10	T
Fluorene	18	24	<10	<10	T	<10	T	<10	T
Indeno[1,2,3-c,d]pyrene	12	<10	<10	<10	T	17	L	<10	T
Phenanthrene	53	18	<10	<10	T	<10	T	<10	T
Pyrene	103	98	99	71	28.3	<10	T	<10	T
Date	01/06			09/06					
Location	SF	L1	SF-L1	L1					
Acenaphthene	<10	<10	ND	<10					
Acenaphthylene	<10	<10	ND	32					
Anthracene	22	20	9.09	41					
Benzo[a]pyrene	<10	<10	ND	<10					
Benzo[b]fluoranthene	<10	<10	ND	<10					
Benzo[g,h,i]perylene	<10	<10	ND	<10					
Benzo[k]fluoranthene	<10	<10	ND	<10					
Fluoranthene	<10	<10	ND	102					
Fluorene	<10	<10	ND	64					
Indeno[1,2,3-c,d]pyrene	<10	<10	ND	<10					
Phenanthrene	<10	<10	ND	18					
Pyrene	109	66	39.45	85					

*Red highlight represents leaching and green represents treated. Gray represents values below detection limit

Appendix XI: Results of alkylphenols and alkylphenolethoxylates analysis

Date		27-Apr	06-May	26-maj			
Location		L1	L1	SF	L1	L2	L3
Alkylphenols ethoxylates	4-t-Octylphenol mono-ethoxylates	42	40	48	44	<10	<10
	4-t-Octylphenoldi-ethoxylate	13	<10	<10	11	<10	<10
	4-t-Octylphenoltri-ethoxylate	12	<10	<10	<10	<10	<10
	iso-Nonylphenolmono-ethoxylate	200	155	<100	170	<100	<100
	iso-Nonylphenoldi-ethoxylate	161	<100	<100	<100	<100	<100
Alkylphenols	4-tert-Octylphenol	570	530	450	420	<10	110
	iso-Nonylphenol	690	640	670	580	<100	<100
	4-tert-Butylphenol	7800	8000	1600	350	<10	1000
	4-tert-Pentylphenol	670	720	410	300	<10	210
	Bisphenol A	1140	15	34	14	<10	<10
Date		01/06/2011		23/06/2011			
Location		SF	L1	L1	L2	L3	
Alkylphenol ethoxylates	4-t-Octylphenolmono-ethoxylate	43	21	29	<10	<10	
	4-t-Octylphenoldi-ethoxylate	<10	11	<10	<10	<10	
	4-t-Octylphenoltri-ethoxylate	<10	<10	<10	<10	<10	
	iso-Nonylphenolmono-ethoxylate	<100	170	<100	<100	<100	
	iso-Nonylphenoldi-ethoxylate	<100	<100	<100	<100	<100	
Alkylphenols	4-tert-Octylphenol	490	570	470	<100	<10	
	iso-Nonylphenol	640	1600	520	<100	<100	
	4-tert-Butylphenol	1100	930	5100	<100	19	
	4-tert-Pentylphenol	360	370	690	<100	<10	
	Bisphenol A	34	19	9310	<100	24	

Appendix XII: Phthalates results

Date	27/04	06/05	26/05						
Location	L1	L1	SF	L1	Eff. SF-L1	L2	Eff. L1-L2	L3	Eff. L1-L3
Diethyl phthalate	180	200	<50	<50	T	<50	T	<50	T
Diisobutyl phthalate	730	730	<50	<50	T	140	L	<50	T
Dibutyl phthalate	750	310	<50	<50	T	<50	T	<50	T
Benzylbutyl phthalate	180	84	<50	<50	T	<50	T	<50	T
Dicyclohexyl phthalate	280	250	<50	<50	T	<50	T	<50	T
Di-2-ethylhexyl phthalate	1300	510	<50	<50	T	400	L	<50	T
Diisononyl phthalate	690	3700	<50	<50	T	500	L	<50	T
Di-n-octyl phthalate	<50	<50	<50	<50	T	<50	T	<50	T
Date	01/06			23/06					
Location	SF	L1	Eff. SF-L1	L1	L2	L3			
Diethyl phthalate	<50	350	L	<50	<50	<50			
Diisobutyl phthalate	<50	<50	T	<50	<50	<50			
Dibutyl phthalate	<50	<50	T	<50	<50	<50			
Benzylbutyl phthalate	<50	<50	T	<50	<50	<50			
Dicyclohexyl phthalate	<50	<50	T	140	<50	<50			
Di-2-ethylhexyl phthalate	180	290	L	<50	<50	<50			
Diisononyl phthalate	<50	8500	L	<50	140	530			
Di-n-octyl phthalate	<50	<50	T	<50	<50	<50			

Appendix XIII: Analyses result from oxy-PAH analysis

Date	27/04	06/05	26/05		01/06/2011		09/06/2011	
Location	L1	L1	SF	L1	SF	L1	SF	L1
9-fluorenon	0.47	0.44	0.14	0.16	19	0.36	0.59	0.39
9,10-antrakion	0.59	0.51	0.42	0.47	37	0.43	0.43	0.44
2-metylantracem-9,10-dion	<0.10	0.20	0.14	0.16	0.13	0.14	0.19	0.19
7H-bens(de)antracem-7-on	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
bens(a)antracem-7,12-dion	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
6H-bens(cd)pyren-6-on	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
bens(a)fluorenon	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
4H-cyklopenta(def)fenantrenon	0.35	0.10	0.39	0.29	0.37	0.28	0.28	0.35
naftacem-5,12-dion	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10

*Bold Values represents values higher than the inlet concentration and ash represents concentration values that are below the detection limit.

A- 6: Concentration variation of oxy-PAH and parent PAH

Date		27/04/2011	06/05/2011	26/05/2011		01/06/2011	
Location		L1	L1	SF	L1	SF	L1
PAH (µg/L)	Anthracene	46	35	24	19	22	20
	Fluorene	18	24	<10	<10	<10	<10
	Phenanthrene	53	18	<10	<10	<10	<10
	Pyrene	103	98	99	71	109	66
Oxy-PAH (µg/L)	9,10-antrakion	0.59	0.51	0.42	0.47	0.37	0.43
	9-fluorenon	0.47	0.44	0.14	0.16	0.19	0.36
	4H-cyklopenta(def)fenantrenon	0.35	0.10	0.39	0.29	0.37	0.28
	2-metylantracem-9,10-dion	<0.10	0.20	0.13	0.16	0.19	0.19

Date	27/04	06/05	26/05		01/06		09/06/2011			23/06			
Location	L1	L1	SF	L1	SF	L1	SF	L1	L2	L3	L1	L2	L3
9-fluorenon	0.47	0.44	0. 14	0. 16	0. 19	36	0.5 9	0. 39	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1
9,10-antrakinon	0.6	0.51	0. 42	0. 47	0. 37	43	0.4 3	0. 44	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1
2-metylantracen-9,10-dion	<0.10	0.2	0. 14	0. 2	0. 1	14	0.1 9	0. 19	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1
7H-bens(de)antracen-7-on	<0.1	<0.1	<0 .1	<0 .1	<0 .1	<1 0	<0. 1	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1
bens(a)antracen-7,12-dion	<0.1	<0.1	<0 .1	<0 .1	<0 .1	<1 0	<0. 1	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1
6H-bens(cd)pyren-6-on	<0.1	<0.1	<0 .1	<0 .1	<0 .1	<1	<0. 1	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1
bens(a)fluorenon	<0.1	<0.1	<0 .1	<0 .1	<0 .1	<1	<0. 10	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1
4H-cyklopenta(def)fenantrenon	0.35	0.1	0. 39	0. 29	0. 37	28	0.2 8	0. 35	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1
naftacen-5,12-dion	<0.1	<0.1	<0 .1	<0 .1	<0 .1	<1	<0. 1	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1	<0 .1

Appendix XIV: Metals result from ICPMS analysis

A- 7: Concentration of metals found from ICPMS analysis (Results are in $\mu\text{g/L}$)

Date	loc		Cu	Ni	Al	Cr	Zn	Cd	Pb
27/04/2011	L1	Carbon alt	81.77	52.66	22.40	7.89	12.59	0.07	3.13
	L2		6.47	51.05	7.02	5.75	10.21	0.04	0.24
	L4		4.25	55.61	9.07	5.65	22.84	0.04	0.11
	L1	Peat alt	81.77	52.66	22.40	7.89	12.59	0.07	3.13
	L3		12.16	45.28	59.29	8.37	12.28	0.02	0.46
	L5		2.39	64.06	13.21	5.38	18.30	0.06	0.17
06/05/2011	L1	Carbon alt	79.08	71.31	18.50	12.45	12.37	0.17	1.09
	L2		6.77	59.11	5.99	6.54	16.81	0.06	0.62
	L4		2.58	50.44	5.72	6.68	13.68	0.05	6.05
	L1	Peat alt	79.08	71.31	18.50	12.45	12.37	0.17	1.09
	L3		20.61	46.60	28.09	7.76	28.16	0.10	1.02
	L5		4.65	45.93	9.34	5.73	13.15	0.09	0.36
2011-05-26	SF	Carbon alt	11.19	85.25	21.45	22.34	11.37	0.07	0.61
	L1		119.11	92.08	11.85	24.10	25.68	0.04	5.41
	L2		47.94	64.70	7.43	22.64	68.29	0.05	0.20
	L4		1645.21	5904.15	409.78	615.86	400.73	3.37	28.36
	SF	Peat alt	11.19	85.25	21.45	22.34	11.37	0.07	0.61
	L1		119.11	92.08	11.85	24.10	25.68	0.04	5.41
	L3		53.08	116.44	23.70	24.25	24.00	0.10	3.20
	L5		5.01	134.97	36.41	50.35	13.93	0.25	0.55
2011-06-01	SF	Carbon alt	34.06	157.38	29.52	28.55	143.07	0.11	1.44
	L1		76.03	58.19	8.41	18.64	13.06	0.02	1.31
	L2		19.01	58.08	4.82	14.10	4.95	0.03	0.23
	L4		4.74	57.51	2.55	12.36	6.77	0.06	0.27
	SF	Peat alt	34.06	157.38	29.52	28.55	143.07	0.11	1.44
	L1		76.03	58.19	8.41	18.64	13.06	0.02	1.31
	L3		16.58	51.57	8.23	15.30	8.66	0.01	1.02
	L5		1.97	33.46	6.51	10.82	4.66	0.02	0.15
2011-06-09	SF	Carbon alt	13.92	97.93	37.25	24.51	25.62	0.06	1.26
	L1		96.21	156.55	24.90	24.84	24.63	0.08	2.50
	L2		40.69	90.71	4.47	14.81	14.77	0.07	2.20
	L4		11.84	54.95	2.73	13.74	55.39	0.04	0.24
	SF	Peat alt	13.92	97.93	37.25	24.51	25.62	0.06	1.26
	L1		96.21	156.55	24.90	24.84	24.63	0.08	2.50
	L3		19.02	68.00	12.94	19.57	12.61	0.03	3.28
	L5		5.82	50.97	14.51	17.25	15.44	0.05	0.36
2011-06-16	SF	Carbon alt	18.17	102.36	86.23	20.92	14.62	0.08	0.95
	L1		277.42	105.74	15.11	20.30	38.35	0.03	2.35
	L2		19.90	72.52	11.05	11.26	14.54	0.03	1.43
	L4		7.18	67.71	13.37	11.53	9.78	0.03	0.34
	SF	Peat alt	18.17	102.36	86.23	20.92	14.62	0.08	0.95
	L1		277.42	105.74	15.11	20.30	38.35	0.03	2.35
	L3		19.37	79.06	16.02	16.18	10.53	0.03	2.49
	L5		5.71	65.80	27.33	9.87	6.07	0.01	0.27

Appendix XV: Analysis result from TOC and DOC test

Date	Location	Analysis	Dilution	TOC/DOC	Results
27/04/2011	L1	DOC	0,1	3,36	33,38 = DOC
	L2	DOC	0,1	0,5349	5,13 =DOC
	L3	DOC	0,1	3,925	39,03 = DOC
	L4	DOC	0,1	0,2433	2,22 = DOC
	L5	DOC	0,1	0,3931	3,72 = DOC
06/05/2011	L1	DOC	0,1	0,07796	0,56 = DOC
	L2	DOC	0,1	0,1168	0,95 = DOC
	L3	DOC	0,1	4,517	44,95 = DOC
	L4	DOC	0,1	0,2262	2,05 = DOC
	L5	DOC	0,1	0,1841	1,63 = DOC
26/05/2011	SF	DOC	0,1	3,595	35,73 = DOC
	L1	DOC	0,1	4,335	43,13 = DOC
	L2	DOC	0,1	0,259	2,37 = DOC
	L3	DOC	0,1	3,146	31,24 = DOC
	L4	DOC	0,1	0,186	1,64 = DOC
	L5	DOC	0,1	0,3018	2,80 = DOC
01/06/2011	SF	DOC	0,1	4,035	40,13 = DOC
	L1	DOC	0,1	3,243	32,21 = DOC
	L2	DOC	0,1	0,246	2,24 = DOC
	L3	DOC	0,1	3,502	34,80 = DOC
	L4	DOC	0,1	0,07642	0,55 = DOC
	L5	DOC	0,1	0,3443	3,23 = DOC
16/06/2011	SF	DOC	0,1	4,3	42,78 = DOC
	L1	DOC	0,1	4,929	49,07 = DOC

Date	Location	Analysis	Dilution	TOC/DOC	Results
	L2	DOC	0,1	0,1001	0,79 = DOC
	L3	DOC	0,1	4,448	44,26 = DOC
	L4	DOC	0,1	0,1955	1,74 = DOC
	L5	DOC	0,1	0,5992	5,78 = DOC
16/06/2011	SF	TOC	0,1	5,189	51,67 = TOC
	L1	TOC	0,1	4,713	46,91 = TOC
	L2	TOC	0,1	0,07949	0,58 = TOC
	L3	TOC	0,1	4,491	44,69 = TOC
	L4	TOC	0,1	-0,00783	0 = TOC
	L5	TOC	0,1	0,5524	5,31 = TOC
04/05/2011	Inlet	TOC	0,1	2,078	20,56 = TOC
	Outlet	TOC	0,1	1,886	18,64 = TOC
	Inlet	TOC	0,1	2,936	29,14 = TOC
	Outlet	TOC	0,1	3,942	39,20 = TOC
06/05/2011	Inlet	TOC	0,1	3,125	31,03 = TOC
	Outlet	TOC	0,1	1,978	19,56 = TOC
	Inlet	TOC	0,1	1,559	15,37 = TOC
	Outlet	TOC	0,1	3,498	34,76 = TOC
2011-05-06	L1	TOC	0,1	3,048	30,26 = TOC
2011-05-06	L2	TOC	0,1	-0,6123	0 = TOC
2011-05-06	L3	TOC	0,1	3,734	37,12 = TOC
2011-05-06	L4	TOC	1	-3,304	0 = TOC
2011-05-06	L5	TOC	1	-3,511	0 = TOC
2011-05-26	SF	TOC	0,1	3,944	39,22 = TOC
2011-05-26	L1	TOC	0,1	4,188	41,66 = TOC

Date	Location	Analysis	Dilution	TOC/DOC	Results
2011-05-26	L2	TOC	1	-4,138	0 = TOC
2011-05-26	L3	TOC	0,2	6,992	34,74 = TOC
2011-05-26	L4	TOC	0,2	-1,769	0 = TOC
2011-05-26	L5	TOC	1	-1,93	0 = TOC
2011-06-01	SF	TOC	0,2	8,162	40809,78 = TOC
2011-06-01	L1	TOC	0,2	7,395	36974,78 = TOC
2011-06-01	L2	TOC	1	-0,2562	N/A = TOC
2011-06-01	L3	TOC	0,2	6,721	33604,78 = TOC
2011-06-01	L4	TOC	1	-2,673	0 = TOC
2011-06-01	L5	TOC	1	-0,2366	N/A = TOC
2011-06-09	SF	DOC	0,2	9,572	47,64 = DOC
2011-06-09	L1	DOC	0,2	8,639	43194,78 = DOC
2011-06-09	L2	DOC	1	-1,188	0 = DOC
2011-06-09	L3	DOC	0,2	8,455	42274,78 = DOC
2011-06-09	L4	DOC	1	-3,171	0 = DOC
2011-06-09	L5	DOC	1	-0,6779	N/A = DOC
2011-06-09	SF	TOC	0,1	4,737	47369,78 = TOC
2011-06-09	L1	TOC	0,1	4,511	45109,78 = TOC
2011-06-09	L2	TOC	0,1	-0,8860	N/A = TOC
2011-06-09	L3	TOC	0,1	3,450	34499,78 = TOC
2011-06-09	L4	TOC	1	-3,096	0 = TOC
2011-06-09	L5	TOC	1	0,4496	N/A = TOC
	Blank	TOC	1	0,2159	0 = TOC

Appendix XVI: TN concentration changes on various dates

Location	Leachate	After sand filter	after GAC	After Peat	After GAC (1st)	After GAC (2nd)
27/04/2011		66.5	80.04	74.25	103.4	45.24
06/05/2011		96.42	92.27	94.77	90.62	77.68
26/05/2011	99.1	88.8	89.3	95.5	95.1	80.3
01/06/2011	86.03	84.98	16.35	83.43	77.62	78.31
09/6/2011	99.83	95.50	188.88	86.95	94.17	95.82
16/06/2011	109.8	106	106.5	106.7	107.8	101.5

Appendix XVII: Average performance of the columns

A- 8: Average performance of the columns

	Cu	Ni	Al	Cr	Zn	Cd	Pb
Avg. of all GAC colm.	73.61	11.75	21.99	14.73	-11.68	-12.56	14.2
std crbn	15.5	21.7	54.3	36.4	90.3	75.1	229.9
Avg. of 1st GAC colm	78.134	20.8	58.7	33.2	-5.4	-6.6	60.4
std	16.45	16.48	21.54	15.22	85.75	69.92	33.92
Avg. 2nd GAC colm	61.226	10.8	-1.4	3.4	-55.7	29.0	-118.9
std	15.9	17.7	57.9	15.9	131.3	28.9	422.2
GAC colm after Peat	79.396	3.49	4.84	5.72	18.72	-53.20	78.98
std	8.76	28.45	61.31	56.32	43.19	93.39	12.17

Appendix XVIII: Beaker test results

A- 9: Experimental result of beaker test for Iron removal

Date	State of leachate	Parameter	Beaker 1 (added CaC O ₃)	Beaker 2 (Added NaOH)	Beaker 3 (raw leachate)
13/06/201	Raw	pH	-		7.49

Date	State of leachate	Parameter	Beaker 1 (added CaCO ₃)	Beaker 2 (Added NaOH)	Beaker 3 (raw leachate)
1	leachate	Conductivity (mS/cm)			2.69
		Oxygen Level (mg/L)			6.56
		Total Iron(mg/L)			10.5
	Aeration for 1 hour	pH	7.783	8.869	8.5
		Conductivity (mS/cm)	2.33	2.47	2.44
		Oxygen Level (mg/L)	7.58	8.11	7.68
		Total Iron(mg/L)	3.375	6.7	7.85
14/06/2011	Sedimentation for 20 hour	pH	8.295	8.47	8.292
		Conductivity (mS/cm)	2.37	2.44	2.36
		Oxygen Level (mg/L)	6	6.06	5.64
		Total Iron(mg/L)	3	3.75	3.55
14/06/2011	Further aeration for 2 hour	pH	8.95	9	9
		Conductivity (mS/cm)	1.934	8.12	7.91
		Oxygen Level (mg/L)	7.61	2.27	2.12
15/06/2011	Sedimentation 24 hr	Total Fe	1.9	2.8	2.0

A- 10: Summary of result from beaker test.

Date	Total iron content (mg/L)		Reduction of iron in %
13/06/2011	Leachate	10.5	
	Aeration for 1 hr		
	Beaker with CaCO ₃	3.375	67.85
	Beaker with NaOH	6.7	36.19
	Beaker with only leachate	7.85	25.23
14/06/2011	Settling for 20 hr		
	Beaker with CaCO ₃	3	71.42
	Beaker with NaOH	3.75	64.28
	Beaker with only leachate	3.55	66.19
15/06/2011	Further Aeration 4 hr and Settling for 20 hr		
	Beaker with CaCO ₃	1.9	81.90476
	Beaker with NaOH	2.8	73.33333
	Beaker with only leachate	2	80.95238