



**KTH Land and Water  
Resources Engineering**

# **PHOSPHORUS REMOVAL FROM DOMESTIC WASTEWATER USING DUAL REACTIVE MATERIALS POLONITE® AND ABSOL®**

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**December 2011**

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Degree project for Master's program in Environmental Engineering and Sustainable Infrastructure

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Reference to this publication should be written as: Fatehi Pouladi, S (2011) "Phosphorus Removal from Domestic Wastewater Using Dual Reactive Materials Polonite® and Absol®"  
TRITA LWR Degree Project 11:38, 22 p.

## SUMMARY IN SWEDISH

Behovet av filtermaterial är stort för vattenrening i enskilda, kommunala och industriella sammanhang. Vid enskild avloppsvattenhantering används idag filtersand eller motsvarande jordmaterial vid anläggning av markbäddar. Enligt de preliminära tester som utförts vid KTH är Absol® ett mycket bättre material med egenskaper att binda organiskt material och fosfor. Absol har ett pH av 9,5 vilket är lägre än de vanligast förekommande filtermaterialen på marknaden, t ex Filtralite och Polonite®.

Anläggningar för rening av enskilda avlopp släpper ut många ton fosfor (P) till vattenmiljön per år på grund av otillräcklig reningsgrad i de vanligt förekommande markinfiltrationssystemen. Alkaliska reaktiva filtermaterial har visat lovande resultat vid avskiljning av P. Vid KTH bedrivs forskning i flera spår för att påskynda framtagandet av en ideal lösning för små avlopp och inte minst återvinning av fosfor till jordbruket. Här kan de reaktiva filtermaterialen få stor betydelse för att uppfylla uppställda politiska mål med fosforåterföring.

I denna studie utfördes laboratorieförsök med kolonnexperiment där Absol och Polonite i dualfilter jämfördes med Polonite som det enda lager av reaktivt filtermaterial. Två uppsättningar av experiment arrangerades med filter längder på 5 cm och 15 cm som var i drift i 50 respektive 119 dagar. Kolonner med ett extra lager med Absol visade mycket god genomsnittlig avskiljning på 86 % och 99 % i båda experimenten, medan utflödet i den senare överskridit det maximala tillåtna P koncentration strax efter hälften av den totala tiden för experimentet.

Å andra sidan var P koncentrationen i insamlade prover från dualfiltret med 15 cm lager av Absol och Polonite så lågt som 0,04 mg/l efter 119 dagars drift, vilket uppvisar stor potential för Absol i enskilda avloppsanläggningar.

Undersökningen pekar på att dualfilter kan förlänga livslängden hos en filterbädd och att den inte behöver göras så djup. Avskiljningsförmågan av P är också mycket hög.



## **ACKNOWLEDGEMENTS**

I am truly thankful to my supervisor Professor Gunno Renman for his continuous help and guidance throughout my thesis and his valuable experience and expertise that he has shared with me. He has always been available for discussions with patience offering beneficial directions and advice.

I would also like to express my gratitude to Agnieszka Renman for her assistance and arrangements in the laboratory. My experiments would have been fruitless without her help.

My deepest appreciation and greatest thanks go to my beloved parents and sweet sister whom I love the most in my life. Had it not been for their constant support and encouragement, it would have been impossible for me to begin, carry on and complete my studies in Sweden. They have made my life enjoyable by always being there for me and I hope one day I will be able to return part of their love and care.



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## ABSTRACT

Private wastewater treatment facilities release tons of phosphorus to the aquatic environment due to the insufficient removal efficiency in conventional soil infiltration systems. Reactive filter materials have demonstrated promising P removal rates. Laboratory-scale column experiments were carried out using Absol® and Polonite® in dual infiltration media and results were compared with Polonite® functioning as the only layer of reactive filter material. Two sets of experiments were arranged with layer lengths of 5 cm and 15 cm which were operated for 50 and 119 days respectively. Columns with an additional layer of Absol® demonstrated very good average removal rates of 85.99 % and 99.13 % in both experiments while the effluent in the former exceeded the maximum allowed P concentration shortly after half of the total time of the experiment. On the other hand, O-P concentration in collected samples from dual filter media with 15 cm layers of Absol® and Polonite® (column B1) was as low as 0.04 mg/l after 119 days of operation exhibiting high potentials for Absol® in local wastewater treatment. Levels of pH in treated samples showed a decreasing trend in all columns which was similarly simultaneous with high removal rates observed in B1.

**Key words:** Polonite; Absol; Domestic wastewater; Phosphorus removal; Reactive filter material; Soil infiltration bed.

## INTRODUCTION

### Small-scale wastewater treatment

Wastewater is daily produced in all societies around the world and it cannot be avoided. Due to the harmfulness of wastewater, it needs to be treated before disposal to water bodies and the environment in general. Large-scale wastewater treatment facilities are operated to remove nutrients and contaminants by mechanical, chemical and biological mechanisms. However, in many countries such as Sweden, it is economically unjustified to connect all the residential units to centralized wastewater treatment plants. In urban areas with small houses scattered in relatively large areas of land, the costs of laying long networks of pipes and their maintenance for connection between the households and the large-scale treatment facilities become too expensive. On-site wastewater treatment systems are therefore common solutions for removal of pollutants and nutrients from wastewater before discharging it into the environment. On-site wastewater treatment solutions vary according to case specific requirements and goals. Different alternatives have been suggested taking into account the removal rate, recycling capacity of nutrients, health risks, economics, local suitability, controlling, etc., with both advantages and disadvantages in each system. (SwedEnviro Report No. 1999:1). However, the management and control of on-site treatments are limited and this has led to variations in treatment results. (Renman and Renman, 2010).

### Phosphorus loads

Nutrient levels in soil and water have become a serious threat to the environment. Phosphorus enters the environment from several points and diffuse sources. P loads from agricultural lands by run-off and drainage account for the main diffuse source of releasing P from fertilized lands. As phosphorus is a major ingredient in food production, human waste is known as a rich source of phosphorus. Many types of detergents used in humans daily lives discharge P into sewage. The key point source in releasing phosphorus is therefore considered to be domestic wastewater as it can discharge huge amounts of P into the environment if left completely or partially untreated. Excessive levels of

nutrients in surface waters cause a well-known phenomenon called eutrophication; an undesirable state where lives of native animal and fish species are endangered, oxygen in water is depleted and increasing unwanted biomass is produced. Phosphorus is the single most important nutrient that contributes to eutrophication and the reason is because this nutrient is the most deficient in the lakes i.e. limiting nutrient (Gustafsson et al., 2007).

Sweden has adopted a Zero Eutrophication objective which is aimed to ensure that by year 2020 nutrient levels in soil and water do not adversely affect human health and the conditions of biological diversity. However, it has been reported that phosphorus emissions target in Zero Eutrophication objective is not possible to achieve by 2020 even if further action is taken (Environmental Objectives Council, 2009). In this report, single-household sewage systems with inadequate treatment efficiencies are considered as a major concern. Local on-site wastewater treatment plants in Sweden account for discharging 170 tons of phosphorus per year into the sea. They contribute to 11 % of total phosphorus load caused by human activity (anthropogenic sources) and 4.8 % of all sources (Brandt et al., 2009). Phosphorus is a nutrient that is used by many industries and can be found in many products used by humans; and therefore, it is one of the main contaminants found in wastewaters (Zhao and Zhao, 2009). At the same time, it is a crucial element that is needed for all forms of life and no other element can replace it (Adam et al., 2007). Phosphorus together with nitrogen and potassium are essential required elements in fertilizers to be applied on agricultural lands. Since phosphate rock as a non-renewable source of phosphorus may be depleted in 50-100 years, the demand for this critical element is on the increase (Cordell et al., 2009). Considering the damage phosphorus can pose to the aquatic environment and on the other hand its limited availability, makes it significantly important to investigate noble solutions of removing it from wastewater and recovering it back to its life cycle.

### **Phosphate phases**

Phosphorus in raw domestic wastewater usually occurs in dissolved form. Important groups of phosphorus compounds in wastewater are organic phosphates, inorganic poly- and metaphosphates, and inorganic orthophosphates ions.

Organic phosphates (with -P-O-C bounds) are available in wastewater in both dissolved and suspended forms. These compounds are mostly from plastifiers for plastics and pesticides. Organic phosphates constitute approximately 4 % of total phosphorus and they are degraded chemically and/or biologically to orthophosphates in a water environment. Inorganic polyphosphates are basic constituents of detergents and water softeners and therefore these types of polyphosphates are common in domestic wastewater. Both phosphoric acid anions and most common polyphosphates dissociate easily in water. Polyphosphates in water are unstable and eventually convert to orthophosphate which is the most stable form of phosphates (Metcalf and Eddy, Inc., 2003; Murphy, 2007). The amount of phosphorus in a typical raw domestic sewage is highly variable (Omoike and vanLoon, 1999), but different phosphorus compounds have been approximately estimated as orthophosphate 5 mg P/l, tripolyphosphate 3 mg P/l, pyrophosphate 1 mg P/l and organic phosphate less than 1 mg P/l (Jenkins et al., 1973). Most authors agree on orthophosphates being the predominating group of phosphates in domestic wastewater and it is even estimated that it can consist up to

80 % of the total phosphorus present in the wastewater (Personal communication: Renman, Gunno).

### Infiltration systems

There are many different methods for phosphorus removal in large and small scale systems. All the available technologies, however, eliminate phosphorus ions by converting them into solid phases such as salt precipitates, microbial mass or a plant biomass (de-Bashan and Bashan, 2004). Among small-scale options, phosphorus removal by sand infiltration and constructed wetlands are common employed treatment technologies that have been favored for their low operational costs, less energy demand, no chemical dosage and little maintenance. Figure 1 shows a general layout of a vertical flow filter bed system which is typically comprised of a septic tank, pump well, distribution well, subsurface filter bed, aeration tubes and outlet. In some cases, the infiltration media is succeeded by an aerobic biofilter, an essential section designed for removal of organic matter and facilitating nitrification (Heistad et al., 2006).

Common soil infiltration beds have been in use for wastewater treatment from households for a long time. However, ability of conventional sand and gravel in such soil beds has been questioned in recent years. Phosphorus accumulation of only 8 % is found in an infiltration bed that had been in operation for 16 years (Eveborn et al., 2009b). According to the same study, many infiltration beds were even found to be less efficient in phosphorus removal. There is ongoing research to investigate efficiency and sustainability of various types of filter materials in filter beds. Few examples of studied filter materials are P-saturated alum sludge (Zhao and Zhao, 2009), natural weathered rock (Kadam et al., 2008), mixture of sand and dolomite (Prochaska and Zouboulis, 2006), natural wollastonite, water-cooled blast furnace slag (WCBBFS), Filtra P and Polonite® (Gustafsson et al., 2008). Among different materials tested, Polonite®, a mineral-based sorbent made from siliceous sedimentary Opoka rock, has demonstrated promising results in phosphorus removal from domestic wastewater. Column experiments filled with Polonite® and fed with domestic wastewater have resulted in  $\text{PO}_4\text{-P}$  removal efficiency of more than 95 % (Renman and Renman, 2010; Gustafsson et al., 2008). Polonite® is an alkaline material which contains calcium and due to the removal mechanisms happening in the filter media, the pH value of the effluent is quite high. The effluent pH of a fresh layer of Polonite® filter can be in the range of 10-12 (Renman and Renman, 2010). However pH values generally decrease in time when alkaline filter materials are in use (Heistad et al., 2006).

The main focus of earlier studies and experiments has been on an efficient material as a substitute media for conventional sand in soil filters. In most cases there is only one layer of reactive filter in column or

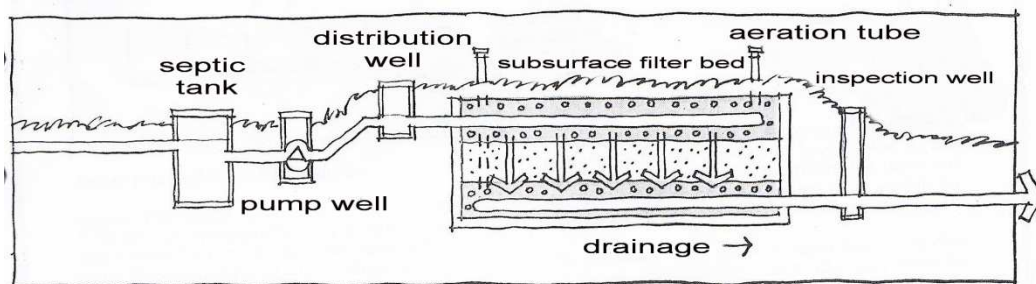


Figure 1. General layout of a vertical flow filter bed system (after Bjur and Malbert, 1982).

batch experiments which is designed to enable the comparison of the material with other alternatives or to investigate it independently. However, it is of interest to consider two or more layers of different reactive filter materials together and study the removal efficiencies of a multi-layer media. In this study, Polonite® is selected to function with an additional layer of a material called Absol® with a commercial application as sorbent of oil and paint spills. In earlier studies, phosphorus retention in filter materials such as Polonite® and Filtralite P at high pH has been attributed to the high calcium content of these materials (245 and 312 g/kg respectively) which results in Ca phosphate formation (Gustafsson et al., 2008; Jenssen et al., 2010). Absol® is similarly rich in calcium (194 g/kg) and in an assessment of on-site wastewater treatment sites, significant amounts of calcium phosphate compounds have been identified in the filter media made of Absol® (Eveborn et al., 2009a). However, use of this material as an infiltration media for wastewater treatment is quite new and still under research.

### **Aims and objectives**

The aim of this study is to investigate the effects of an additional layer of Absol® on the whole filter media. Combination of Polonite® and Absol® in a “dual filter media” is expected to increase the longevity of the treatment system by raising the pH level of the wastewater. In other words, higher pH values in the influent can increase the life-span of dual-filter before it is exhausted. Since a strong relationship between higher PO<sub>4</sub>-P removal in Polonite® and higher level of pH in the effluent have been previously shown (Renman and Renman, 2010), it can be expected that a more alkaline influent with higher pH values which lasts for a longer period of time, can delay the drop in orthophosphate removal rate or make it occur in a more gentle slope. The important issue regarding the analysis of filter media is that the experiments should be carried out in a relatively long period of time so that the researcher can analyze performance of the material over a time-frame comparable to a full-scale system. For this reason, the column experiments in this study have been down-scaled in terms of geometric dimensions and hydraulic loads in order to have a comparable model with real-scale systems. Two experiments, one with filter layers of 5 cm and the other with layers of 15 cm have been designed to reveal the potential capacity of Absol® in combination with Polonite® in phosphate removal from domestic wastewater. Moreover, the relationship between the varied thickness of layers and the orthophosphate content of the effluent and pH values are evaluated. A well-performed analysis on columns with different lengths of layers, their PO<sub>4</sub>-P removal and pH dependency can assist small-scale treatment designers with a more efficient approach and optimized utilization of reactive filter materials.

### **MATERIALS**

Filter materials used for the experiments were sand, Polonite® and Absol®. It is desirable to increase the contact of wastewater with any filter materials as phosphate in the wastewater would have a longer time to react with filter media. However, particle size is not the only parameter that needs to be taken into account. The optimal particle size of a filter media has to provide the infiltration system with proper hydraulic properties. Specifically in the experiments carried out in this study, tubes and filters could easily clog due to the laboratory-scaled design of the experiment. Although a finer selection of a material can result in higher removal efficiency, practical particle size distributions

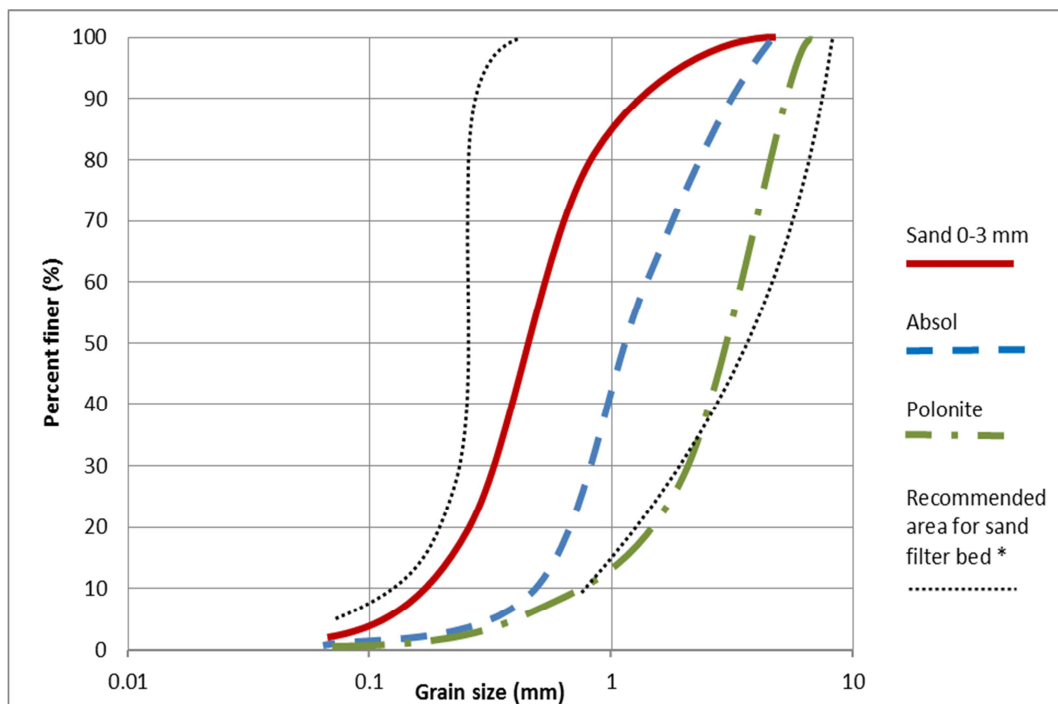
for all three materials should be a compromise between two equally important issues, i.e. surface contact and hydraulic conductivity.

Sand was supplied by S:t Eriks AB made for filling sandboxes and with particle size of 0-3 mm. However, the proportion finer than 0.074 mm was removed to prevent potential clogging and wash-out of the grains into the layers below.

Polonite® is manufactured from siliceous sedimentary Opoka rock that was deposited in Mesozoic era. Opoka is originally from south-eastern Poland and its high porosity is because of its amorphous structure.  $\text{CaCO}_3$  and  $\text{SiO}_2$  are the main compounds that compose Polonite® by 50 % and 40 % respectively; whereas Al, Fe and other oxides compose the rest (Vohla et al., 2011). Polonite® is produced by heating Opoka to 900 °C in different fractions. This material is strongly alkaline due to the reactive lime and wollastonite phases (Gustaffson et al., 2008). Polonite® for this study was supplied by Bioptech AB and a range of particle size between 2 and 4 mm is selected for infiltration.

The third material is a mixture of sand, crushed concrete and heated lime-stone, called Absol®. This white granular material was supplied by Yxhult/Svesten AB and it is applicable as sorbent for oils, paint spills etc. (Renman et al., manuscript in preparation, as cited in Ekeborn et al., 2009a). The same particle size of 2-4 mm has been selected for the additional layer of Absol® in the column experiments.

Sieve analysis for sand, Polonite® and Absol® was carried out in the laboratory according to ASTM D6913. The analysis was done on materials delivered from the companies prior to the removal of the unwanted fine fractions. Figure 2 demonstrates the distribution curves for three materials. In this figure, a recommended distribution of particle size for a sand bed filter is also presented from its source. The recommended area is limited by two dotted curves in black and as it can be seen from the figure, all three materials, with a reasonable



**Figure 2. Particle size distribution for three materials and sand bed filter recommendations (after Bjur and Malbert, 1982).**

approximation, fit within the suggested limits. However, it should be noted that the materials used for the experiment, as explained earlier, are customized in their particle size due to the practical issues concerned. Nonetheless, this figure can be used to demonstrate the suitability of granular size of materials supplied by the mentioned companies for large-scale filter beds with little or no needed modification.

Chemical composition of the reactive filter materials can be seen in Table 1. The unit of figures presented is g/kg dry matter and it should be noted that this table lists major elements in the filter materials and the total chemical composition is not limited to the elements shown in the table.

Wastewater used to feed the experiments was collected from on-site treatment systems for residential households in Vallentuna municipality. Collection of wastewater was carried out in late winter and spring of 2011 and containers were kept in the laboratory of “Land and Water Resources Engineering” at the Royal Institute of Technology, where the experiments, sampling and measurements were performed.

## EXPERIMENTAL METHODS

### Experiment set-up

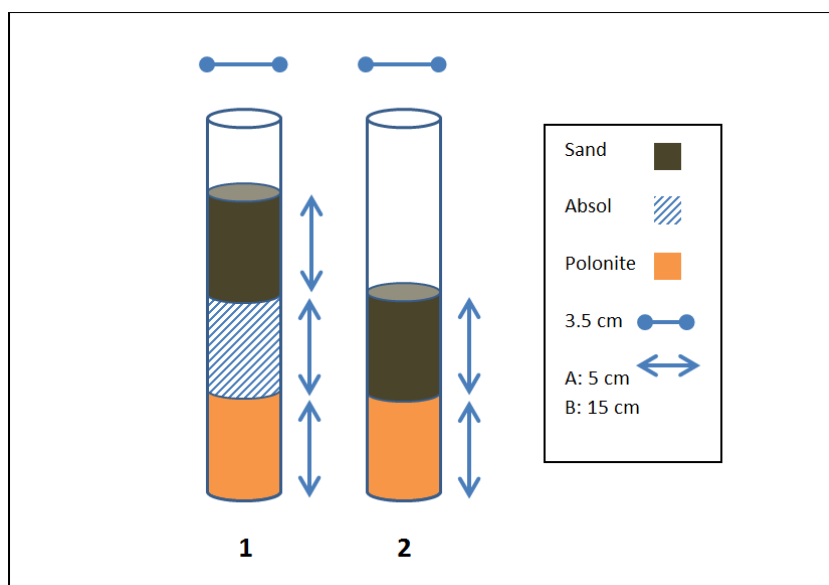
To analyze the influence that height of dual filter media has on phosphorus removal, two column experiments were performed. In the first experiment (A), two transparent cylindrical plastic pipes with total length of 20 cm and inner diameter of 3.5 cm were filled with filter media. Bottom of columns were filled with a 5 cm layer of Polonite® with particle size of 2-4 mm; column A1 was filled with an additional layer of Absol® as the second layer (2-4 mm) and finally both A1 and A2 columns were filled with a top 5 cm layer of sand (0.074-3 mm). Filter pads were placed on bottom of the columns and between each of two filter layers to prevent loss of the filter material into other layers and the effluent tubes. A piece of filter pad was also used on the top layer of each column in order to distribute the wastewater over the whole section of the sand layers.

Experiment B had a generally similar design with layers of a larger thickness. Columns were prepared by 15 cm layers of reactive filter materials and sand. The total length of columns was 55 cm with inner diameter of 3.5 cm. Figure 3 shows the schematic design of columns in experiments A and B with the only different part being the thickness of layers (See appendix II for column images in the laboratory). The amount of material used for each layer was weighed and the figures are presented in Table 2. Columns were completely covered with aluminum foil to protect the media from light and simulate filter beds under the ground. Columns were fed in the room temperature (20-22°C) with domestic wastewater, three times a day: 06:00 (30 minutes), 12:00 (15 minutes) and 15:30 (15 minutes), with similar intervals to those of real filter bed for on-site treatment systems. Wastewater was pumped by means of a peristaltic pump at approximately 15 ml per minute resulting in an unsaturated vertical-flow infiltration system. Influent pumping rate

**Table 1. Chemical composition of reactive filter materials.**

	Elements (g/kg)				Source
	Si	Al	Ca	Fe	
Polonite	241	27	245	16.5	Gustafsson et al., 2008
Absol	232	10	194	8.2	Renman et al.*, as cited in Eveborn et al., 2009

\*: Manuscript in preparation.



**Figure 3. Layout of experiments A and B.**

was calculated according to design value of 60 liter wastewater generation per square meter bed filter per day. A large container was used for storage of the untreated wastewater. This container was equipped with an air filter made of glass and filled with Polonite® to provide an aerobic environment in the bucket and reduce the unpleasant odor. Experiment A was run from April 8<sup>th</sup> 2011 for 50 days and experiment B was started on May 27<sup>th</sup> 2011 and continued for 119 days.

### Sampling

Effluent samples for experiment A were taken five times a week for the first half of the total running time and thereafter three times a week. Effluent sampling for experiment B was done according to a schedule of three times per week and the intervals between sampling increased when approaching the end of the experiment. One 20 ml sample was collected from each column and sample bottles were kept in freezer before they were analyzed for their phosphorus content. Fewer samples were also collected from wastewater container throughout the experiments to monitor the natural variations of concentrations of influent in matter of time.

### PO<sub>4</sub>-P and pH measurements

Inorganic phosphate constitutes orthophosphate and polyphosphates with the former being the most stable form of phosphate. In this study orthophosphate ion of the samples was measured by colorimetric method, using Aquatec Analyzer which operates based on Flow Injection Analysis (FIA). Prior to running the equipment samples were removed from the freezer and they were allowed to melt back to liquid phase and afterwards, they were filtered through 0.45 µm filter (See appendix II for the image of Aquatec Analyzer used for determination of

**Table 2. Weight of materials in experiments A and B.**

	Weight (g)	
	A	B
Polonite	46.6	226.1
Absol	15.3	46.1
Sand	71.1	106.6

PO<sub>4</sub>-P). Each sample was analyzed for its pH value using Orion 210A pH-meter. Analysis was carried out on melted samples on the same day orthophosphate concentrations were measured.

### Theoretical assumptions

Phosphorus removal efficiency is calculated according to the formula below:

$$P_{removed} = \frac{C_{ave} - C_e}{C_{ave}} \times 100$$

$P_{removed}$  (%) is the percentage of removed orthophosphate ions,  $C_{ave}$  (mg/l) is the average influent concentration in the untreated wastewater during the experiment period and  $C_e$  (mg/l) is the orthophosphate concentration collected from each column. Phosphorus retention capacity of filter media is based on the simple mass balance equation as follows:

$$P_{captured} = \sum \frac{(C_{ave} - C_{e(i)}) \times V_i}{m}$$

In the equation above,  $P_{captured}$  (g/kg) is the amount of phosphorus captured in the filter media,  $C_{ave}$  (mg/l) is the average concentration in the effluent,  $C_{e(i)}$  (mg/l) is the outlet concentration of the wastewater collected from the bottom of the columns,  $V_i$  (l) is the volume of wastewater treated in each interval and  $m$  (kg) is the weight of the filter material used in the columns. In captured phosphorus calculation, each column is assumed as a single layer without taking into account the top layer of sand as it is not believed to play a direct role in phosphorus retention.

## RESULTS AND DISCUSSION

Results obtained from both experiments are presented in the following sections. Experiment A and B are discussed individually and on their own circumstances. Thereafter, outcomes of both experiments are examined to draw reasonable conclusions.

### Phosphorus analysis

#### *Experiment A*

Orthophosphate concentrations for experiment A during the operation time of 50 days are measured (Fig. 4; and see appendix I-1 for details). In this figure, A1 represents the column filled with Polonite®, Absol® and sand whereas A2 denotes the two-layer column of only Polonite® and sand. Samples from influent wastewater were taken from the container used for sewage storage and pumping. Sampling from the feeding container was only aimed to monitor the variations of phosphorus in the untreated wastewater due to biological reactions. For this reason, frequency of sampling from stored sewage was scheduled to be lower. Wastewater was refilled on day 29 resulting in a minor drop in phosphate concentration of the inlet. Phosphate content in the untreated wastewater fluctuates between 3.59 and 4.57 mg/l with an average value of 4.13 mg/l. Irregular phosphate concentrations are found in effluent during the first 7 days in columns A1 and A2. From day 7 onwards, filter layer of Polonite® (A2) still showed unstable concentrations although outlet values seem to follow a more stable increasing trend from day 29. Column A1, on the other hand, demonstrates a smooth and consistent trend for samples in the treated sewage. The column with Polonite® as the only reactive filter material exceeds 1.0 mg/l of concentration after day 12 while the double-layered reactive filter keeps phosphate



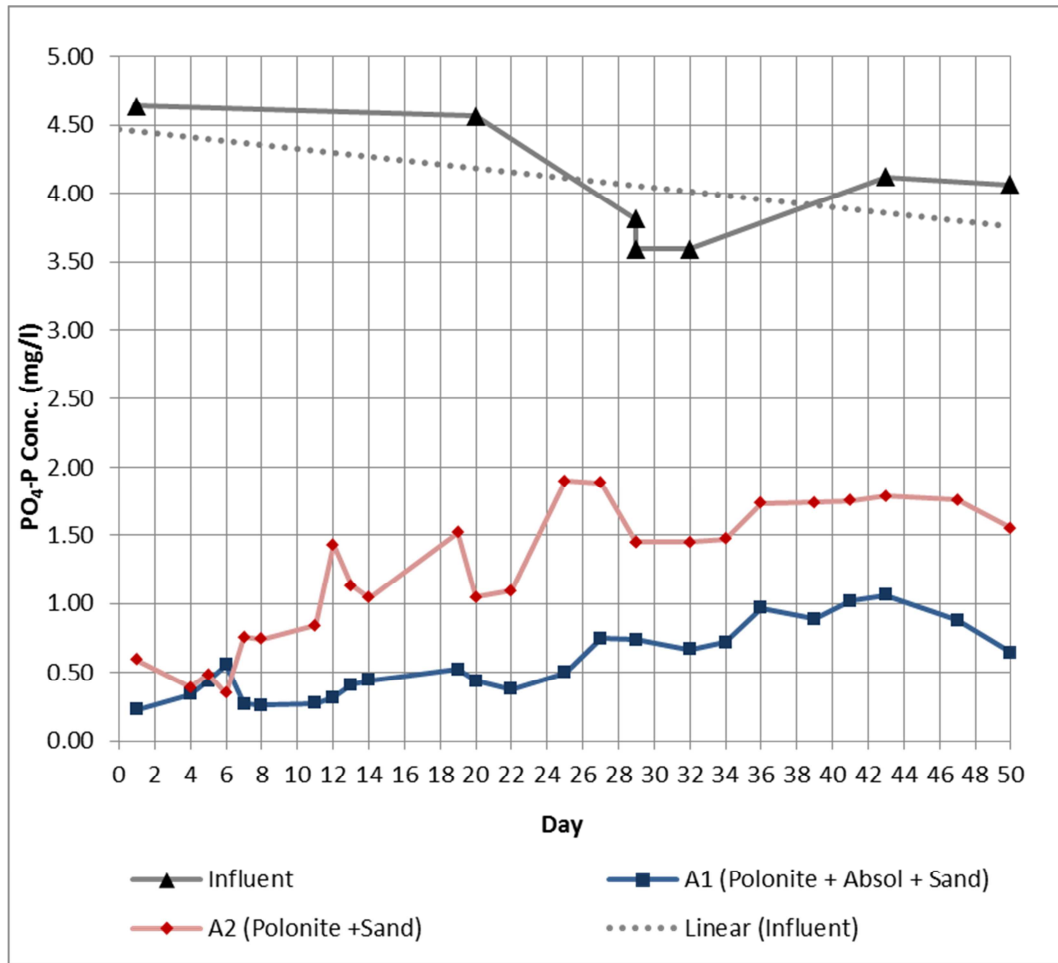
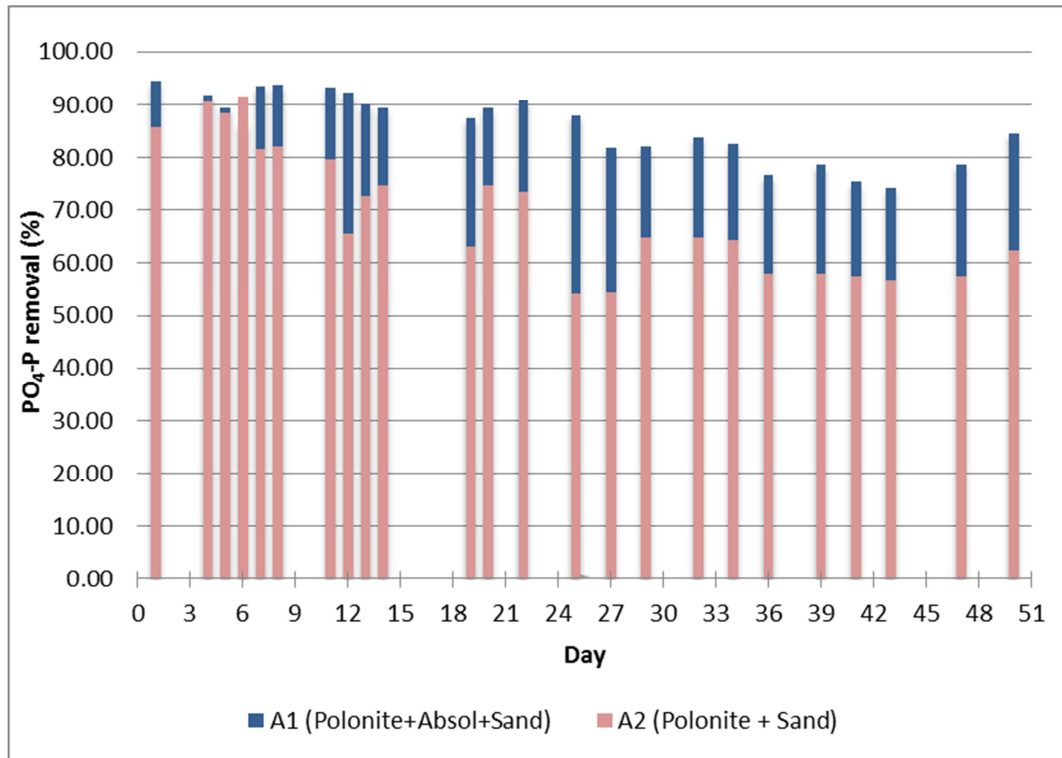


Figure 4. O-phosphate concentrations in Experiment A

concentrations almost below 1.0 mg/l with exception of day 41 and 43 (Fig. 4). Both columns show less variation in outlet contents while approaching to the end of the experiment. Although the amount of phosphorus captured in the filter media is reduced against the elapsed time, it can be implied that reactive filter materials in both columns exhibited more reliable removal results after a certain period of time. In other words, even though treatment performance has been reduced compared to the beginning of the experiment, fluctuation and sudden rise and falls seem to be eliminated during the second half of the operation. The drop seen in phosphate concentration on day 47 and 50 can be associated with the lower phosphorus availability in the influent. The results show a continuous increase of orthophosphate ions in outlets from both columns while the double-layered filter material demonstrates a more gradual increase over time.

The difference between orthophosphate concentrations of purified wastewaters from two columns seem to be constant during most of the running time (Fig. 4). Wastewater collected from A1 had in average 0.67 mg/l less  $\text{PO}_4\text{-P}$  because of its additional layer of Absol® in its configuration. It is of interest to forecast the performance of the infiltration columns in a longer time frame. For this purpose, trend-lines can be drawn on the available data and the mathematical equations may help us extrapolate the data. Linear trend-lines for phosphorus concentrations would give slopes of 0.0148 and 0.0283 for columns A1 and A2 respectively (Effluent trend-lines are not previewed on Fig. 4).



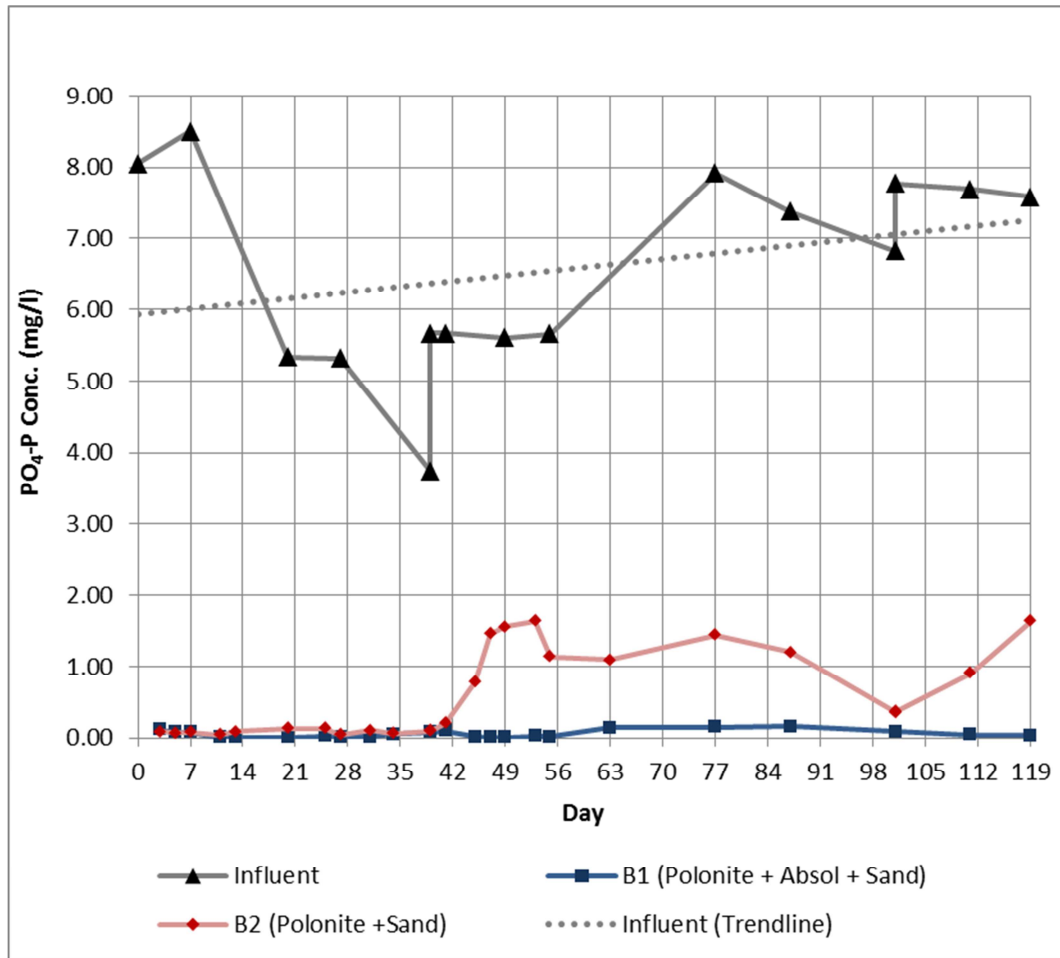
**Figure 5. Removal efficiency of columns A1 and A2.**

While a linear regression is not a perfect approach to model the performance of filters, the slope magnitudes show that the difference between orthophosphate concentration in wastewater treated by A2 and A1 increases by a factor of 0.0135. That is to say, if the experiment had continued the difference in amount of retained phosphates in two columns would have become larger and A1 would have showed a better performance over A2. Such forecast is however valid only until the reactive materials are saturated and fail to capture any more amounts of phosphorus. Phosphorus removal efficiencies (Fig. 5) are calculated against the average inlet concentration equal to 4.13 mg/l. The further phosphorus capture in column A1 due to the 5 cm layer of Absol® is clearly seen in this figure.

### **Experiment B**

Samples collected from two columns in experiment B were measured together with influent concentrations (Fig. 6; and see appendix I-2 for details). The lengths of the columns and consequently the heights of each filter layer are enlarged three times in comparison with experiment A. For this reason, orthophosphate concentrations in the samples collected from outlets remain relatively low during the time of operation.

Columns B1 and B2 functioned well with fresh reactive filter materials until day 41. In this phase, single and double-layered reactive media showed very low concentrations of phosphorus with the latter showing slightly lower values. This is expected due to the freshness of reactive media in the beginning. From day 41, a sudden rise is noted in column B2. This rise in the phosphorus content of the treated wastewater is apparently synchronized with the refilling of the influent container with new wastewater. Although this quick increase seems to be due to the higher phosphorus load on the columns, B1 demonstrates no impulsive response to this greater load. Moreover, phosphate concentration



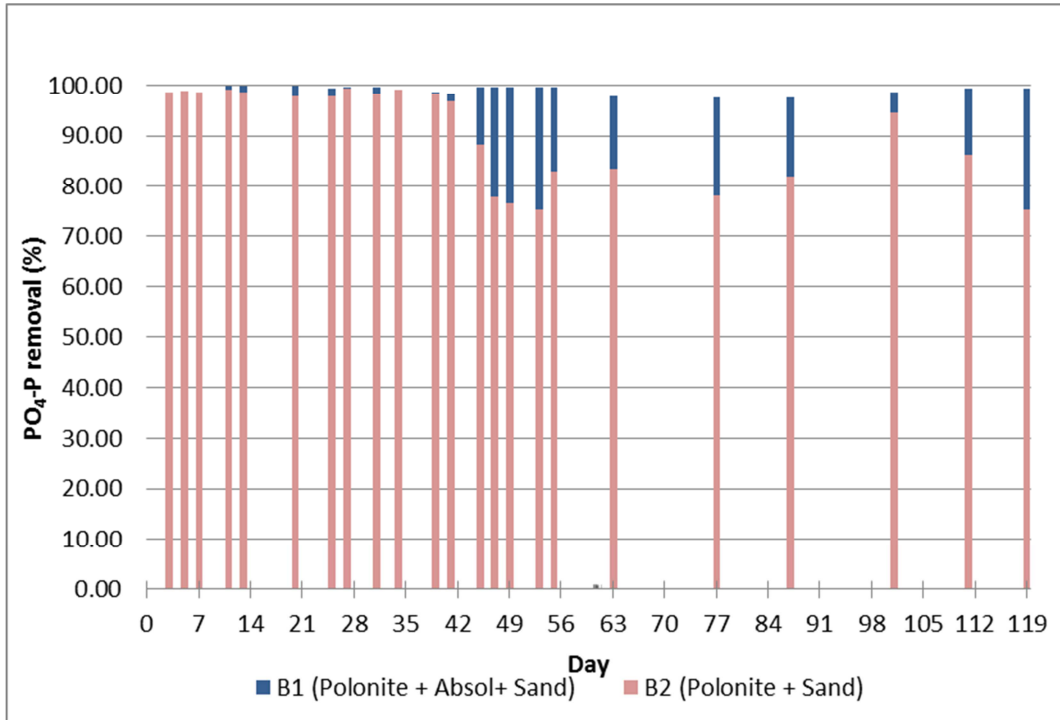
**Figure 6. O-phosphate concentrations in Experiment B.**

exceeded 1.0 mg/l as early as day 46 in wastewater treated by column B2. Absol®-complemented column i.e. B1, continuously captured a considerable level of phosphate resulting in the maximum outflow concentration of 0.16 mg/l on day 87. Samples collected from B1 showed 0.53 mg/l (mean value) lower  $\text{PO}_4\text{-P}$ . However, as B2 fails to keep up its high efficiency after day 41, treated samples from B2 showed 1.0 mg/l higher concentration between days 41 and 119. A linear trendline for infiltrated wastewater would show a slope of 0.0108 and 0.0004 for B2 and B1 respectively. This simple approximate model indicates the gap between two columns with a factor of 0.0104 especially in longer time perspectives.

Removal efficiency of two columns against the influent phosphate concentration can be distinguished in percentage (Fig. 7). Since the inflow values fluctuate from day to day, the average value of 6.65 mg/l is taken as the reference. The effect of the additional layer of Absol® is visible in the bars as time progresses.

#### **Experiment A vs. B**

Influent and effluent orthophosphate concentrations and removal efficiencies of experiment A and B are summarized in Table 3. In Norway and Sweden, total P concentration should be limited to 1.0 mg/l (Renman and Renman, 2010). As stated earlier, orthophosphate ions in domestic wastewater can exist up to 80 % or more of the total phosphorus content (Personal communication: Renman, Gunno). A



**Figure 7. Removal efficiency of columns B1 and B2.**

maximum level of 0.8 mg/l PO<sub>4</sub>-P can therefore be assumed as the criterion for orthophosphate ions in treated wastewater. Column A2 exceeded the limit very shortly after only 8 days of being in operation (Fig. 4). B2 with three times larger layer of Polonite® was able to keep the limit until day 45 and resulted in sudden increase in phosphate ions afterwards (Fig. 6). Among columns with Absol®, A1 exceeded the criterion after 34 days (Fig. 4) while B1 with 15 cm layers of reactive filter material, yielded in very low PO<sub>4</sub>-P concentration (0.04 mg/l, day 119) and was far from the assumed limit (Fig. 6).

Hylander et al., (2006) did a similar experiment with several columns filled with sorption materials. They have shown that the 50 cm layer of Polonite® with particle size between 2-5.6 mm and under unsaturated conditions had a mean concentration of P of 0.1 mg/l. The average P concentration of 4.2 mg/l of influent in their experiment shows more than 97 % removal of PO<sub>4</sub>-P in 67 weeks. On the contrary, average values of effluents and the total removal efficiencies for columns A2 and B2 with the same material in our experiments do not show promising results (Table 3). Polonite® layer of neither 5 cm nor 15 cm was not able to reduce phosphate ions of domestic wastewater to the level below the required limit. Since Polonite®, as mentioned earlier, had previously shown good removal performance by Hylander et al., (2006) it is apparent that the defined height of the layers in columns A2 and B2 did not provide the wastewater with sufficient contact surface with reactive materials. Results from column A1 similarly demonstrate insufficient removal efficiency in double-layered column of Polonite® and Absol® when the layers are only 5 cm long. Although the additional layer improved treatment outcomes with further sorbed phosphorus and more gentle and stable increase in effluent concentrations over time, it could not fulfill outlet criterion for more than 34 days (Fig. 4). B1 exhibits the best performance among four column experiments carried out in this study. Two layers of reactive materials 15 cm each with a layer of sand

**Table 3. Influent and effluent orthophosphate concentrations and removal efficiencies of experiment A and B (mean  $\pm$  standard deviation)**

Experiment	Operation time (day)	Influent (mg/l)	Column	Effluent (mg/l)	Removal (%)
A	50	4.05 $\pm$ 0.43	A1	0.58 $\pm$ 0.25	85.99 $\pm$ 6.14
			A2	1.25 $\pm$ 0.49	69.62 $\pm$ 11.92
B	119	6.65 $\pm$ 1.41	B1	0.06 $\pm$ 0.05	99.13 $\pm$ 0.72
			B2	0.59 $\pm$ 0.61	91.07 $\pm$ 9.19

on top was able to keep the outlet concentration of PO<sub>4</sub>-P far less than the limit with the average concentration of 0.06 mg /l during 119 days. Layer dimensions in column B1 is near the optimal lengths required to meet the phosphorus discharge limit (1 mg/l total phosphorus).

#### ***Phosphorus removal mechanism in columns***

Phosphorus removal from wastewater by chemical processes is mainly based on chemical precipitation. Calcium-phosphorus precipitation is one of the common methods of removing phosphorus due to the lower cost and easier handling. In this process, orthophosphate is removed by formation of hydroxyapatite Ca<sub>5</sub>(PO<sub>4</sub>)<sub>3</sub>OH a calcium phosphate salt (HAp). However, as domestic wastewater is deficient in calcium, calcite or other artificial sources are used to compensate for the deficiency. By providing the sewage with sufficient calcium ions, orthophosphate crystallizes as a calcium phosphate (de-Bashan and Bashan, 2004). Reactive filter media such as Polonite® and Absol® as we have in our case are referred to adsorbents or sorbents and interact with chemical species such as phosphate ions (Cucarella and Renman, 2009). These reactive filter materials generally have high pH values and release calcium to the water phase and causes phosphorus removal by formation of HAp. While HAp formation in a short time requires a large supersaturation, many filter materials are likely to provide such conditions for HAp to be accumulated. Once HAp is formed, it would not dissolve back to the water phase due to its low solubility (Gustafsson et al., 2008). However, it should be noted that the crystallization of calcium phosphate is complicated, because it concerns with the formation of several possible precursors and their transformation (Song et al., 2006). According to Cucarella and Renman (2009), chemical processes that control the interactions between phosphorus ions in sewage and reactive filter materials are not absolutely recognized. For this reason, they have identified that “sorption” is an appropriate expression defined by McBride (1994) to explain chemical reactions ranging from precipitation to adsorption. It is also used generally as a synonym for retention, which covers physical, chemical and biological processes in which P is immobilized (Hylander et al., 2006)

Eveborn et al., (2009a) investigated chemical forms of phosphorus present in a set of used filter materials including Polonite® and Absol®. It is reported that filter material Polonite® contained phosphorus species in forms of octacalcium phosphate (OCP), hydroxyapatite (HAp), monetite (MTE), amorphous calcium phosphate ACP and phosphate adsorbed to aluminum oxide (Alox-P). Reactive filter Absol® in this study accumulated only ACP and OCP. The percentage of OCP present in Polonite® and Absol® were found to be 31 % and 37 %. Octacalcium (OCP) with a formula of Ca<sub>8</sub>H<sub>2</sub>(PO<sub>4</sub>)<sub>6</sub>.5H<sub>2</sub>O, has structural similarities with HAp (Ca<sub>10</sub>(PO<sub>4</sub>)<sub>6</sub>(OH)<sub>2</sub>) while its Ca/P ratio differs (LeGeros, 1985). The major phosphate species in Absol®, however, was ACP with

63 % of total phosphate compounds in the filter media. The percentage of ACP in Polonite® was reported to be only 14 %. It is therefore implied that Absol® as a filter material has a greater ability of accumulating phosphorus as non-crystalline compounds (ACP) while Polonite® mostly contained crystalline phosphates.

### Retention capacity and lifetime

The accumulated phosphorus in each layer of reactive filter material is not individually analyzed in this study and sorbed phosphorus calculations are based on mass balance equation described earlier. According to the assumptions made, the columns with two layers of reactive filters i.e. Polonite® and Absol® are considered as one single layer and the total weight was calculated as the sum of two layers. Phosphorus sorbed in the columns in milligram and the phosphorus sorption capacity of the columns in one kilogram of reactive material are summarized in Table 4. In this table, the difference in phosphorus captured between columns 1 and 2, can be attributed to the additional layer of Absol® in columns 1. As this difference is relatively low compared to the amount of phosphorus captured in Polonite®, it could be understood that Absol® had a relatively lower contribution to the treatment efficiency. However, it should be noted that the outlet concentration in column B1 was still far from the target value required as quality criterion (i.e. 1.0 mg/l). In experiment B, the efficiency of double-layered column (B1) over B2 increased over time. That is to say, the contribution of the additional layer cannot be clearly seen in a short period of operation time and specially before reaching the target limit.

Life time of a filter media is often calculated by multiplying the retention capacity of the filter material by the volume of the filter bed with the assumption that when the outlet concentration exceeds the target value, the entire filter material is saturated with phosphorus (Kløve and Søvik., 2005). In experiments A, effluent concentrations reached 1.0 mg/l few days before the end of the experiment in both columns (Fig. 4). Column B2 exceeded the limit, whereas B1 showed low values of phosphorus until the last day. Since column B1 was not saturated and did not exceed the limit, it is impossible to propose a reliable life time for its reactive filter configuration.

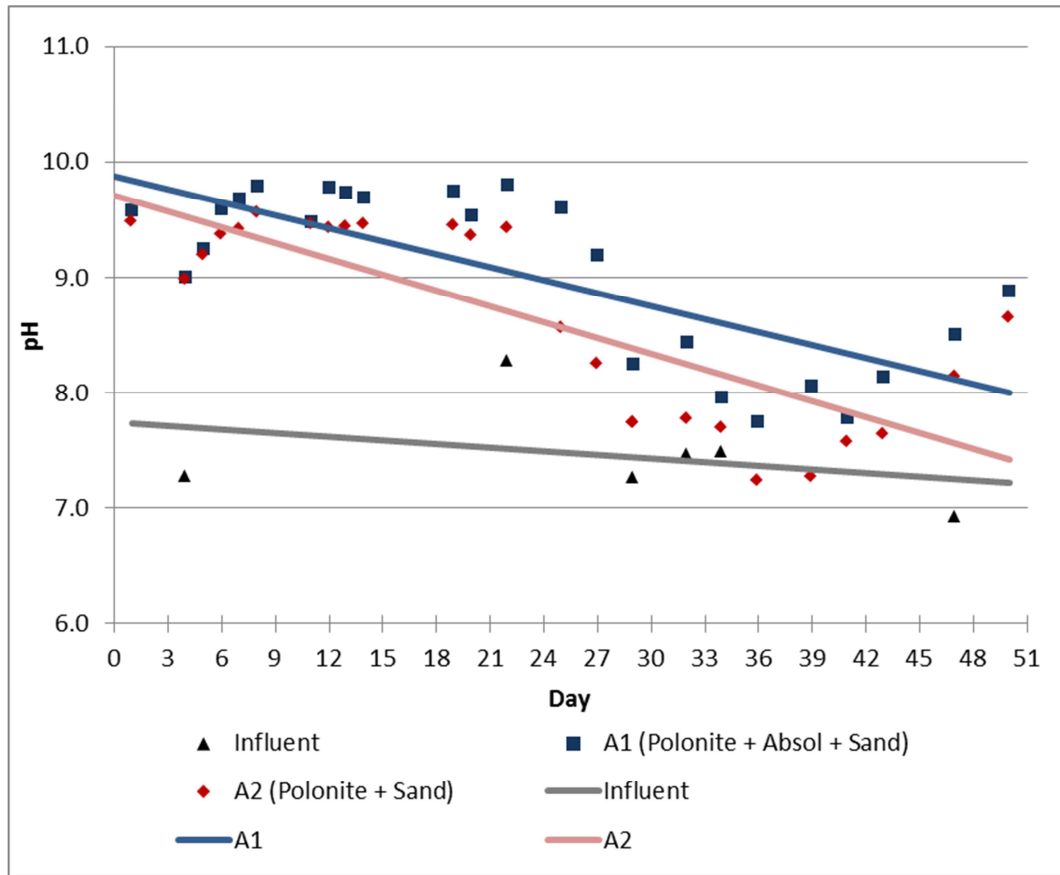
### Phosphorus vs. pH

#### *Experiment A*

Values of pH in treated and raw wastewater in experiment A were measured (Fig. 8; and see appendix I-3 for details). Reactive filter media increased the level of pH to the range of 09-10 in the beginning of the experiment and the alkalinity of the treated wastewater dropped rather rapidly. There is an unexpected increase in pH values during the last third of the total operation time. Extra layer of Absol® in column 1 has resulted in a slightly more alkaline effluent according to the linear

**Table 4. P sorbed (mg) in reactive filter layers and P sorbed in unit weight of reactive materials (g/kg).**

Column	P sorbed (mg)	P sorbed (g/kg)
A1	10.31	0.166
A2	8.06	0.173
B1	32.58	0.120
B2	29.20	0.129



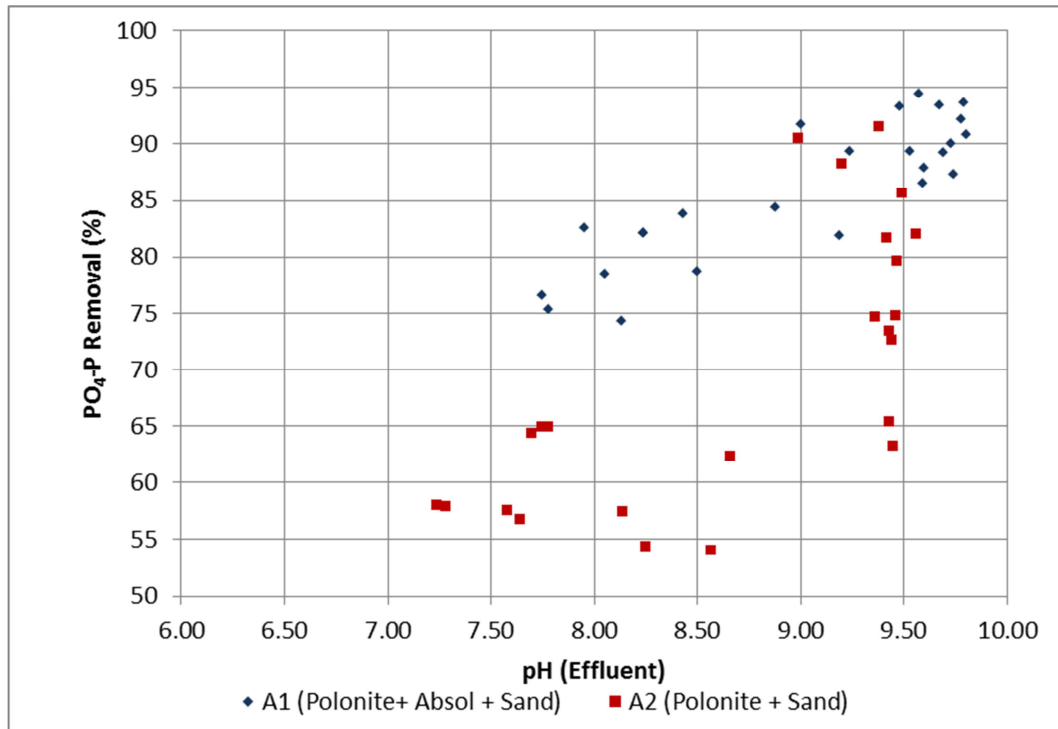
**Figure 8.** pH values for experiment A.

regression lines. Level of alkalinity dropped rather quickly during the experiment. Level of pH in column B2 with Polonite® approached the influent level near the end. Absol® resulted in a less steep decrease of alkalinity, however, the difference between two columns were not considerable.

It is of interest to study pH values of effluent and the efficiency of treatment. Hence relationships between pH in the effluent and orthophosphate removal efficiency in the columns are considered (Fig. 9). According to this figure, higher removal efficiencies are concentrated around higher pH values. That is to say, the removal mechanism in filter media can be connected to the alkalinity of the wastewater collected from the outlet of columns. Similarly, lower orthophosphate concentrations are spread over lower pH values.

### **Experiment B**

Variations in pH values for experiment B is demonstrated in Figure 10 (See appendix I-4) for details). Due to the longer filter layers, treated wastewater samples are greater in alkalinity especially in the beginning and the gradual decrease of pH against time is visible on the graph. Column B2 shows more irregular values compared to column B1. The total pH drop approximately reached 3 units during the age of experiment not taking into account the unexpected rise found on the last samples. Regression lines demonstrate the decrease of pH level in columns B1 and B2. Although B1 had a higher pH during the operation, both columns exhibited similar slopes of pH values against time. Effluent samples collected from B2 on the last days of the experiment, had nearly similar alkalinity to the raw wastewater. B1 does not seem to



**Figure 9. pH vs. Orthophosphate removal, experiment A.**

be able to keep its effluent alkalinity for a significantly long time either. Considering the current slope, column B1 would have no effect on the alkalinity of wastewater after 154 days.

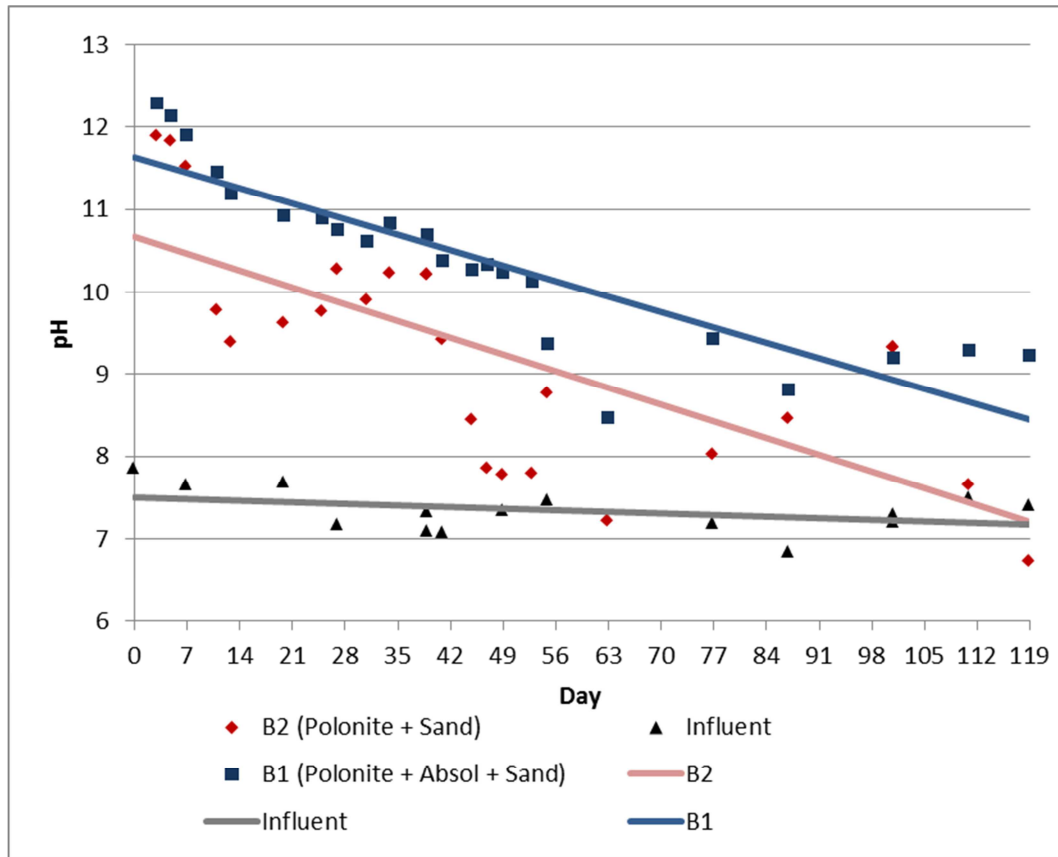
Similar to experiment A, higher removal efficiency is seen around more alkaline samples (Fig. 11), whereas a correlation is found between lower pH values and reduced removal efficiency.

#### ***pH implications***

Different ranges of pH in effluent are believed to affect the type of calcium phosphate that is produced. In conditions when pH is greater than 9, amorphous calcium phosphates (ACPs) are thought to convert directly into HAp, whereas in pH between 7 and 9, they are converted to a precursor phase OCP phase and then to HAp (House, 1999). However, these pH range conditions do not seem to agree with phosphorus speciation carried out on Absol®. Ekebom et al., (2009) found that ACPs constituted about 63 % of total phosphate species in the used filter media while no HAp was detected (pH: 9.25). In our experiments, pH ranged above and below 9. It is therefore difficult to judge which phosphate species were exactly formed in each layer.

Correlation between alkalinity of reactive filter materials and orthophosphate removal efficiency has already been shown by Renman and Renman (2010). As it was previously showed, effluent from reactive filter materials had a higher level of pH. When wastewater is in contact with solid reactive matter, some H<sup>+</sup> ions are removed by the reactions in the solution. Subsequently, removed H<sup>+</sup> ions are replaced by other cations such as Ca<sup>2+</sup>. Charge balance is therefore altered and alkalinity is increased. The genuine reason for alkalinity increase is not the presence of new positive ions. Alkalinity is increased because hydrogen ions are consumed to give Ca<sup>2+</sup>. Reduction of pH during the operation time of the filter media can be a consequence of calcium loss after crystallization of calcium phosphate (Adam et al., 2007; Song et al., 2006). Relationship





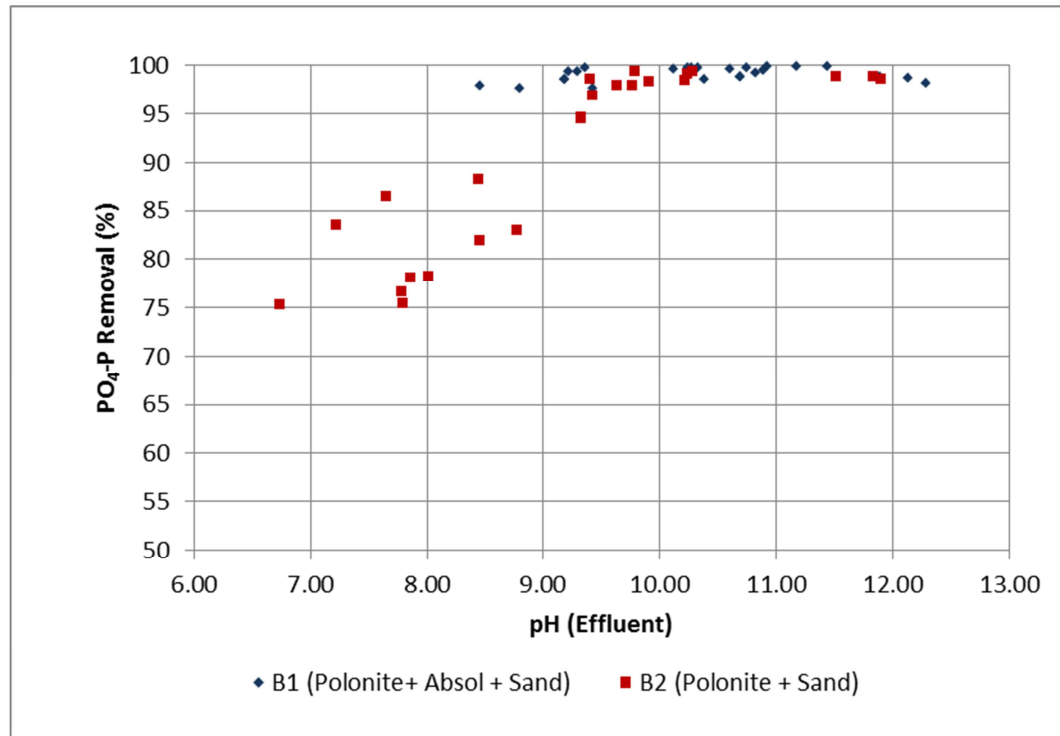
**Figure 10. pH values for experiment B.**

between decreased pH and lower removal efficiency observed in Fig. 9 and Fig. 11 can be explained by the same reason. Phosphorus in wastewater solution develops Ca-P compounds. Less availability of soluble calcium ions reduce the ability of filter materials to consume more  $H^+$  and therefore effluent level of pH declines.

As long as infiltration bed is efficiently removing orthophosphates in real-life systems, discharged treated wastewater seems to continue its high level of alkalinity. High levels of pH in treated wastewater using Polonite® and Absol® would pose a threat to the environment if the water body receiving the effluent is too small. However, as the volume of effluent that exits onsite treatment facilities is relatively small, it can readily be diluted. Moreover, high levels of pH can be an improvement to many Scandinavian streams with low levels of pH (Jenssen et al., 2010).

Heistad et al., (2006) have suggested that the absence of *E. coli* in the virus analyses of their reactive-filter based compact system can be due to the inactivation effect caused by high pH levels. Therefore, higher levels of alkalinity can probably reduce the spread of harmful bacteria with providing undesirable environment for bacteria.

In wastewaters supersaturated with respect to calcium phosphates, it can happen that no calcium phosphate crystallization is occurred. This phenomenon is believed to be caused by some inhibitors (Song et al., 2006). Song et al., (2002) reports carbonate as the most common cause inhibiting calcium phosphate formation. Since negative effect of carbonate on precipitation rate varies in different levels of pH, solution pH is the key element which governs the reduced precipitation caused by



**Figure 11. pH vs. Orthophosphate removal, experiment B.**

carbonate. The reduction observed by carbonate is explained by how both carbonate and phosphate compete for calcium. Carbonate decreases availability of free calcium ions by developing ion pairs between carbonate and calcium. Moreover, at pH levels between 9 and 11, carbonate may be co-precipitated with phosphate and produce a precipitate with relative low phosphorus content (de-Bashan and Bashan, 2004). The contribution of carbonate in reduced phosphorus removal from wastewater needs to be investigated deeper in wastewaters with higher  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$ .

### Potential for nutrient recovery

With exploitation of rock phosphate at current rate, it is so important to find an alternative source for the high demand of phosphorus in industry and agriculture. Removed phosphorus from wastewater can be recovered for reuse depending on the type of nutrient removal mechanism that has been applied. Reactive filter materials that have a very high adsorption capacity can have a good potential for phosphorus recovery. The main field for using removed phosphorus by reactive materials is agricultural fertilizers. The most important factor is the availability of phosphorus for uptake by plants. The availability of phosphorus is in turn dependent on the solubility degree of calcium phosphates. In a phosphorus recovery perspective, it is preferred to have phosphorus in non-crystalline structures or structures with less complexity rather than more crystalline calcium phosphates (Eveborn, 2010). As mentioned earlier, the major fraction of phosphorus captured in Absol® was previously reported to be in form of ACP (amorphous calcium phosphate). Therefore, Absol® with ACP would have larger fractions of available phosphorus to plants, whereas Polonite® with more crystalline precipitates, i.e. HAp and OCP, might need pre-treatments before being used as fertilizer. De-bashan and Bashan, (2004) have proposed using two common soil microorganisms PSB and PSF for recovery of precipitated phosphorus. These microorganisms produce organic acids

that are strong enough to dissolve HAp formed in wastewater treatment process.

The column experiments carried out in this study are in small laboratory scale and the amount of phosphorus captured in the filter materials was not substantial. However, the above suggestions can be applied in large-scale infiltration systems to recover phosphorus as soil fertilizer. It is also worth mentioning that nutrient availability for different sorts of plants and various soil types cannot be judged only by phosphorus speciation. On the contrary, there are a number of other factors that influence the rate and quality of plant uptake. The type of the plant, soil mechanical conditions, acidity of the soil, elements already available in the soil and temperature are all factors that seem to have influence on the efficiency of applying a certain type of fertilizer on an agricultural land.

## CONCLUSION

In experiment A, effluent concentrations of  $\text{PO}_4\text{-P}$  from columns 1 and 2 exceeded the phosphorus discharge limit in Sweden and Norway during its operation time. Absol® in the additional layer of 5 cm (A1) resulted in an acceptable average  $\text{PO}_4\text{-P}$  concentration (0.58 mg/l) during 50 days but the last analyzed samples contained unacceptable amounts of phosphorus. Similarly, column 2 in experiment B failed to keep the phosphorus content below the limit although the effluent had in average 0.59 mg/l  $\text{PO}_4\text{-P}$  during 119 days. Between four column tests, column B1 demonstrated very good treatment results with average orthophosphate concentration of 0.06 mg/l during its time of operation. Absol® proved to assist for a more efficient performance and longer lifetime with respect to very low phosphorus concentrations in treated samples particularly in B1.

Among the tested configurations, it can be concluded that the length of infiltration materials is a key factor in its performance. Polonite® and Absol® have a good potential to function together in a dual-layered infiltration bed with optimal lengths, hydraulic conditions and other practical issues. Decrease of pH during the age of the experiment had a nearly similar slope in double and single layered columns. It can be a hint showing similar calcium phosphate crystallizations that occurred in both infiltration units. It can further be concluded that the increased longevity and better removal rates exhibited by Absol® cannot be directly measurable by levels of pH as expected in the aims and objectives.

The amount of captured phosphorus in investigated materials is too small to be judged upon. Materials were not saturated in respect to phosphorus due to the short time frame of the project and unsaturated conditions. Life time estimation of studied materials needs deeper research in larger pilot studies and alternative circumstances e.g. saturated conditions. Absol® is a potential reactive filter material in terms of nutrient recovery. It has been shown that phosphorus compounds in Absol® are mainly in forms of amorphous calcium phosphates which is easier to be used by plants due to its non-crystalline structure compared to other commonly formed crystals (HAp).

## SUGGESTIONS FOR FUTURE RESEARCH

It would be of interest to investigate the performance of dual filters in more details and with different experiment set-ups. This project was limited in time and therefore, several aspects of filter materials are not addressed. This study can be further continued employing the following suggestions:

- Phosphorus chemical speciation in each layer of multi-layered column experiment can be performed. Compounds found in each layer assist to distinguish each material's contribution to the total removal efficiency.
- Same column configuration can be operated in saturated condition and removal efficiencies can be evaluated and compared.
- A longer operation time of more than one year, with real-scale filter lengths would yield insights into the life-time and long-term performance of multi-layered infiltration systems.
- It is of benefit to see how one filter material can be replaced by the other. Two column experiments with equal total lengths can be designed to see how conventional infiltration materials can be substituted with noble reactive filter materials in multi-layered systems.
- Similar mentioned experiments can be carried out and complemented with total organic carbon (TOC), biochemical oxygen demand (BOD) and nitrogen measurements. Such measurements would allow a better understanding of infiltration efficiency in nutrients removal from domestic wastewater.
- Filter materials namely Absol® and Polonite® might function differently if placed in reverse order. It is therefore of interest to see how these materials would perform in a reverse order.

## UNCERTAINTIES AND LIMITATIONS

Onsite wastewater infiltration treatment facilities are often constructed under the ground not very far from residential houses that are connected to the treatment unit. The temperature varies according to the season and time of the day. In most lab-scaled studies and due to the practical considerations, experiments are performed under the room temperature (20-22 °C). The outdoor temperature and especially colder weather affects the removal efficiency and it can even lead to frozen pumps and serious practical problems.

As mentioned before, the cross section of columns, rate and frequency of wastewater pumped into the filters were proportional to large-scale filter beds. However, the small size of the experiment and the defined short time-frame would make it difficult to use exact conclusions for real-scale filter beds, especially their life-time. Further decisions based on the results should be made with caution and taking these limitations in mind.

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## APPENDIX I – MEASUREMENT DETAILS

1- PO<sub>4</sub>-P analysis experiment A*Table 5. Orthophosphate measurements in experiment A.*

Date Taken	Date Taken	Conc. (mg/l) A2	Conc. (mg/l) A1	Influent Con. (mg/l)
	0			
8-Apr	1	0.59	0.23	4.64
11-Apr	4	0.39	0.34	
12-Apr	5	0.49	0.44	
13-Apr	6	0.35	0.56	
14-Apr	7	0.76	0.27	
15-Apr	8	0.75	0.26	
18-Apr	11	0.84	0.28	
19-Apr	12	1.43	0.32	
20-Apr	13	1.13	0.41	
21-Apr	14	1.04	0.44	
26-Apr	19	1.52	0.52	
27-Apr	20	1.05	0.44	4.57
29-Apr	22	1.10	0.38	
2-May	25	1.90	0.50	
4-May	27	1.88	0.75	
6-May	29	1.45	0.74	3.81
6-May*	29	1.45	0.74	3.59*
9-May	32	1.45	0.67	3.59
11-May	34	1.47	0.72	
13-May	36	1.73	0.97	
16-May	39	1.74	0.89	
18-May	41	1.76	1.02	
20-May	43	1.79	1.06	4.12
24-May	47	1.76	0.88	
27-May	50	1.55	0.64	4.06

\*: Wastewater refilled

*Table 6. Orthophosphate removal efficiencies in experiment A.*

Date Taken	Date Taken	O-P Removal (%) A2	O-P Removal (%) A1
	0		
8-Apr	1	85.64	94.47
11-Apr	4	90.53	91.70
12-Apr	5	88.25	89.41
13-Apr	6	91.51	86.50
14-Apr	7	81.65	93.50
15-Apr	8	81.96	93.67
18-Apr	11	79.64	93.28
19-Apr	12	65.38	92.26
20-Apr	13	72.57	90.00
21-Apr	14	74.71	89.30
26-Apr	19	63.16	87.32
27-Apr	20	74.66	89.35
29-Apr	22	73.45	90.80
2-May	25	54.07	87.89
4-May	27	54.39	81.84
6-May	29	64.86	82.08
6-May*	29	64.86	82.08*
9-May	32	64.85	83.78
11-May	34	64.32	82.57
13-May	36	58.00	76.59
16-May	39	57.93	78.52
18-May	41	57.50	75.35
20-May	43	56.73	74.32
24-May	47	57.47	78.68
27-May	50	62.35	84.40

\*: Wastewater refilled



2- PO<sub>4</sub>-P analysis experiment B*Table 7. Orthophosphate measurements in experiment B.*

Date Taken	Date Taken	Conc. (mg/l) B2	Conc. (mg/l) B1	Influent Con. (mg/l)
27-May	0			8.053
30-May	3	0.091	0.118	
1-Jun	5	0.075	0.082	
3-Jun	7	0.077	0.077	8.499
7-Jun	11	0.04	0.01	
9-Jun	13	0.09	0.01	
16-Jun	20	0.13	0.01	5.34
21-Jun	25	0.14	0.03	
23-Jun	27	0.04	0.02	5.32
27-Jun	31	0.11	0.02	
30-Jun	34	0.06	0.05	
5-Jul	39	0.10	0.08	3.75
5-Jul*	39	0.10	0.08	5.67*
7-Jul	41	0.21	0.10	5.67
11-Jul	45	0.78	0.02	
13-Jul	47	1.46	0.01	
15-Jul	49	1.56	0.01	5.61
19-Jul	53	1.64	0.02	
21-Jul	55	1.13	0.01	5.66
29-Jul	63	1.09	0.14	
12-Aug	77	1.45	0.15	7.92
22-Aug	87	1.20	0.16	7.38
5-Sep	101	0.36	0.09	6.83
5-Sep*	101	0.36	0.09	7.77*
15-Sep	111	0.90	0.04	7.70
23-Sep	119	1.64	0.04	7.59

\*: Wastewater refilled

**Table 8. Orthophosphate removal efficiencies in experiment B.**

Date Taken	Date Taken	O-P Removal (%) B2	O-P Removal (%) B1
27-May	0		
30-May	3	98.56	98.13
1-Jun	5	98.81	98.70
3-Jun	7	98.78	98.78
7-Jun	11	99.30	99.87
9-Jun	13	98.59	99.88
16-Jun	20	97.87	99.88
21-Jun	25	97.82	99.56
23-Jun	27	99.37	99.71
27-Jun	31	98.31	99.71
30-Jun	34	99.09	99.18
5-Jul	39	98.42	98.74
5-Jul*	39	98.42	98.74*
7-Jul	41	96.70	98.48
11-Jul	45	87.60	99.73
13-Jul	47	76.89	99.81
15-Jul	49	75.39	99.81
19-Jul	53	74.08	99.66
21-Jul	55	82.04	99.79
29-Jul	63	82.69	97.80
12-Aug	77	77.12	97.61
22-Aug	87	81.01	97.52
5-Sep	101	94.54	98.65
5-Sep*	101	94.59	98.65*
15-Sep	111	86.42	99.37
23-Sep	119	75.32	99.44

\*: Wastewater refilled

## 3- pH values experiment A

*Table 9. pH values in experiment A*

Date Taken	Date Taken	pH A2	pH A1	pH Inflow
	0			
8-Apr	1	9.49	9.57	7.3
11-Apr	4	8.99	9.00	
12-Apr	5	9.2	9.24	
13-Apr	6	9.38	9.59	
14-Apr	7	9.42	9.67	
15-Apr	8	9.56	9.79	
18-Apr	11	9.47	9.48	
19-Apr	12	9.43	9.78	
20-Apr	13	9.44	9.73	
21-Apr	14	9.46	9.69	
26-Apr	19	9.45	9.74	
27-Apr	20	9.36	9.53	8.3
29-Apr	22	9.43	9.80	
2-May	25	8.57	9.60	
4-May	27	8.25	9.19	
6-May	29	7.75	8.24	7.3
6-May*	29	7.75	8.24	7.5*
9-May	32	7.78	8.43	7.5
11-May	34	7.7	7.95	
13-May	36	7.24	7.75	
16-May	39	7.28	8.05	
18-May	41	7.58	7.78	
20-May	43	7.64	8.13	6.9
24-May	47	8.14	8.50	
27-May	50	8.66	8.88	7.1

\*: Wastewater refilled

#### 4- pH values experiment B

*Table 10. pH values in experiment B*

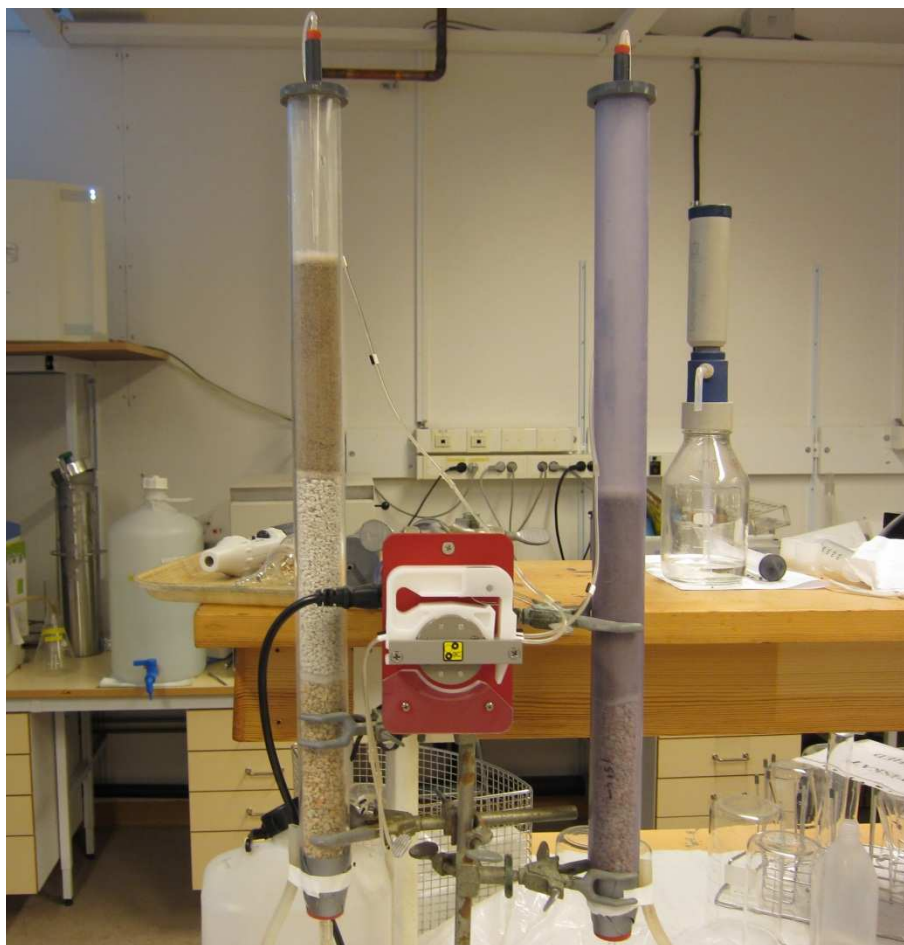
Date Taken	Date Taken	pH B2	pH B1	pH Inflow
27-May	0			7.9
30-May	3	11.9	12.29	
1-Jun	5	11.83	12.13	
3-Jun	7	11.52	11.89	7.7
7-Jun	11	9.79	11.44	
9-Jun	13	9.4	11.18	
16-Jun	20	9.63	10.92	7.7
21-Jun	25	9.77	10.89	
23-Jun	27	10.28	10.75	7.2
27-Jun	31	9.91	10.60	
30-Jun	34	10.24	10.82	
5-Jul	39	10.221	10.69	7.3
5-Jul*	39	10.221	10.69	7.1*
7-Jul	41	9.43	10.38	7.1
11-Jul	45	8.45	10.27	
13-Jul	47	7.86	10.33	
15-Jul	49	7.78	10.24	7.3
19-Jul	53	7.8	10.12	
21-Jul	55	8.78	9.36	7.5
29-Jul	63	7.22	8.46	
12-Aug	77	8.02	9.43	7.18
22-Aug	87	8.46	8.80	6.85
5-Sep	101	9.33	9.19	7.29
5-Sep*	101	9.33	9.19	7.20*
15-Sep	111	7.66	9.29	7.49
23-Sep	119	6.74	9.22	7.41

\*: Wastewater refilled

## APPENDIX II – PICTURES



*Figure 12. Experiment A: Columns filled with filter materials. (Left: A1, Right: A2)*



**Figure 13. Experiment B: Columns filled with filter materials. (Right B1, Left: B2)**



**Figure 14. Aquatec Analyzer, used for orthophosphate analysis.**