

ON-SITE WASTEWATER TREATMENT SYSTEM IN HØYÅS FARM, ÅS NORWAY

(A COMPARATIVE STUDY ON P-SORPTION OF TWO FILTER MATERIALS (FILTRALITE P AND FILTRAMAR) AND EVALUATION OF TECHNICAL AND TREATMENT PERFORMANCE OF SYSTEM COMPONENTS)

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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Environment and Natural Resources - Specialization Sustainable Water and Sanitation, Health and Development

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Abstract

Norway has endorsed strict regulations regarding wastewater discharge also in rural areas. In areas defined as vulnerable i.e. most inland area the phosphorus (P) discharge limit is 1 mg P/l or 90% removal. Both package treatment plants and nature based systems (constructed wetlands, soil infiltration) are used. Constructed wetlands or filterbed system (wetlands without macrophytes) have excellent purification performance, but require a large area according to current guidelines resulting in large investment costs. When using the phosphorus sorbing material Filtralite P, leaching of calcium in the early stage of the system may clog outlet pipes or form a white layer of CaCO_3 at the discharge point. The lost calcium may also reduce the longevity of the systems P-removal. At Høyås farm in Ås municipality a compact filter bed system with post polishing sand filter to trap the leaching calcium has been built. A compact P-filter combined with a polishing sandfilter has not been tested in Norway before. Two different P-sorbing materials Filtramar and Filtralite P are tested and compared in the two 4m^3 P-filter units of the system. to find the maximum phosphorus retention capacity in order to increase the life time and to reduce the investment cost.

Samples were collected during the first month of system operation in October 2012. Samples were taken at an interval of around two weeks. Samples were analyzed for pH, conductivity BOD_5 (mg/l), COD (mg/l), total phosphorus (mg/l) and orthophosphate (mg/l). In addition a batch experiment has been conducted to find the phosphorus sorption capacity of Filtralite P and Filtramar.

The Batch experiment results showed that the sorption isotherms of Filtralite P and Filtramar had different behaviors at high initial concentrations (50-480 ppm) and at low initial P concentrations (0-50 ppm). With an initial concentration of 480 ppm, Filtramar (shellsand) had a P sorption capacity of 8.22 g P/kg, while Filtralite P was found to have a P sorption capacity of 1.23g P/kg. At low initial concentrations comparable to real wastewater concentrations Filtramar (shellsand) had a P sorption capacity of 149 mg P/kg, while Filtralite P was found to have a P sorption capacity of 476 mg P/kg. Thus at lower initial concentrations of phosphorus, Filtralite P had higher P-sorption capacity than Filtramar did. The use of Langmuir equation to calculate the maximum sorption capacity and the saturation points of the filter materials showed that Filtramar had life time (26.2 years) ten times more than service life of Filtralite P (2.45 years). However it

is not wise to determine replacement time of filter materials based on batch experiments results only. Batch experiments can only be used to compare and rank filter materials according to their phosphorus retention capacity and not for estimation of their life time.

The overall removal of the Høyås treatment system in its first three months of operation was 90% BOD₅ removal, 76% COD removal, 98% total phosphorus removal and 99% orthophosphate removal. The results meet or exceed current discharge limits for the recipient with eutrophication risk and user interests.

Insulation of bio-filter and sand filter by tree bark is a good solution to protect from frost but it leaches organic substances and produces color in wastewater and that may increase COD in the effluents and also block P-sorption sites of the filter media. The bark should be replaced.

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List of abbreviations

ATP	Adenosine Triphosphate
BF	Bio-Filter
BOD	Biochemical Oxygen Demand
CEC	Cation Exchange Capacity
COD	Chemical Oxygen Demand
CW	Constructed Wetland
DNA	Deoxyribonucleic Acid
EU	European Union
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy
LECA	Light Expanded Clay Aggregate
LWA	Light Weight Aggregate
Pe	Person equivalent
PF	Phosphorus Filter
PP	Particulate Phosphate
PVC	Polyvinylchloride
RNA	Ribonucleic Acid
SD	Standard Deviation
SF	Sand Filter
S _o	Sorting
SP	Soluble Phosphate
SRP	Soluble Reactive Phosphate
SS	Suspended Solid
ST	Septic Tank
SUP	Soluble Unreactive Phosphate
TCB	Total Coliform Bacteria
TDS	Total Dissolved Solid
TOC	Total Organic Carbon
Tot N	Total Nitrogen
Tot P	Total Phosphorus
WC	Water Closet

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1.0 Introduction

In Norway 22.5% of the population is living in rural areas (World Bank, 2010), where connection to a centralized sewer network is neither cost effective nor sustainable. The most reliable and the sustainable ways to treat domestic wastewater from rural settlements is to construct decentralized (on-site) treatment facilities. In Norway, approximately 17% of inhabitants are served by decentralized systems handling wastewater from less than 50 Pe (1 Pe = 60g BOD₅/day) in size. Septic tanks are most commonly used as wastewater treatment systems in Norway (47%) (Paruch et al., 2011, Johannessen, 2012). However, septic tanks are not so effective in removing pollutants. The expected removal efficiencies in septic tanks are 5-10% of total phosphorus (Tot-P) and total nitrogen (Tot-N), 25-35% of organic matter (BOD₅), 95% of settleable/floatable materials, 30-60% of suspended solids (SS), and low reduction of pathogens (viruses, bacteria, and parasites) (Jenssen et al., 2006). Similarly, soil infiltration systems show high reduction of organic matter (> 90%), high nitrification (> 90%) and very good bacteria removal (< 200 thermotolerant coliforms (TCB)/100 ml) and more than 95 % phosphorus (P) removal, but due to soil conditions they cannot be used everywhere (Jenssen et al., 2006).

The discharge of phosphorus (P) from anthropogenic sources such as municipal wastewater, domestic wastewater, runoff from agricultural areas and landfill leachate to lakes, rivers, and coastal areas constitutes the main risk for reduced water quality and eutrophication (Adam et al., 2007, Vohla et al., 2011). Due to adverse effects of phosphorus, general discharge regulations are formulated depending on the areas of sensitiveness. For example in recipients with eutrophication risk and user interests 90% total phosphorus and BOD₅ removal is required. In recipients with eutrophication risk but without user interests require 90% total phosphorus removal and 70% BOD₅ removal. If neither eutrophication risk nor user interests, 60% of total phosphorus and 70% of BOD₅ are required [¹]. Due to high phosphorus and organic matter removal requirement the small-scale conventional treatment systems such as package treatment plants with chemical and biological units are used (Jenssen et al., 2010). However due to high operational cost and unstable performance of package treatment plants (Johannessen, 2012), there is a need for new or improved robust and low maintenance onsite systems with high level of performance (Jenssen et al., 2010).

¹ <http://www.lovddata.no/for/sf/md/td-20040601-0931-042.html>

Constructed wetland systems (CWs) are as an alternative to the conventional, chemical-based methods used in package treatment systems (Drizo et al., 1999, Adam et al., 2007). According to Paruch and Mæhlum (2011), constructed wetland or filterbed systems can be considered some of the most efficient treatment systems with respect to P removal. These systems are broadly established and investigated, and are considered as a suitable technology options for small to medium-sized communities. Studies regarding phosphorus removal in constructed wetlands have been done in many countries including U.S.A., Australia, and Denmark, Norway, U.K., Czech Republic as well as in Sweden and the Netherlands (Drizo et al., 1999).

During winter season when the plants are dormant, the removal of BOD in constructed wetlands is limited. To overcome this, all constructed wetlands in Norway built after 1991 has an aerobic biofilter unit (pre-treatment filter). The aerobic biofilter is used to remove BOD and achieve nitrification (Jenssen et al., 2006). Based on results from the national research program “Natural systems for wastewater 1994-98 “ NAT program” and experience from full scale systems, design guidelines were developed for sizing and designing of CWs (NORVAR and NKF, 2001, Jenssen et al., 2005) CWs designed according to VA/Miljø-blad nr. 49 (2001b) have shown stable and high quality effluent throughout the year (Heistad et al., 2006, Jenssen et al., 2010). However, they occupy relatively large area with 40 m² per household (8-12 m²/person) when mixed black water and greywater should be treated (Jenssen et al., 2006) . According to the guidelines in VA-Miljø blad (2001b), 8-10 m²/person and 1 m depth is recommended (Jenssen et al., 2006). This recommended deep depth is important in Nordic climatic conditions and the large volume is needed to obtain 10-15 years of service life before it is needed to change the filter (Jenssen et al., 2006) . Due to the large amount of phosphorus sorbing materials (as Filtralite P) required the cost of installation becomes high (Heistad et al., 2006) .

To reduce the need for filter material compact filter bed systems have been designed using to the same principles and components as in constructed wetland systems but with smaller phosphorus filter unit (Heistad et al 2006, Jenssen et al 2010). Such compact systems are constructed with a P-filter volume of about 6 m³ per household. Despite the small P-filter volume the treatment performance is comparable to the CWs designed according to the current guidelines.

Filtralite P has been the dominating filter material use in Norway but it is expensive and also creates a challenge in handling the calcium leaching resulting from the startup phase of such filters. The calcium leaching clog outlet pipes and reduces the potential P-binding of the filter media. Other filter materials with high P-sorbing capacity are therefore interesting to compare to the Filtralite P. In Norway shellsand was tried by Roseth (2000) and internationally other materials also have been used (Drizo et al., 1999). Most of these studies are batch studies and full scale comparison of filter media using the same wastewater is not performed in Norway.

The Høyås farm treatment system was designed as filter bed systems with a dual unit compact P-filter so that Filtralite P and Filtramar could be tested under equal conditions. To compensate calcium loss, polishing sand filters are used after phosphorus filters. The installation of sand filters after phosphorus filters can potentially increase the longevity of the system regarding phosphorus removal. The combination of filter beds and post-polishing filter has not been experimented in Norway previously (Jenssen et al., 2010). Hence the main objective of thesis is to compare phosphorus sorption capacity of Filtralite P and Filtramar using batch experiment and to evaluate performance of the system as a whole.

2.0 Background

2.1 Wastewater constituents

“Wastewater is characterized in terms of its physical, chemical and biological composition. The most important physical characteristics of wastewater is its total solids content, which is composed of floating matter, settleable matter, colloidal matter and matter in solution. Other important physical characteristics include particle size distribution, turbidity, color, temperature and conductivity. The chemical constituents of wastewater are typically classified as inorganic and organic. Inorganic constituents mostly related with pH, nutrients like phosphorus and nitrogen, chloride, sulphur, heavy metals, and gases like methane, carbondioxide (CO₂), oxygen (O₂), nitrogen (N₂), hydrogen sulphide (H₂S) and ammonia (NH₃). The organic constituent is the combination of carbon, hydrogen and oxygen together with nitrogen in some cases. The most widely used parameter of organic pollution in wastewater is biochemical oxygen demand (BOD₅), chemical oxygen demand (COD) and total organic carbon (TOC). In addition to the above mentioned chemical constituents, a variety of emerging compounds have been identified.

They are veterinary and human antibiotics, human prescription and nonprescription drugs, sex and steroidal hormones. The biological characteristics of wastewater are of fundamental importance in the control of diseases caused by pathogenic organisms of human origin and because of the extensive and fundamental role played by bacteria and other microorganisms in the decomposition and stabilization of organic matter in wastewater treatment plants. Pathogens like bacteria, viruses and protozoa are of most concern in wastewater treatment” (Metcalf and Eddy, 2003).

Table 1 shows the typical inlet concentrations of Tot-P, Tot-N, BOD, COD and TCB for onsite treatment systems (<50 Pe) in Norway, measured in the outlet of the septic tank. Generally, the influent measurement of wastewater in many onsite systems is performed at the outlet of the septic tank, where approximately 5-10% of total phosphorous and total nitrogen is removed (Skjøsberg, 2010). Table 2 shows an overview of the average amount of phosphorus, nitrogen and organic matter, produced per person per day in Norway. Natural systems as soil infiltration and constructed wetland/filterbed systems normally have a high and stable performance (Jenssen and Siegrist, 1990, Jenssen et al., 2010). The effluent concentrations and the expected removal efficiency (%) of the different wastewater fractions in the effluent of septic tank and saturated filter bed systems built according to current guidelines (VA-Miljø Blad Nr.49) are shown in Table 3.

Table 1: The typical inlet concentrations for onsite treatment systems (<50 Pe), measured in the outlet of septic tank (Yri et al., 2007)

Parameters	Effluent concentrations (mg/l)
Tot-P	8-11
Tot-N	60-78
BOD ₅	200-260
COD	470-615
Total Coliform Bacteria	1-20 millions/100 ml

Table 2: The Percentage of Total P, Total N and organic matter a person produces per day (Yri et al., 2007).

Parameters	The amount produced g/pe.d
Tot-P	1.6
Tot-N	12
BOD ₇	46
BOD ₅	40
COD	94

*BOD₇: Biochemical Oxygen Demand according to Norwegian concept.

Table 3: The expected removal efficiency in % and the final effluent concentrations (mg/l) in filter bed systems with septic tank and pre-treatment filter (NORVAR and NKF, 2001).

Parameters	% removal efficiency	Final effluent concentrations
Tot-P	>90%	<1 mg/l
Tot-N	>50%	<30 mg/l
BOD	>90%	20 mg/l
COD	50-90	<40 mg/l
Total Coliform Bacteria	>99%	1000 TCB/100ml

2.2 Theoretical background about Phosphorus

Phosphorus (P) is an important nutrient that is critically needed for the normal functioning of ecosystems (Vohla et al., 2011). It has been called “the key of life” because it directly involves in most essential life processes. Since it is a part of the nucleic acids DNA and RNA which carry the genetic code, it is an essential component of every living cell (Brady and Weil, 2002). It can also be found in bio-chemicals. These bio-chemicals include nucleotides coenzymes, phosphoproteins, phospholipids, and sugar phosphates. Another significance of phosphorus is that it is considered as an essential element in the physical framework of protoplasm and cell membranes and phospholipids. In addition, it plays a vigorous role in the energy transfer compounds needed to keep life activities, and this in the form of ATP (Adenosine Triphosphate) (Ahmed, 2007).

However, the discharge of P from anthropogenic sources such as municipal wastewater, domestic wastewater, runoff from agricultural areas and landfill leachate to lakes, rivers, and

coastal areas constitutes the main risk for reduced water quality and eutrophication (Adam et al., 2007, Vohla et al., 2011). At the same time, P is an essential nutrient for all forms of life and cannot be replaced by any other element (Adam et al., 2007).

Serious problems due to eutrophication has led to governmental regulatory pressure for lowering phosphorus concentrations from wastewater (Kadlec and Wallace, 2008) in order to reduce the negative effects of overloading the ecosystems with P as well as reducing the high costs that accompany the mining and processing of P (Adam et al., 2007, Vohla et al., 2011). Further research is necessary to investigate various techniques and materials that could contribute to the removal as well as recycling of P (Adam et al., 2007). Constructed wetlands have evolved as one simple ecologically adapted technique for control of water pollution (Adam et al., 2007).

2.2.1. Phosphorus cycle

The cycle of phosphorus in ecosystems varies from that of carbon, hydrogen, oxygen and nitrogen, which have much faster cycles (Holtan et al., 1988).

The phosphorus binding process by iron (Fe) - and aluminum (Al)-oxide and oxyhydroxide phases is of vast importance in terrestrial ecosystems, and has been extensively studied in soil science. Its importance refers to the fact that phosphorus can be a limiting nutrient for algal growth in terrestrial ecosystems, and the removal of natural phosphorus or its use as fertilizer can influence the health and production level of crops and forests (K. C. Ruttenberg, 2003).

The phosphorus is found as organic and inorganic phosphate in soil. Inorganic p is connected to phosphorus minerals originated. The organic Phosphate is originally originated from plant residues but also can be produced by human excreta and animal manure (Lusk et al., 2011). There is a consideration that plants can uptake their P only from inorganic sources and that organic P compounds must be mineralized before their uptake by plants. There has been a focus on the inorganic rather than the organic P in soil, and this refers to the limited knowledge of the specific nature of most of the organic bound P in soils (Ahmed, 2007).

Ortho-phosphoric acid and mono and di-esters have been considered to be the most naturally occurring organic forms of P. These organic P esters have been classified into: (a) inositol phosphates, phosphate esters of a sugar-like compound, inositol [C₆H₆(OH)₆]; (b) nucleic acids;

(c) phospholipids; (d) nucleotides and (e) sugar phosphates. Black (1968) concluded that about 2% of the total organic P in soil was present in nucleic acids, 1% in phospholipids, and 35 % in inositol phosphates, with the remaining 62 per cent unrevealed (Ahmed, 2007).

The inorganic phosphate compounds in soil are classified into two groups: (a) calcium compounds and (b) iron and aluminum compounds. The calcium compounds are found in alkaline soils, while the iron and aluminum compounds mainly exist in acidic soils. As soil pH decreases, the degree of calcium compounds dissolution becomes high such as apatite. Apatite is the less soluble among the calcium phosphates (Ahmed, 2007).

The inorganic phosphate is also referred as “available or reactive P” (Lusk et al., 2011). However, Phosphorus is unavailable in high and low pH ranges of soil solution (Ahmed, 2007). The dissolved forms of inorganic P include: H_3PO_4 , H_2PO_4^- , HPO_4^{2-} , and PO_4^{3-} (Lusk et al., 2011). The distribution of these species is pH dependent and can reflect the P availability for plants. The most favorable pH for P availability is near neutral to slightly acid. Phosphorus is absorbed by plants largely as H_2PO_4^- , HPO_4^{2-} and PO_4^{3-} . Most of the P absorbed by plants is in the monovalent orthophosphate form, H_2PO_4^- which is predominant at pH values below 7.2 and is typical of most agricultural soils. At pH above 7.2, the HPO_4^{2-} is more dominant, and may be used by some plants. When the pH is too high, the concentration of the tertiary orthophosphate PO_4^{3-} will be high, which makes this form of P a significant source in plant nutrition. Even at a pH of 12 the HPO_4^{2-} , concentration is still greater than that of PO_4^{3-} . From this relationship, the hydrogen ion activity will to a great extent influence all phosphate reaction systems. Some plants may also absorb certain soluble organic phosphates but these are very minute amounts (Ahmed, 2007). This can be shown in Fig. 1 below:

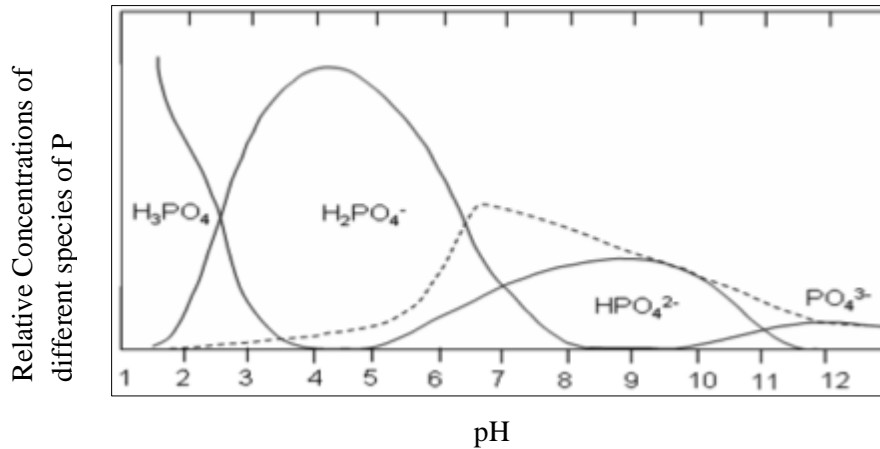


Fig. 1 The available forms of P ions and their relative concentrations at different pH values (Ahmed, 2007).

The organic and inorganic forms of soil P and the soil P cycle are shown in Fig. 2 below.

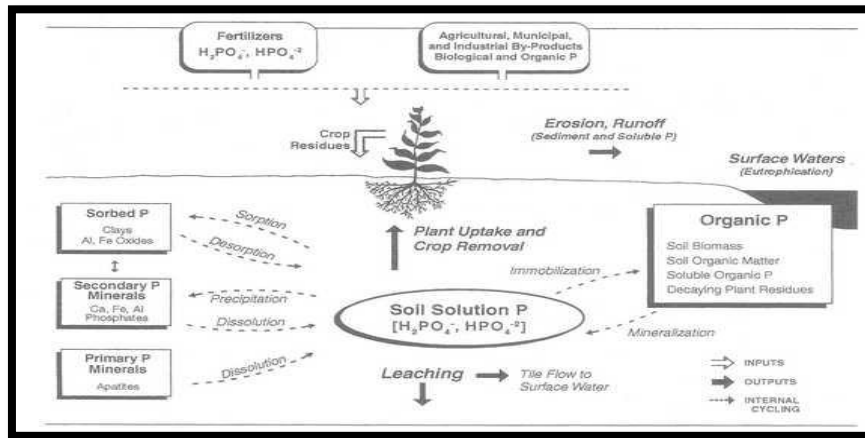


Fig. 2: Soil-plant phosphorus cycle (Ahmed, 2007).

The diagram shows that P fertilizer added to soils can be converted to ionic forms available to plants. Ionic P can become unavailable to the plant after adsorption reactions with clay, Al, and Fe Oxides, and through precipitation of Ca, Fe and Al phosphates. Some available P becomes unavailable by immobilization with the soil biomass. Available P is taken up by plants and is lost from the soil by crop removal (Ahmed, 2007).

Phosphorus is mainly found in phosphorus rocks. Due to erosion processes caused by rainfall and water runoff, the particulate phosphorus, which is bound to the soil particles, will to some extent

be dissolved in water. As a result, it will be taken by the plants by their roots to build their tissue. When animals eat plants, the phosphorus will be transferred to their tissue. Again the phosphorus will be returned to the soil by means of the animal droppings and in the residues of plants and animals. These organic forms of phosphorus are converted back into inorganic phosphorus by bacteria (Ádám, 2006).

Phosphorus transformations in wetlands are: adsorption/desorption, precipitation/dissolution, plant/microbial uptake, fragmentation and leaching, mineralization and burial. Thus, when evaluating a wetland ecosystem to retain P, all these components should be quantified. (Vymazal, 2007). The increasing consumption of phosphorus may as time goes on be a serious problem for modern agriculture and some other activities (Holtan et al., 1988). Therefore, it is important to recirculate phosphorus in order to avoid the overexploitation of P containing rocks for fertilizers (Ádám, 2006).

2.2.2. Forms of phosphorus in soil and in the soil solution

Phosphorus occurs in nature almost exclusively as phosphate, in all known minerals more specifically as orthophosphate with an ionic form of PO_4^{3-} . The distribution of the different species of orthophosphate is pH-dependent. The dissociation of the ortho-phosphoric acid in aqueous systems as a function of pH is shown in Fig. 3.

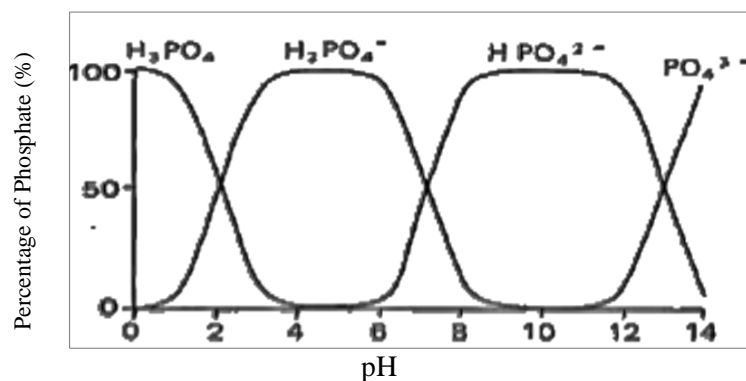


Fig 3: Distribution of phosphate species with pH (Holtan et al., 1988)

As seen from Fig. 3, H_2PO_4^- is the predominant species that can be expected to take part in phosphate sorption in the pH range 4-6. At higher pH, as can be found in cultivated soils, the importance of HPO_4^{2-} may increase. Since the soil solution will contain several kinds of metallic

cations capable of forming complexes with H_2PO_4^- and HPO_4^{2-} a part of the soil solution phosphorus will exist as soluble metallic phosphate complexes. In some cases the degree of complexation of solution phosphorus may be a significant part of the total soil solution phosphorus (Berkheiser et al., 1980). A great part of the phosphorus in soil is sorbed to soil particles or incorporated into soil organic matter. Since phosphorus is also a nutrient it will be found in living organisms (Holtan et al., 1988).

Phosphorus availability in most soils is at a maximum in the pH range 6.0 to 6.5. Above pH 7.0 the ions of calcium and magnesium, as well as the presence of carbonates of these metals in the soil, cause precipitation of the added P and its availability again decreases (Fig. 4) (Ahmed, 2007), because by decreasing the pH, the Ca phosphate also becomes slightly soluble (Ádám, 2006).

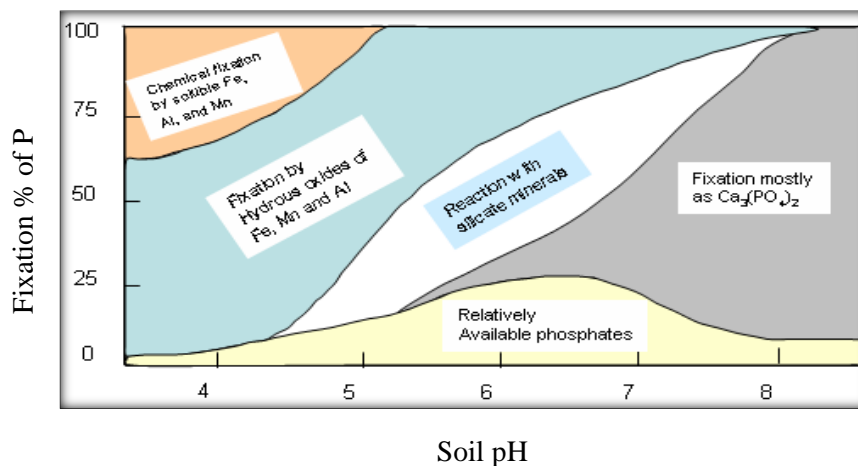


Fig. 4: Phosphate availability and fixation as related to soil pH (Ahmed, 2007).

2.2.3. Forms of phosphorus in water

Under normal conditions phosphorus in soil, water and sediments appear only in the form of chemical compounds. Usually phosphorus occurs in the oxidized state, either as ions of inorganic orthophosphate (HPO_4^{2-} , $\text{H}_2\text{PO}_4^{2-}$) or inorganic compounds.

Phosphorus in solution is normally considered to be orthophosphate, inorganic polyphosphates, and organic phosphorus compounds dissolved in the water phase (Holtan et al., 1988).

From the analytical chemical point of view it is usual to define natural fractions as outlined in Fig 5.

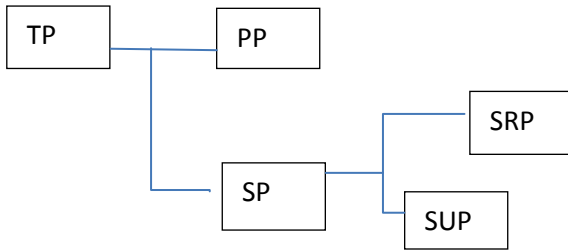


Fig. 5: Natural fractions of phosphorus (P) in water (Holtan et al., 1988)

Fig. 5 shows the natural fractions of phosphorus P in water: TP (Total Phosphorus); PP (Particulate Phosphorus); SP (Soluble Phosphorus); SRP (Soluble Reactive Phosphorus); SUR (Soluble Un-reactive phosphorus) (Holtan et al., 1988).

Particulate Phosphorus (PP) includes adsorbed, exchangeable P, organic phosphorus, precipitates fertilizer, reaction products with Ca, Fe, Al and other cations, crystalline minerals and amorphous P. Soluble Phosphorus (SP) consists of orthophosphate, inorganic polyphosphates, and organic phosphorus compounds dissolved in the water phase. Both inorganic and organic forms of phosphorus are involved in the transformations.

The results of these transformations are release of water-soluble phosphorus from the solid phase or uptake of dissolved phosphorus by the solid phase (Holtan et al., 1988). The release of water-soluble phosphorus from the solid phase P constitutes the soluble reactive phosphorus (SRP). This reactive form of soluble P plays a major role in maintaining soil fertility, when the concentration of P in solution is decreased due to uptake by plants. Then, the released from the solid phase can replace this deficiency/depletion of P. The uptake of dissolved phosphorus by the solid phase constitutes the soluble un-reactive Phosphorus (SUP) or it is called the fixed P. This fixed P contains inorganic phosphate compounds that are very insoluble (crystalline structure) and organic compounds that are resistant to mineralization (Ádám, 2006). These reactions play major roles in influencing the bioavailability of phosphorus in soil (Holtan et al., 1988).

2.3 Types of onsite wastewater treatment systems in Norway

In Norway, approximately 17% of inhabitants are served by onsite wastewater treatment systems (<50 Pe) (Paruch et al., 2011). Totally about 340000 such systems are in operation in Norway with different technologies as shown in Fig. 6 below.

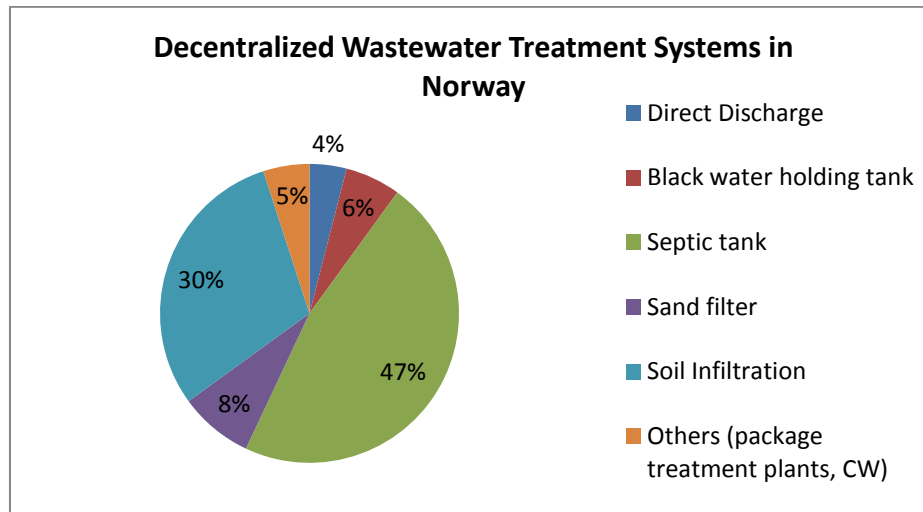


Fig. 6: Distribution of on-site wastewater treatment technologies in Norway (Johannessen, 2012)

Fig. 6 shows different treatment systems adopted in rural areas of Norway. The most commonly used are septic tanks only (47%) and soil infiltration systems (30%) and sand filters (8%). In addition there are a few package treatment plants and now emerging constructed wetlands with and without vegetation. Wetlands without vegetation are termed filter beds (Paruch et al., 2011).

The septic tank has low purification ability for most parameters and very little removal of pathogens. A septic tank is commonly used as a pretreatment unit in infiltration systems, filter bed systems, sand filters and biological filters. Septic tanks are considered as prerequisite for achieving satisfactory purification in the main treatment processes. Septic tanks have removal efficiency 20-30% of organic matter (BOD), 30-60% of suspended solids (SS) and 5-10% of nutrients (phosphorus and nitrogen). Smaller septic tanks are normally emptied at an interval of two years in Norway (Jenssen et al., 2006).

The infiltration system is a well-known treatment system in Norway. The majority of the existing onsite wastewater treatment systems in Norway that have more treatment than only a septic tank

are based on filtration through native soil. These systems require large area and may not be applied in all site conditions. When infiltration was not possible sandfilters were used. Sandfilters consist of a trench (or trenches) filled with a filter sand. The septic tank effluent is applied on top of the sand through an infiltration pipe surrounded by gravel (as in infiltration trenches). Below the sand layer that usually is 70-90cm there is a drainage pipe collecting the treated water. In the last 1-2 decades package treatment plants and constructed wetlands have been developed and are now supplementing the infiltration systems and sandfilters.

Package treatment plants are downscaled conventional treatment systems mostly used for single household, but also for groups of households. Due to the focus on phosphorus removal most package treatment plants have a chemical step in addition to a mechanical and biological. (Heistad et al., 2006).

One of the most efficient treatment systems that so far has been developed for rural areas and pioneered for cold climatic conditions are constructed wetlands with or without vegetation (Jenssen et al., 2010). It has been nearly two decades since the first horizontal subsurface flow constructed wetland was built in Norway (Brady and Weil, 2002). The constructed wetlands systems in Norway consist of a septic tank, an aerobic bio-filter as a pretreatment unit and wetland filter media with high hydraulic conductivity and binding capacity for phosphorus. Light weight aggregates (LWA) are common filter materials used in CW systems (Heistad et al., 2006). Filter beds have high purification efficiency when they are designed according to the current Norwegian guidelines (NORVAR and NKF, 2001). They have more than 90% removal efficiency for phosphorus, organic matter and pathogens and around 50% nitrogen removal. These removal efficiencies are based on 85% attendance in the housing and wastewater flow of 150 l/Pe/d (NORVAR and NKF, 2001). As the filter material becomes saturated with phosphorus, the phosphorus removal decreases. The life expectancy of the filter material before its replacement is 15-20 years when sizing according to VA /Miljøblad nr. 49. The LWA as filter material contains some readily soluble calcium that may leach from the material in the initial phase (1-2 years). This precipitates as CaCO_3 in outlet. The leaching of calcium may reduce the total P removal capacity of the material. So reducing the calcium leaching or capturing it in a succeeding filter could prolong the P-removal service life of the system as a whole. In addition

there is challenge of designing wetlands or filter beds smaller maintaining the high removal efficiency high and the nutrient recovery in order to recycle it back to agricultural land (ÁdÁm et al., 2007).

2.4 Health and environmental aspect

The primary goal of wastewater treatment is to protect the public from adverse health hazards and to protect the environment from getting polluted. Different pathogens in wastewater cause different diseases and the pollutants in wastewater degrade the water quality in the environment. For instance, elevated levels of nitrogen (N) and phosphorus (P) discharged to lakes, rivers, and coastal areas have been linked with water quality problems associated with eutrophication and reduced water quality (Søvik and Kløve, 2005). This phenomenon of “premature ageing “can result in undesirable presence of algal blooms. This growth of algal blooms will affect the water quality of the downstream water treatment processes and can restrict the recreational activities in the vicinity (Clark et al., 1997). In addition, the eutrophication will lead to a reduction in the oxygen content in the water bodies, and thus some water species will struggle for their survival which ultimately can disturb the aquatic ecosystem.

The nutrients present in wastewater are valuable resources for the agricultural production. Recycling them to agriculture instead of discharge to waterways will reduce the demand of mineral phosphates and nitrates for agricultural use and also help preserve pristine water from getting polluted.

Nitrogen is the main element that causes eutrophication in the coastal areas and phosphorus in the fresh water bodies (Heistad et al., 2006). That is why phosphorus is considered as the main element causing eutrophication in Norwegian waterways. Therefore, phosphorus removal has become a strict requirement for most small decentralized wastewater treatment systems (Heistad et al., 2006). In the same way, bacteria, viruses, protozoa, and helminthes are the most diseases causing pathogens found in wastewater. Those pathogens which when get contacted with living beings, cause the various gastrointestinal diseases like diarrhea, cholera, dysentery. Thus treatment of wastewater is essential to preserve the environment and to have good health of the people.

2.5 General guidelines and regulations

When designing the treatment systems and the discharge of effluents it should be in compliance with general guidelines. There are different guidelines and regulations endorsed in the local level, the national level and the supernational level. The national law on pollution control “Forurensningsloven (Pollution law)” and local regulations (Municipal level) “Local Forskrifter” and the EU directive all influence design of treatment systems and discharge of wastewater. Regarding discharge of wastewater from residential house, recreational houses, tourist resorts and similar, with less than 50 personal equivalents, the municipality is the responsible authority.

New wastewater regulations of the pollution regulations (Forurensningsforskriften) came into force on 1 January 2007 (Yri et al., 2007). For the construction of wetland (CWs) systems the different parameters and recommendations are found. Some of them are described below.

A three-chamber septic tank is recommended for CWs in Norway receiving wastewater including toilet waste (NORVAR and NKF, 2001). The septic tanks should not be placed near the road, or when installation near roads or parking places, the septic tanks should be covered by a relief panel. Septic tanks are dimensioned, designed and installed according to VA/Miljøblad nr.48 “SLAMAVSKILLERE”. Septic tanks should have an alarm for high water level and should be available for inspection and maintenance (NORVAR and NKF, 2001). The sizing of septic tanks for up to seven households is specified by the VA/Miljøblad nr.48 and shown in Annex02.

The filter media in filter beds should be constructed by well-defined and homogeneous filter sand, fine gravel, or other suitable filter material. This is essential to achieve a sufficiently hydraulic conductivity of the filter and at the same time to have a large surface area for sorbing of P and microorganisms (NORVAR and NKF, 2001). The filter material should have a sorting level ($S_0 = d_{60} / d_{10}$) smaller than 5.0. There must be no clay or silt in the filter material. According to these specifications, the permeability will be usually $> 100\text{m/d}$.

To determine the width of filter bed, loading rate and hydraulic conductivity must be known. Thus the Darcy's law can be used where the specific filter characteristics are of great importance:

$Q = K * B * D * i$, where

Q = plant's hydraulic capacity (m^3 / d)

K = hydraulic conductivity of the filter (m / d)

B = width of the plant (m)

D = system filter depth (typically 1.0 m)

i = hydraulic gradient between inlet and outlet.

From this concept, two conditions can be evolved to calculate the width: First: if the loading rate is $1 \text{ m}^3/\text{d}$, then the width can be estimated following the table 4; Second: while if it is different than $1 \text{ m}^3/\text{d}$, the width will change accordingly. The length of the filter bed can be calculated using the formula: $L= V /D*B$ where V is the volume of the filter (m^3), B is the width of the system (can be calculated using Darcy's law), and D is the depth of the system (m) (NORVAR and NKF, 2001).

Table 4: Minimum width requirements for different hydraulic conductivity

K_{dim} (m/d)	Minimum width(m)
10*	10
10 – 20	8
20 – 30	6
> 30	3.5

* Materials with $K_{\text{dim}} < 10 \text{ m/d}$ are not desirable to be used (NORVAR and NKF, 2001)

Phosphorus discharge from onsite wastewater treatment system is regulated by local codes and range varies from 0.5-1 mg/l depending on the sensitivity of the areas. Few municipalities have set limits for nitrogen discharge in order to protect local groundwater or sensitive fjord areas. In addition to removal of nutrients, the prevention of infectious diseases is a major task in modern wastewater treatment (Haas et al., 1999). Municipalities require less than 1000 faecal coliforms per 100ml as the indicator bacteria limit for small onsite systems (Heistad et al., 2006).

3.0 Site and system description

The wastewater treatment plant is located in Høyås farm (Brekkevein 120, Gnr/Bnr. 48/3) about 3 km south from Ås Station with position of $59^{\circ} 38' 5.5''\text{N}$ and $10^{\circ} 47' 13''\text{E}$ (Jenssen and Siegrist, 1990)(Jenssen and Siegrist, 1990) [2] and site is shown in photo below:

² www.kart.finn.no



Fig: 7 Location of the Høyås farm treatment system is shown in yellow

The climate is temperate with an annual precipitation of about 700mm. The average annual temperature is about 8 degrees Celsius. The coldest month has an average temperature of -5°C and the warmest $+15^{\circ}\text{C}$. Temperature can reach -30°C in the winter. The farm is located below or almost at the so called “marine limit”. That means that right after the last glaciation about 10 000 years ago the whole area was covered by the sea. It can therefore be expected that the soils are fine grained marine sediments. However, it may be possible to find patches of sand and gravel (umb K, 2012).

The Høyås farm system consists of a septic tank, a pumping chamber and equalization chamber, three biofilter domes, two phosphorus filter tanks and two sand filters for polishing and calcium capture. The flow from household enters the septic tank via access pipe. The effluent is discharged to agricultural drainage. The layout of the system is as shown below. The system drawings with 3D view and measurements of the different system components are shown in Annex01.

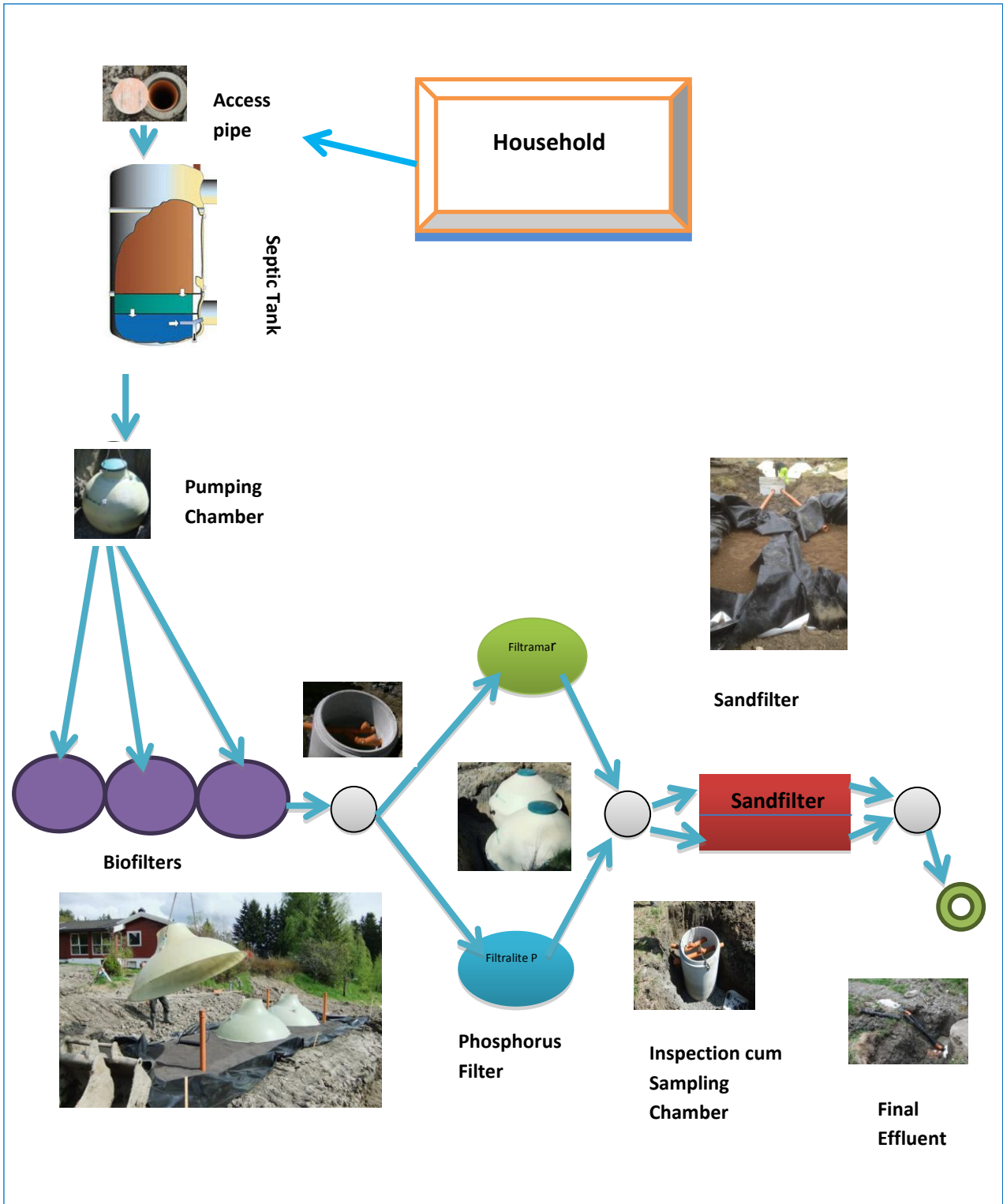


Fig. 8: Layout of the system

4.0 System design

4.1 Design of system components

While designing any treatment systems, hydraulic conductivity, purification performance, safety, economy, durability and ease for operation and maintenance need to be considered (NORVAR and NKF, 2001).

The Høyås farm wastewater treatment system is designed for average population of 8 person equivalents (Pe) per day and maximum capacity of 25 Pe/day. The design concept is based on three fundamental elements: a septic tank, an aerobic biofilter and phosphorus filters.

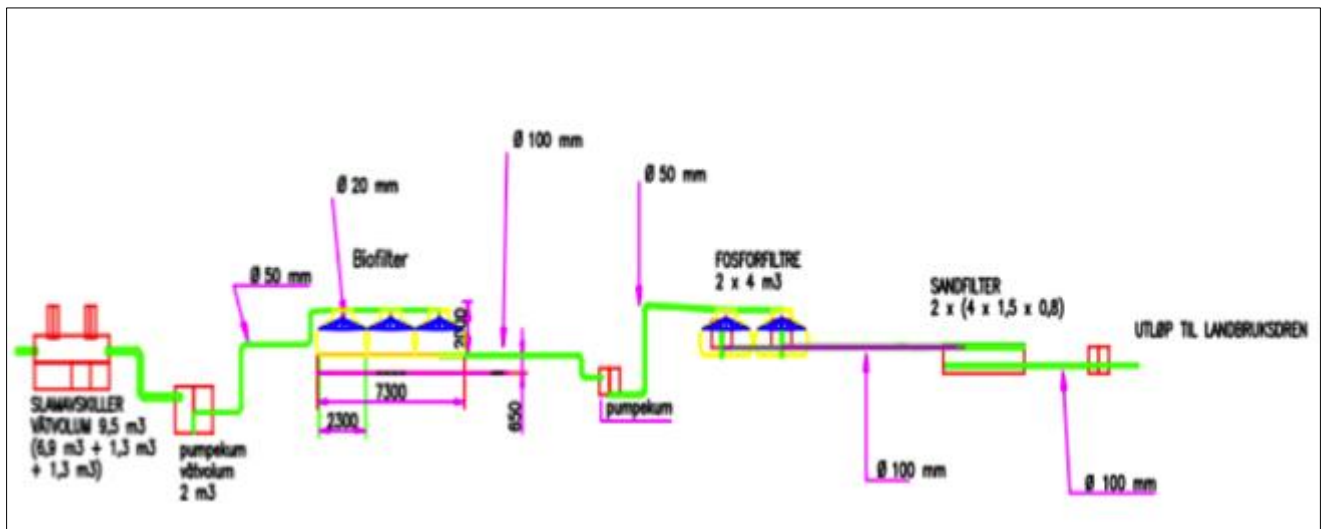


Fig. 9: Cross-section of wastewater treatment system in Høyås farm

4.1.1 Septic tank

The septic tank is designed to provide preliminary treatment for the total wastewater. The preliminary treatment allows solids to settle to the bottom of the septic tank, oils and fats to float on top to form a scum layer, and digest organic matter and discharge treated effluent (Busch, 1958).

In Høyås farm system, wastewater from the resident enters to the septic tank by gravity flow. The septic tank is a fiberglass tank with a total volume of 9.5 m^3 . The tank consists of three chambers of volume 6.9 m^3 , 1.3 m^3 and 1.3 m^3 respectively based on specification of VA/Miljø blad nr. 48. A septic tank of 9.5 m^3 actually corresponds to 3 residential units according to VA/Miljø blad nr. 48 and is therefore seems oversized compared to the average load of 8 person equivalent. This

is done to ensure proper functioning during peak loads of up to 25 Pe that is expected during various activities at the farm. Wastewater from the septic tank is led forward by gravity to the pumping chamber.

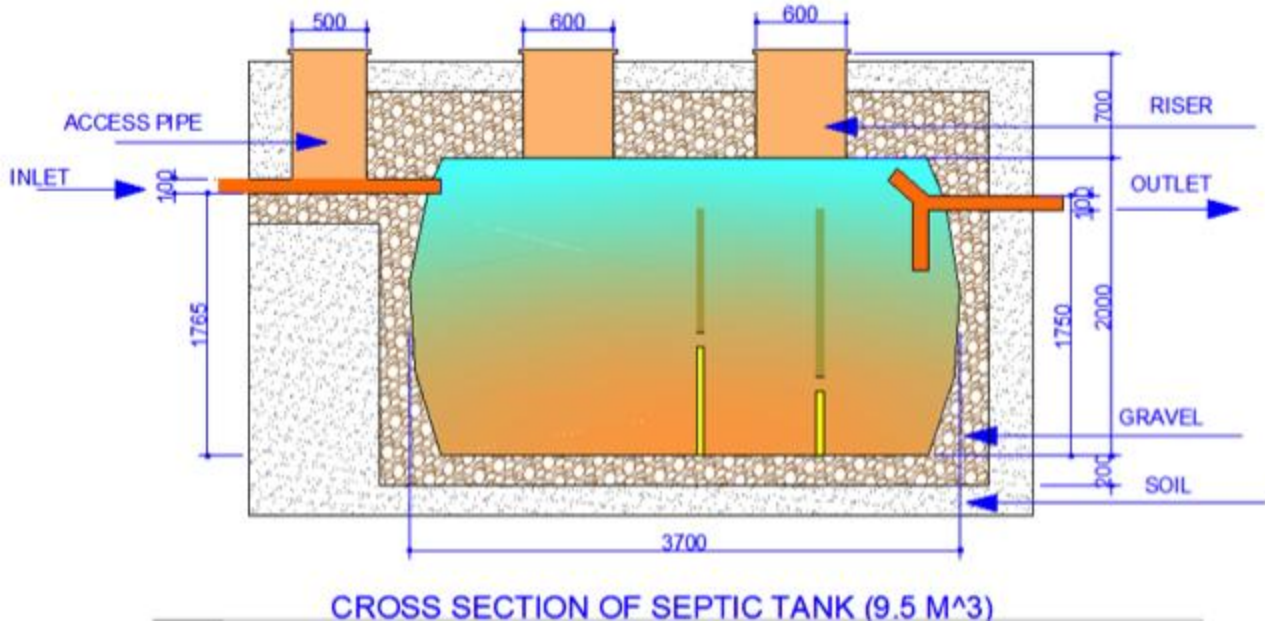


Fig. 10: Cross section of septic tank

4.1.2 Pumping /equalization chamber

The pumping chamber is 2 m³ in volume. This is much larger than the requirement for a system of this size. The pumping chamber is oversized in order to function as equalization chamber during peak loads. The pumping chamber has pump that is controlled by a timer and a float switch. The pump will stop if there is insufficient water in the tank. Under normal conditions the pump will run 72 times per day (around 30 s every 20 minutes), and pump out 30 l/20 minutes which equal 2.16 m³/d. An alarm for high water level in the pumping chamber is mounted so that pump failure is detected. The alarm emits a light signal.

4.1.3 Bio-filter

Bio-filter is designed with total filter area of approximately 12.5 m² and has three domes of 2.3 m in diameter. This gives an average surface load of 128 liters/m² (200 l/Pe/d * 8Pe)/12,5m². VA/Miljøblad nr 49 allows loading up to 200 l/m² of the biofilter. Hence, the biofilter is a bit oversized. This will ensure good performance even at extreme loads. Bio-filter domes comprise 60 cm depth Filtralite HC 2.5-5mm crushed materials. The wastewater is distributed over the bio-

filter through a centrally located nozzle in each dome. The nozzles assure even distribution of the water over the filter surface (Brady, 1990) and the flow down through the filter is unsaturated flow. In the bottom of the bio-filter a drain pipes collects the water. The key purpose of bio-filter is to achieve aerobic treatment of the wastewater especially in the winter when plants are dormant (Brady and Weil, 2002). This even water distribution over the biofilter assure good utilization of the biofilter volume and this can enhance nitrification and as well as break down the organic matter and some reduction of the pathogenic microorganisms. (NORVAR and NKF, 2001).

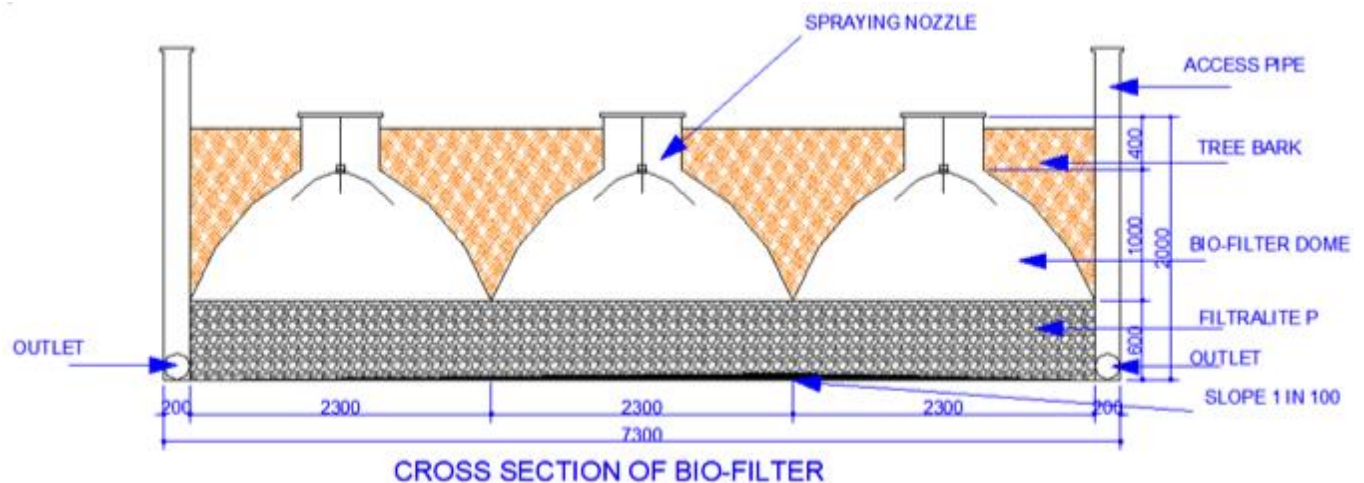


Fig. 11: Cross section of bio-filter

4.1.4 Phosphorus filter

Phosphorus filter is designed of two tanks each with 4 m^3 filter materials totaling 8 m^3 . The water flows vertically down through the filter medium of high phosphorus sorption capacity. Phosphorus in wastewater is bound to the particles and the filter media also provide good possibilities for reduction of pathogenic organisms. Purified water is led by gravity to the polishing sand filters). In a trial period of at least 3 years, the two phosphorus filter will be compared. One P-filter is filled with Filtralite-P of size 2-4 mm and uniform coefficient of less than 5 and the other P-filter is filled with Filtramar (shellsand) with coefficient of uniformity less than 4. Both filter types have very high phosphorus binding capacity. To ensure equal loading during the test period, the water from the bio-filter is distributed with a pump to the phosphorus filters.

4.1.5 Inspection and sampling chambers

The treated water from bio-filters, phosphorus filter and sand filters are collected in inspection and sampling chambers from where samples can be collected for analysis. After bio-filter, samples are taken in the pump chamber where water is distributed to phosphorus filters.

4.1.6 Sand filter

From phosphorus filters, the filtered wastewater enters into two parallel sand filters. The sand filters serve as polishing step but assures a further purification of phosphorus, bacteria and organic material. The sand filter is designed as two parallel trenches each with dimensions (10.0 x 0.7 x 0.7) meters. The sand filter is enclosed by an impermeable membrane and the two parallel sections separated by the same membrane (1mm PVC film). The treated water is fed onto the sandfilters by gravity.

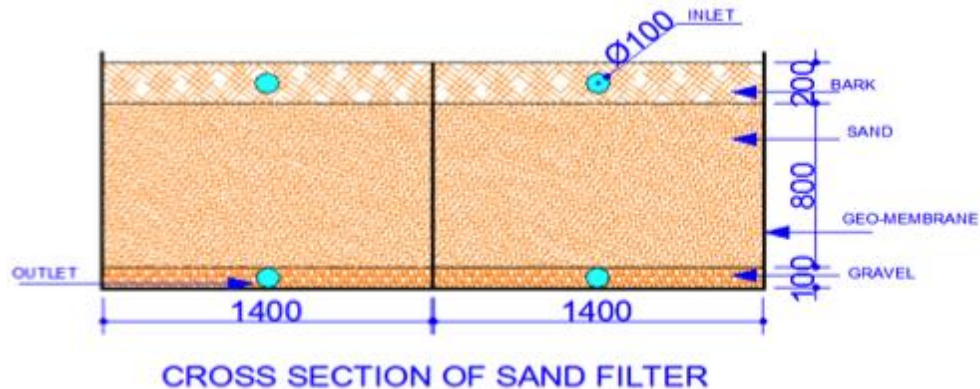


Fig. 12: Cross section of sand filter

4.2 Design parameters of Høyås farm treatment system

The design parameters include: design flow (l/d), hydraulic loading rate (l/m².d), retention time, Phosphate binding capacity (kg/m³), initial concentration, and volume of filter material and grain size.

4.2.1 Design flow (l/d)

Høyås farm treatment system is designed with flow 1.6 m³/d when considering an average water consumption of 200l/pe/d for 8 pe. (NORVAR and NKF, 2001).

4.2.2 Hydraulic loading rate of the system (l/m².d)

According to the Bioforsk Tema (2007) the VA/Miljøblad nr.48 states that Hydraulic loading (l/m².d) is a filter media's capacity to receive treated wastewater from the septic tank. The value

is determined from the filter materials grain distribution and water permeability. According to the VA/Miljøblad nr.49, when the water can be evenly distributed over the filter material surface through nozzles, bio-filters can be loaded with 200 l/m².d septic tank treated wastewater.

The hydraulic loading rate is a critical design factor for wastewater treatment systems (Lan Zhou and Mancl, 2007). Loading rates are used as a control parameter to ensure a long term performance with no clogging when designing natural wastewater treatment systems as CWs. When the loading rate is too high, the wastewater treatment system is more prone to clog.

4.2.3 Hydraulic conductivity of the porous media (m/d)

Hydraulic conductivity is a measure of the clean water conductivity in filter medium. It depends on the grain size, degree of sorting, pore volume and the amount of fine particles in the filter medium. In order to assess this parameter for use in wetlands, the measured hydraulic conductivity is multiplied by 0.3 ($K_{dim}=0.3*K$). This is done to account for blocking of pore space by roots in the filter media and hence is only applicable to constructed wetlands. For the filter beds that do not have macrophytes it should be possible to use the hydraulic conductivity value without multiplying with a reduction factor. In VA/Miljøblad nr.49, it is not recommended the use of filter materials with design hydraulic conductivity of less than 10 m / day.

4.2.4 Retention time (hours):

It is a key factor when sizing the filter bed plant. The water needs to have some retention time in the filter, for e.g. phosphorus to sorb and a satisfactory cleaning effect can be achieved.

According to VA/Miljø nr.49, the filter bed plant should be designed with a retention time of at least 10 days for combined wastewater (both gray water and black water). On the other hand, when designing filter bed plant only for gray water, the retention time in this case should be of minimum 7 days. However Heistad et al. (2006) and Jenssen et al. (2010) have shown that shorter retention times also give excellent treatment.

4.2.5 Phosphate binding capacity (kg/m³):

It is a key characteristic of filter bed systems to bind and retain phosphate into the matrix of the filter medium. The main filter materials used in constructed filter bed systems are LWA as Filtralite P and shellsand (e.g. Filtramar) both with high phosphate binding capacity. Many investigations have shown that the service life time of the system is likely to be connected to the phosphate binding capacity of these filter materials. This capacity of a filter medium will gradually be reduced once its matrix becomes saturated with phosphorus. This reduction in the filter-phosphate binding ability involves the removal and replacement of the filter material after a number of years of system. Thus, filter systems designed according to VA/Miljøblad nr.49 that designs for a P-removal life expectancy of up to 15 years requires fairly large volumes and areas for the final wetland/filterbed section.

5.0 Construction procedure

The construction of Høyås farm wastewater treatment plant involves following steps (see also Fig. 13 below for components and construction details:

Layout: After finalizing sizing and design of the system components and drawings, the orientation of all the system components were laid out. As per site available and the requirement for the installment of components, measurements in the field were done and the required area for different components was marked considering the required elevation differences for the gravity flow.

Excavation:

After demarcation for the different components, excavation was done. Excavation started from the last components. The drainage for the effluent from the system was excavated and then sand filters, put in place. After that, digging for the phosphorus filters and Biofilters was done together with the inspection chamber. The trenches for pumping chamber and septic tank were excavated as per required area. One reason for starting at the low point/ discharge point was that an underdrain of the whole system could be excavated and the system would not flood during construction in case of rain.

Installation of components:

After excavation, the septic tank, pump chamber and the domes for, bio filter and tanks for the phosphorus filters were fitted. Similarly the inspection chambers were installed. The necessary pipe fittings were adjusted with required gradient (1-2%) to allow gravity flow where needed. After that, the filter materials in the sand filter, phosphorus filters and biofilter were placed.

Septic tank:

After digging, the septic tank of 9.5m³ volume is installed on a stable foundation. In addition access pipe (Wavin kum) is connected before septic tank for easy flushing of the pipes when the flow direction is changed. A drainage pipe is placed in the bottom to prevent ponding during precipitation and potentially hydraulic lift of the tank when empty. Filling materials of size 2-12mm is placed all around the septic tank to facilitate drainage. The filling materials are covered by geotextile to protect from intrusion of soil.

Pumping chamber

The pumping chamber was installed including a pump with float switch to distribute water intermittently to Biofilters. Gravel was used below and as backfill surrounding the walls of the chamber to have proper drainage to prevent from uplift during high precipitation. Geotextile above filling materials was used to prevent from intrusion of soil.

The construction details of septic tank, biofilter, pumping chamber and P filter tanks are shown in Fig. 13A (Photos 1-18).



Photo: 1 Trench preparation for Septic tank



Photo: 2 Leveling gravel in a trench as base material for septic tank

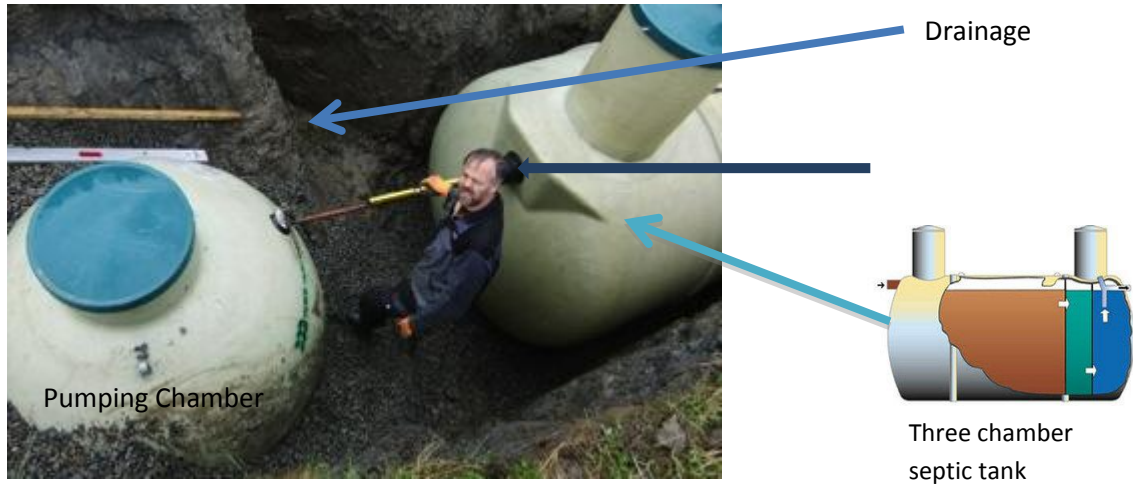


Photo: 3 Septic tank connected with pumping chamber



Photo: 4 Filling gravel around septic tank



Photo: 5 Pumping chamber covered by gravel

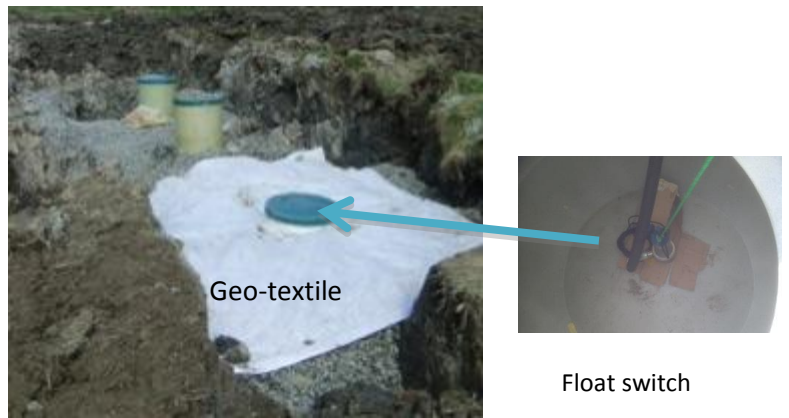


Photo: 6 Pumping chamber covered by geo-textile



Photo: 7 Levelling for biofilter installation

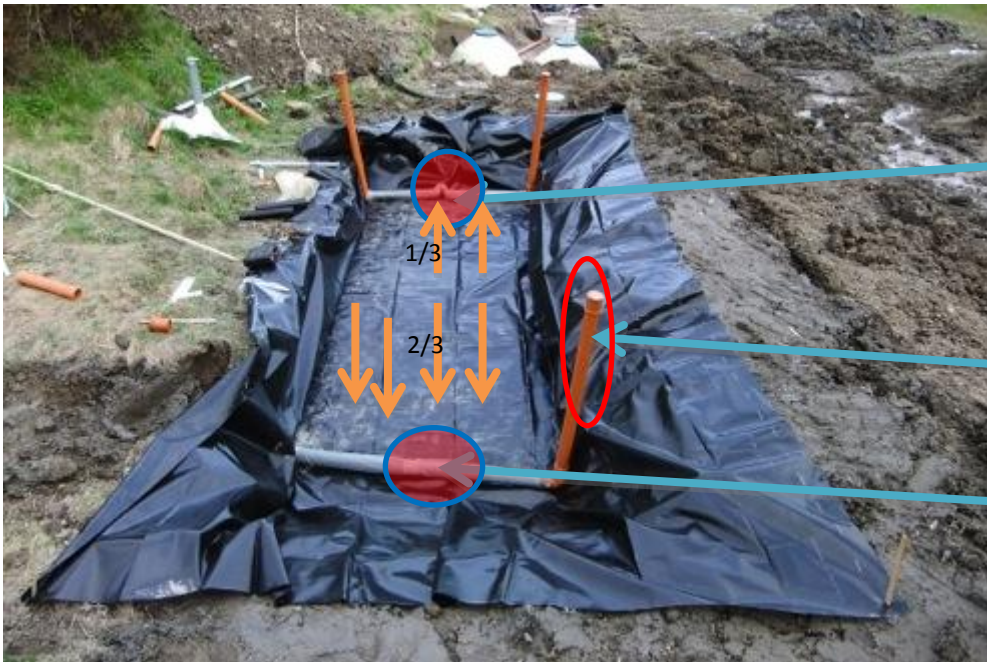


Photo: 8 Black PVC membranes for biofilter



Photo: 9 Filling of Filtralite HC in biofilter installation



Photo: 10 Leveling Filtralite HD for biofilter domes



Photo: 11 Installation of biofilter dome



Photo: 12 Covering of biofilter by tree bark for insulation



Photo: 13 Trench excavations for phosphorus filter tanks



Photo: 14 Phosphorus filter tanks installation



Photo: 15 Pipe fitting arrangements for phosphorus filters



Pipe arrangement for inlet and outlet of p filters

A: Pipe from Filtramar
B: Pipe from Filtralite



Photo: 16 Inspection and sampling chamber



Photo: 17 Covering of P filter tanks with gravel and geotextile Membrane



Photo: 18 Filling of Filtralite P in P filter tank

Fig. 13A Construction details of the components of the Høyås farm treatment system (Photos 1-18).

Sand filter

The sandfilter bed is designed with a filter depth approx. 1.0 m is underlain by a dense geomembrane such as polyethylene (PVC 1mm) to avoid seeping of the wastewater into surrounding ground and system drainage.. The membrane and the berm around the filter was constructed 0.3 m higher than the filter surface on all sides.. The bottom of the filter was laid down with a slight slope in the flow direction (0.5-1.0%), while the surface should be horizontal. The wastewater is distributed by means of gravity through a longitudinal distribution pipe from the inlet end of the filter. A standard perforated 110 mm (outer diameter) wastewater pipe was used. Holes of 9 mm per 0.5 m were drilled in the bottom of the pipe. The distribution pipe must be surrounded by gravel of 1220 mm, with adequate hydraulic conductivity. This is essential to ensure an effective

distribution of wastewater in the filter profile. The distribution pipe can be cleaned by back flushing. The construction details of sandfilter are shown in Fig. 13B (Photos 19-22)



Photo: 19 White geotextile membrane in sand filter trench



Photo:20 Non permeable membrane covering sand filter trench and outlet pipe fittings arrangement



Photo: 21 Two compartment sand filter; one compartment for each phosphorus filter tanks



Photo: 22 Sand filters covered with tree bark for insulation

Fig. 13B Design and construction details of the sand filter.

Drainage System

The system is designed so that rainwater is diverted from the system to the surrounding fields or collected by the system underdrain. This assures no water ponding and minimal dilution by rainwater. Corrugated standard drainage pipes with non-corrugated inner lining were used for the drainage system. The drainage pipes are covered by gravel and then by geotextile above it before filling of soil as seen in Fig. 13C (Photos 23-25). The final effluent is connected to the agricultural drainage as shown in Fig. 13C (Photo 26).



Photo: 23 Drainage around the treatment system



Photo: 24 Perforated drainage pipe



Photo: 25 Pipe laying for outlet and drainage

Soil cover

Geotextile

Gravel

Outlet pipe

Drainage pipe

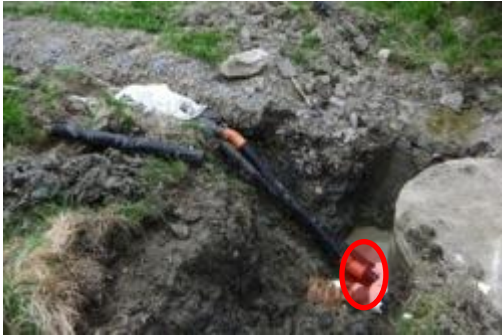


Photo: 26 Final disposal area (agricultural drainage).

Fig. 13C The construction details of the drainage system (Photos 23-26).

6.0 Materials and methods:

The wastewater treatment system that was constructed in Høyås farm has the following components: a septic tank, pumping chamber/ inspection chamber, biofilter domes, phosphorus filter domes and these are described in detail in section 5. The fiber glass domes are manufactured by Bokn Plast AS (Norway-Kopervik) which is the leading supplier of fiberglass tanks and specialist par excellence in environmentally, friendly wastewater, and petroleum solutions. As filter materials, Filtralite P, Filtramar and sand are used in different stages of the treatment process.

Høyås farm was visited right from the construction phase starting from March 2012 and the system observed during the construction procedure. After the treatment plant was put into operation in September, six samples from different treatment components were collected at an interval of around two weeks.

6.1 Water sampling

The sampling method used was grab samples and one was collected per sampling point.. The samples were stored in a freezer for analysis later on. The first samples were collected on first of October 2012. Samples were collected from the septic tank effluent, biofilter effluent, phosphorus filter effluents one from Filtralite P and Filtramar, and sand filter effluents. Samples were analyzed for chemical oxygen demand (COD), 5 days bio-chemical oxygen demand (BOD₅), total phosphorus (Tot-P), orthophosphate (PO₄-P). In addition pH, temperature and conductivity of all the samples were measured. The samples were analyzed at Department of plant and

environmental science laboratory of UMB. The table below shows the date of water sample collection and the lab experiment. From the data collected, the mean and standard deviation values were calculated using Minitab software which is shown as descriptive statistics in the Annex04. The mean value for all the parameters like pH, conductivity, BOD, COD, Tot-P and orthophosphate were calculated for each system effluents using box plot. Graphs were plotted for batch experiment results using Microsoft excel and time series graphs for mean values of parameters using Minitab software.

Table 5: Sample collection date and date of analysis

Samples	Sample Collection Date	Date of analysis
Sample A	01.10.2012	21.11.2012
Sample B	18.10.2012	27.11.2012
Sample C	06.11.2012	09.11.2012
Sample D	20.11.2012	20.12.2012
Sample E	19.12.2012	04.01.2013
Sample F	03.01.2013	04.01.2013

6.1 Physical and chemical analysis

6.1.1 pH:

pH is expressed as negative logarithm of the hydrogen ion concentration.

$$\text{pH} = -\log_{10}[\text{H}^+]$$

The pH range (typically 6-9) suitable for the existence of most of biological life is considered quite narrow and critical. A very acidic or basic wastewater is difficult to treat by biological means. This high concentration of hydrogen ion if is not altered before discharge, the wastewater effluent may alter the concentration in the natural waters. The allowable pH range for treated effluents discharged to the environment usually varies from 6.5 to 8.5. The pH meter “Thermo Scientific Orion Star A329 Portable pH Meter” is used to measure pH of the solution (Tchobanoglous and Burton, 1981).

6.1.2 Conductivity:

The electrical conductivity of water is a measure of the ability of a solution to carry an electrical current. This ability is influenced by the presence of ions; their total concentration, mobility, and valence; and by the temperature of liquid. The conductivity increases as the concentration of ions increases (Tchobanoglous and Burton, 1981). Solutions of most inorganic compounds are

relatively good conductors. In opposition, molecules of organic compounds that do not dissociate in aqueous solution conduct a current very poorly, or may not conduct at all. (COMMITTEE, 1997). In effect, the conductivity value is used as an alternate measure of total dissolved solids concentration (TDS). The electrical conductivity in SI units is expressed as millisiemens per meter or micro-siemens per centimeter and is measured using “Thermo Scientific Orion Star A329 Portable Conductivity Meter” (Tchobanoglous and Burton, 1981).

6.1.3 Biochemical oxygen demand (BOD):

Principle: The determination of BOD concerns the determination of the degradation of organic substances by microorganisms [3]. The 5-days BOD was measured using Respirometric OxiTop system “WTW OxiTop® OC100” [3] which is nothing more than a small-scale wastewater treatment plant, poured into a bottle and operated in the absence of air. Respirometric methods use carbon dioxide and measure change in pressure i.e. respirometric measurement is a pressure measurement. At this point, the role of the sodium hydroxide in the neck of the bottle comes into play. Sodium hydroxide and carbon dioxide react chemically to form sodium carbonate.



The required volume of samples (according to the table 6) was poured into the graduated measuring flask which is a brown glass bottle (to prevent any possible growth of algae) having a capacity of 510ml and threaded neck. 8-10 drops of nitrification inhibitor (C₄H₈N₂S) were added to prevent the conversion of ammonium to nitrate and a magnetic stirrer bar was inserted into the bottle. 3 pellets of sodium hydroxide (NaOH to absorb CO₂) were placed in the rubber sleeve and inserted into the bottle. The rubber sleeve provides leak proof sealing and accommodates CO₂ absorber (sodium hydroxide pellets). Then OxiTop® measuring head was screwed tightly. The measurement on the OxiTop® head was started on the controller “WTW OxiTop® OC100”. The graduated measuring flask was kept in the incubator for five days at 20°C. The results were then read after 5 days as mg/L BOD₅ [3].

The approximate BOD value of the sample must be known in order to estimate the range of measurement. The volume of samples for the different range of BOD (mg /l) is shown in table 6.

Table 6: Volume of samples for different BOD range

³ http://old.omnilab.de/hpb/export/2/BSB_E.PDF

Expected BOD value (mg/l)	Amount of samples used (ml)
0-40	430
0-80	365
0-200	251
0-400	640
0-800	97

6.1.4 Chemical Oxygen Demand (COD):

Principle: oxidizable substances react with sulphuric acid-potassium dichromate solution in the presence of silver sulphate as a catalyst. Chloride is masked by mercury sulphate. The reduction in the yellow coloration of Cr^{6+} is evaluated.

Procedure: Chemical oxygen demand (COD) of the samples was measured using classic COD cuvette test. The cuvette (with necessary chemicals, e.g. LCK 614) was inverted few times to bring the sediment into suspension and 2 ml of diluted samples were added to the solution. The cuvette was closed and cleaned properly and heated in thermostat at 148°C for 2 hours. After heating, cuvette was inverted twice again and allowed to cool to room temperature. The reading for COD was measured in the barcode instrument (HACH LANGE: united for water quality) after cooling. Before doing COD test, one should estimate the range of COD value in order to choose the right cuvette chemicals. The result was expressed as mg /l.

6.1.5 Phosphorus test:

Principle: Phosphate ions react with molybdate and antimony ions in an acidic solution to form an antimonyl phosphomolybdate complex, which is reduced by ascorbic acid to phosphomolybdenum blue.

Procedure: In the laboratory, samples were tested for total phosphorus and orthophosphate. Before test, the approximate range was estimated and chose the correct cuvette with chemicals (e.g LCK 350). For total phosphorus test, the foil from the screwed DosiCap Zip was removed and unscrewed DosiCap Zip. 0.4 ml of samples was pipetted to the solution and screwed the DosiCap Zip from back fluting at the top. The solution was shaken firmly and the cuvette was heated in the thermostat at 100°C for one hour. After heating, the cuvette was allowed to cool to room temperature and then 0.5 ml of reagent B (LCK 350 B) was pipetted into the cooled

cuvette. The cooled cuvette was screwed by a grey DosiCap C (LCK 350 C). Afterwards, the cuvette was inverted a few times, and after 10 minutes the cuvette was inverted few times more and was cleaned thoroughly and evaluated in the barcode instrument (HACH LANGE DR 2800). Similarly, the test for orthophosphate was done except heating the cuvette. The results were expressed as mg P/l.

6.2 P-sorption test: Batch experiment

Principle: There are different experiments which determine the phosphorus sorption by the filter materials. In this project, short batch experiments were used to calculate the P-sorption of the three different filter materials Filtralite P, Filtramar and Sand.

Batch experiment consists of placing a fixed amount of the material with a mass M (g) in a beaker or Erlenmeyer flask containing a volume V (l) of a prepared P solution at one of a range of increasing concentrations. The samples are shaken in a rotator at speed v (rpm) for a time t (h) at temperature T (°c). The difference between initial and final P concentrations in solution at equilibrium (assumed to be reached at time t), C₀ and C_{eq}, respectively, is assumed to be sorbed to the material.

The concentration of P is determined by inductively coupled plasma optical emission spectroscopy (ICP-OES). The amount of P sorbed to the material (S) is expressed in unit mass P (g) per unit mass of the material (kg) and is calculated as:

$$S = [(C_0 - C_{eq}) \times V] / M \text{ (Cucarella and Renman, 2009).}$$

Where S= Amount of P-sorbed (mg/kg)

C₀=Initial phosphorus Concentration (mg/l)

C_{eq}= Final phosphorus concentration (mg/l)

V= Volume of P-concentration solvent (l)

M= Mass of adsorbent (kg)

Procedure:

3mg of filter materials (Filtralite P, Filtramar and Sand) were placed in 90 ml P solutions in pyrex bottles with seven ranges of 0-480 mg/l (0 mg/l, 15 mg/l, 30 mg/l, 60 mg/l, 120 mg/l, 240 mg/l and 480 mg/l) phosphorus as orthophosphate (monobasic potassium phosphate KH₂PO₄) and shook them in mechanical shaker for 24 hours at the rate of 100 rotation per minute. After 24 hours the solutions were filtered using filter paper “Blue Ribon 0.7µm”

The tot-P concentrations were measured using inductively coupled plasma optical emission spectroscopy (ICP-OES) after filtration process. The experiments were replicated.

Altogether 42 Pyrex bottles with samples solutions were prepared for batch experiments. Two liters of 480 mg/l of P-solution was prepared from monobasic potassium phosphate (KH_2PO_4) having molecular weight of 136.09 g/mol and the solutions of different other concentrations were prepared by adding required amount of distilled water. Hence distilled water was used as background electrolyte other than calcium chloride solution used by researchers in other experiments.

Reagents: Phosphorus sorption solution (480 mg/l): 2.106 g of monobasic potassium phosphate (KH_2PO_4) was added to 1.0 liter of deionized water to make 480 mg/l phosphorus sorption solution.

Phosphorus sorption solution (480 mg/l) was diluted to prepare the other phosphorus sorption solutions of concentration (0 mg/l, 15 mg/l, 30 mg/l, 60 mg/l, 120 mg/l, 240 mg/l and 480 mg/l).

6.2.1 Phosphorus adsorption isotherms

The relationship between the equilibrium concentration of a solute in solution (C_{eq}) and the amount of solute sorbed to the material (S) at constant temperature is referred to as the adsorption isotherm (Cucarella and Renman, 2009).

Three P adsorption isotherms often used include Langmuir, Freundlich and Tempkin models the most common of which are Langmuir and Freundlich models (Dunne et al., 2005). To calculate the theoretical P adsorption maxima of the filter materials, the Langmuir model was used for this purpose; and it assumes a uniform adsorbent surface with energetically identical sorption sites (Cucarella and Renman, 2009). In addition, the Langmuir model has advantages in comparison to Freundlich's model, as it provides more information on P sorption parameters. It assumes that adsorption occurs at specific sites and that once these sites are occupied no further adsorption occurs (Dunne et al., 2005).

Adsorption isotherms can be described mathematically with the general formula:

$$S = \frac{K \times C_{eq}}{A + B \times C_{eq}^D} \text{-----Equation (A)}$$

Where K, A, B, and D are isotherm constants.

A number of isotherms have been developed over the years based on different assumptions that simplify the equation A (Cucarella and Renman, 2009).

The Langmuir equation is obtained by setting A = B =1 in the equation below (Equation B), and has the form:

$$S = S_{\max} \times [(K_L \times C_{\text{eq}}) / (1 + K_L \times C_{\text{eq}})] \text{-----Equation (B)}$$

Where K_L is the Langmuir constant and is related to the energy of adsorption and S_{\max} is the maximum adsorption capacity. By linearizing Eq. B, the Langmuir parameters K_L and S_{\max} can be obtained from the slope and intercept of plotting the inverse sorption and equilibrium concentrations (Cucarella and Renman, 2009).

As it is mentioned above that the sorption maximum can be calculated from Langmuir equation, where the advantage of using Langmuir equation. On the other hand, this equation assumes that the sorption energy not to vary with the degree of surface saturation. However, this is the case for the Freundlich equation (Holtan et al., 1988). The Freundlich model is often described in linear form as follows: $\log S = \log K + n \log C$, where S is the amount of P sorbed mg /kg, K is the adsorption constant (mg /kg), n is a constant (l /kg), and C is solution P concentration (mg /l) (Dunne et al., 2005). The Tempkin equation can be derived from Freundlich equation by introducing that the sorption energy decreases linearly with increasing surface saturation. The Tempkin equation is written as $S/S_{\max} = RT/b \ln (AC)$ where R is the gas constant, T is absolute temperature, A and b are constants, and other symbols are as defined above (Holtan et al., 1988)

The phosphorus adsorption capacity (S) of the filter materials used in Høyås farm treatment system and using a solution of 480mgP/l was calculated and plotted according to the following equation:

$$(C_0 - C_{\text{eq}}) (\text{mg P/l}) * (0.09\text{L}) / 3\text{g} = S = \text{adsorption in mg P/g material.}$$

C_0 was the initial concentration of phosphate in the solution and C_{eq} was the phosphate concentration at the end of the experiment (equilibrium concentration) in mg P/l. 0.09l was the total volume and 3g was the material mass added to the solution.

The phosphorus retained (S) (mg P/kg) and equilibrium solution concentration (C) (mg P/l) were fitted to the Langmuir isotherm equations. The Langmuir equation allows the calculation of the maximum retention (S_{\max}) and the binding energy constant (K_2) (Søvik and Kløve, 2005). This is

possible by simulation with the linear equation ($Y = a.X + b$) obtained from the plotting of the ratio C/S versus the average of the equilibrium solution concentrations after experiment (mg P/l), and may be written as:

$$S = K_2 S_{\max} C / (1 + K_2 C)$$

Where C is solution P concentration (mg P/l), K_2 (l/mg P) is the binding energy constant and S_{\max} (mg P/kg kg/l) is designated as the Langmuir sorption maximum, and S is the amount of P sorbed (mg P/kg) (Dunne et al., 2005)

This equation may also be written as:

$$C/S = 1/K_2 S_{\max} + C/S_{\max}$$

Which gives a linear test plot with $1/(K_2 S_{\max})$ as the intercept and $1/S_{\max}$ as the slope.

6.3 Filter Materials

6.3.1 Filtralite HC 2.5-5mm

Filtralite HC is suitable for water treatment, whether it is drinking water, or wastewater. It is a crushed clay aggregates, easy to install in filters. It provides a large surface area for bacteria to grow on, and is characterized by a high filtration of particles as well [4]. In Høyås farm treatment system, Filtralite HC 2.5-5mm is used in biofilter.

The specifications of Filtralite HC 2.5-5 mm from Filtralite.com are shown below and in Annex03.

Specification of Filtralite HC

Coefficient of uniformity $S_o d_{60}/d_{10} < 1.5$
Specific density 0.8
Particle density 1.55
Effective porosity 48

Source: filtralite.com [5]

6.3.2. Filtralite P

⁴ <http://www.weber-norge.no/filtralite/weber-produkter/filtralite/filtralite-hc-25-5-mm.html>.

⁵ http://www.filtralite.com/media/92/datasheets/pdb_juni2011/16h - Data sheet Filtralite HC 25-5.pdf

Filtralite P is the registered trade mark for all expanded clay products used as filter media that are manufactured by Weber. They are inert ceramic particles with a dense shell surrounding a porous core. The chemical and physical composition gives the beads several properties used for many different purposes included filter materials [6]. The specifications of Filtralite P according to “filtralite.com” are shown below, and in Annex03.

<u>Specifications of Filtralite P</u>
Coefficient of uniformity $S_o: d_{60}/d_{10} < 15$
Specific density 0.5
Particle density 0.95
Effective porosity 42%
Hydraulic conductivity $K=150$
pH 12

Source: www.filtralite.com [7]

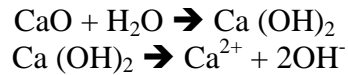
In Høyås farm wastewater treatment system, Filtralite P, are used in one of the phosphorus filter tanks. Filtralite P is the last generation of Norwegian light weight aggregate (LWA) for especially made for phosphorus sorption. It produced by heating clay to 1200°C where it expands and forms porous particles. Filtralite P of grain size 0-4mm is used in one of the phosphorus filter tanks. Filtralite P contains magnesium, calcium, iron and aluminum and high pH as mentioned by Ádám 2007. Filtralite P contains about 7 g Mg/kg , 31 g Ca/kg, 6 g Fe/kg and 20 g Al/kg (Ádám et al., 2007) and has initially a high pH (>10). This high pH (above 10) promotes pathogen removal but may hinder microbial processes as nitrification and denitrification, which are responsible for the removal of nitrogen (N) (Ádám et al., 2007).

During its production, 10-15% of dolomite is added ($Ca Mg (CO_3)_2$) (Jenssen and Krogstad, 2003) to clay prior to heating. This provides for the high phosphorus sorption capacity of the Filtralite P produced in Norway (Jenssen and Krogstad, 2003). Dolomite is a calcium magnesium carbonate formed by carbonate deposits (Tarbuck & Lutgens, 2005). By heating the dolomite, (CaO) and (Mg O) will be formed. Calcium oxide (CaO) dissociates in water and forms

⁶ www.filtralite.com

⁷ http://www.filtralite.com/media/92/datasheets/pdb_juni2011/16k - Data sheet Filtralite P 0-4.pdf

alkaline conditions (Zhu et al., 1997). Since CaO is very reactive, it will react with air humidity forming calcium dihydroxide (Ca (OH)₂), a calcium hydroxide mineral (Jørgensen, 1997). The reaction below shows what happens when CaO reacts with water (Skjønberg, 2010):



Reactions that will occur between clay and dolomite during the heating process will lead to an increase of pH when the water comes into contact with the filter material (Jenssen and Krogstad, 2003, Mander and Jenssen, 2003).

6.3.3 Filtramar (Shellsand):

It is a naturally available material along the coastline all around the world (Ádám et al., 2007). It is mainly sourced from shells, snails and coral algae with a grain consistently similar to sand or gravel. The quality varies and can be separated according to its origin and weathering (Erstad, 1982). According to Roseth (2000) one million tonnes are annually harvested on the Norwegian coastline (Roseth, 2000). According to Ádám (2007), Filtramar (shellsand) also composes of 14 g Mg/kg, 300 g Ca/kg, 0.6 g Fe/kg and 0.3 g Al/kg (Ádám et al., 2007). Shellsand has a porosity of 35-50% and grain size in the range 3-7mm (Roseth, 2000, Adam et al., 2007).

The specifications of Filtramar according to Bokn Plast AS are shown below:

<u>Specification of Filtramar</u>
Coefficient of uniformity $S_o : d_{60}/d_{10} < 4$
Specific density 0.8
Particle density 1.4
Effective porosity 50%
Hydraulic conductivity $K=300$
P-removal capacity 3-4 g/kg
pH 8-8.5
Life time depends on number Pe

Source: Bokn Plast AS (Web: <http://www.boknplast.no/>) [⁸]

6.3.4 Filtralite P Vs Filtramar (Shellsand):

⁸ http://www.bokn-plast.no/PDF/avlopsanlegg_tanker/brosjyrer/naturen_rensanlegg_bokn-plast.pdf

Filtralite has high pH (>10) which promotes pathogen removal but may hinder microbial processes as nitrification and denitrification, which are responsible for the removal of nitrogen. Thus if N removal is required, Filtramar is probably a more suitable filter material than Filtralite P. Alternatively a combination of the two types of material may be used; shell-sand in the first part of the horizontal bed promoting N and P removal, while use of Filtralite P in the last part of the bed ensures removal of pathogens and further removal of P. Such combinations of filter materials should be examined in long-term trench studies (ÁdÁm et al., 2007).

The dolomite addition during Filtralite production provides high phosphorus sorption capacity. Filtralite P has also a good hydraulic conductivity and highly studied with batch, box, trench, column and full scale studies. Also the saturated Filtralite P can be used as an alternative fertilizer in agriculture. However, leaching of calcium from Filtralite P leads to the formation of CaCO₃ in outlet during the initial phase (1-2 years) of operation. This causes clogging of the system (ÁdÁm et al., 2007).

The production of Filtralite P is energy consuming, hence it is expensive. However, Filtramar is abundantly available in the coastal areas, so it is relatively cheaper than Filtralite P. Filtramar also has a good hydraulic conductivity and a good P sorption capacity measured in laboratory tests. But it has low pH about 8 which is not sufficient for pathogen removal but favorable for nitrogen removal (ÁdÁm et al., 2007).

6.3.5 Sand:

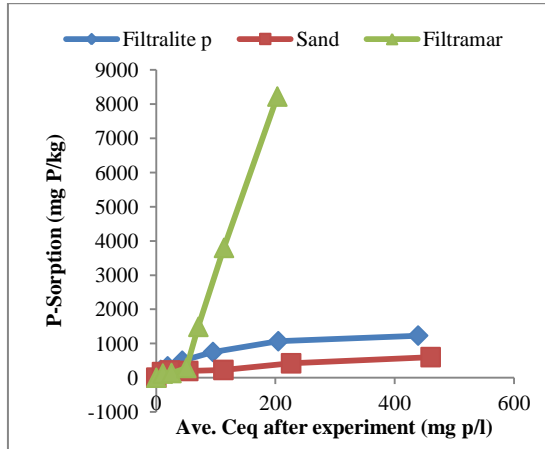
In Høyås farm treatment system, the sand rich iron is used in sandfilter. Sand filters are also known as efficient units for complex wastewater purification (BOD, COD, NH₄-N), and also in some cases PO₄-P and faecal (Jenssen and Siegrist, 1990, Vohla et al., 2011).

In sand or gravel substrates, phosphorus is bound to the media mainly as a consequence of adsorption and precipitation reactions with calcium (Ca), aluminium (Al) and iron (Fe) (Vohla et al., 2011).

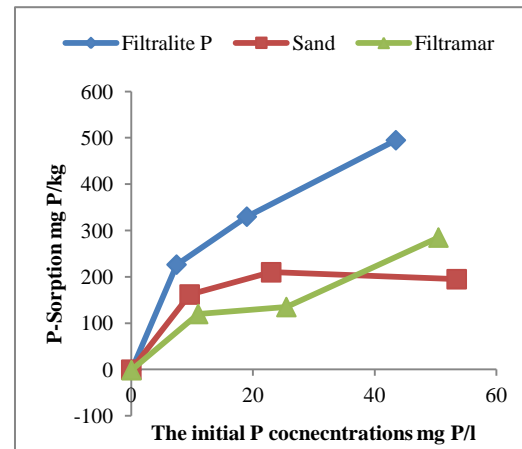
7.0 Results and Discussion:

7.1 Batch experiment

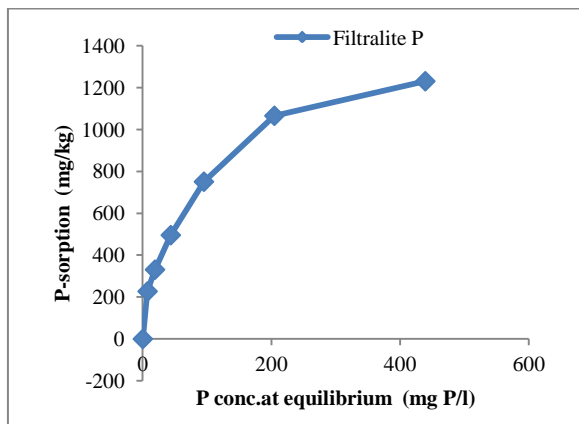
A batch experiment was carried out to compare the Filtralite P to Filtramar and graphs are shown in Fig. 14.



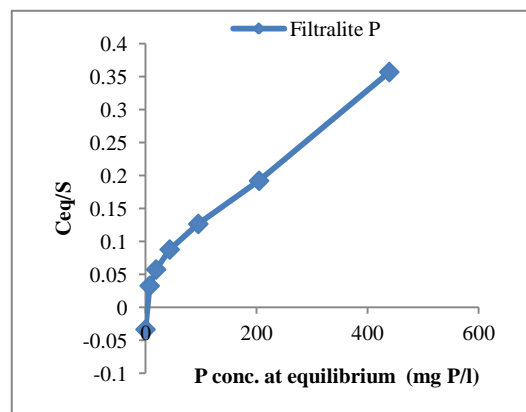
A: The entire P-Sorption Isotherm



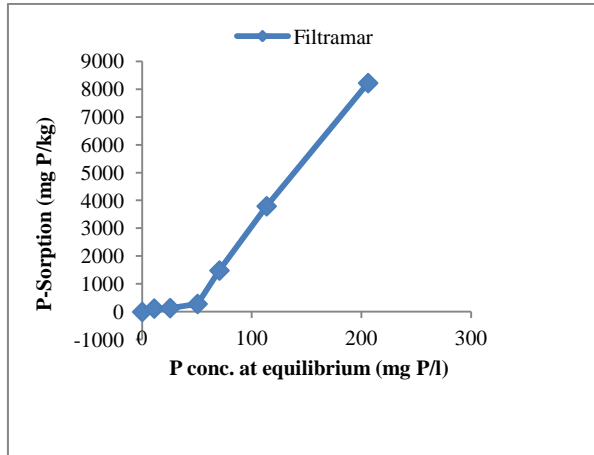
B: The first part of the P-Sorption Isotherm



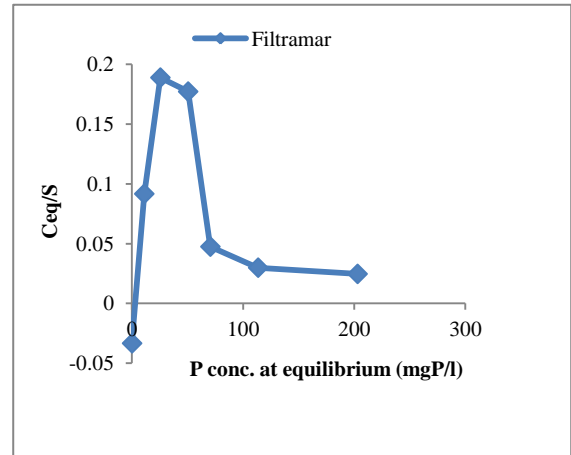
C: The P-sorption of Filtralite P at different equilibrium. P concentrations.



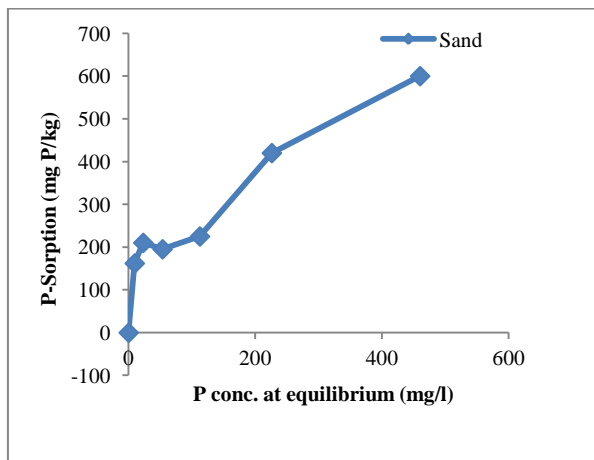
D: S_{\max} (C_{eq}/S) values of Filtralite P at different Equil. Conc. of P according to Langmuir Model.



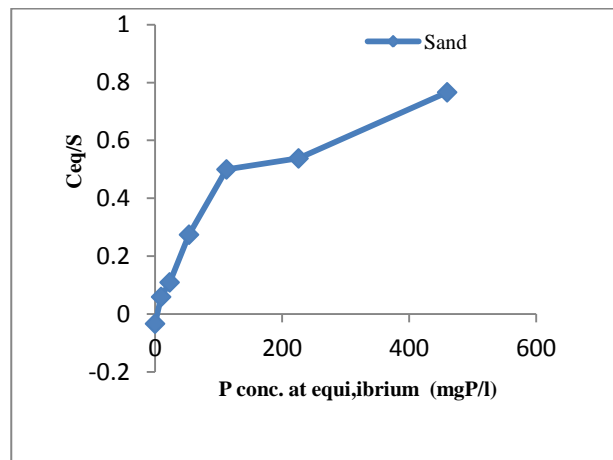
E: The P-sorption of Filtramar at different equilibrium P concentrations. Showing two types of sorption mechanisms (first part corresponds to adsorption process at low initial P concentrations (indicating the realistic conditions of field investigations, and the second part indicates the precipitation mechanism at high initial P concentrations; with absence of linearity which doesn't fit Langmuir Model).



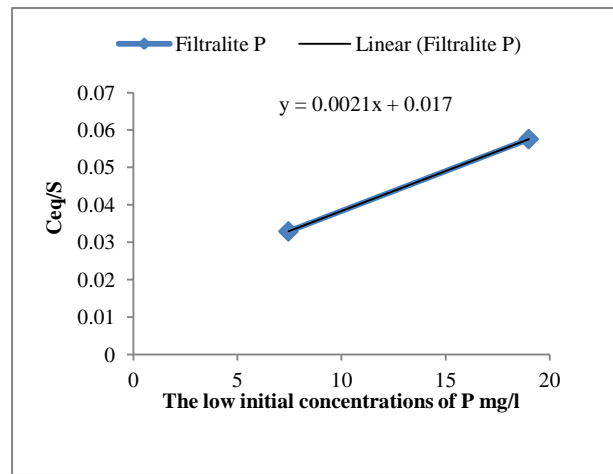
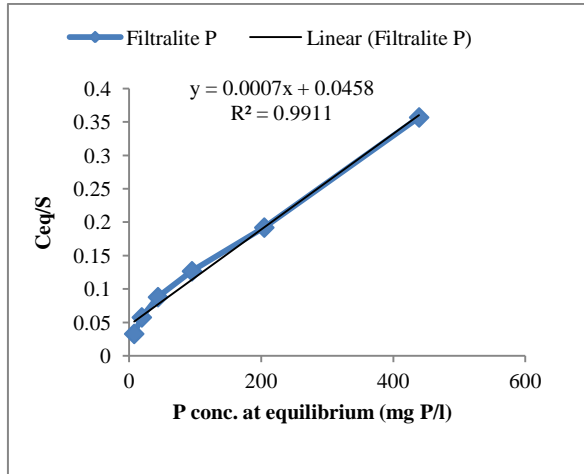
F: S_{max} (C_{eq}/S) values of Filtramar as a function of eq. P. Conc. The linearity of S_{max} is obvious at low initial verifying the Langmuir equation, while at high initial conc. of P, the non-linearity takes place by decreasing and then stabilizing, where the Langmuir model is not confirmed.



G: P-sorption of sand Vs equilibrium P concentration, With one type of sorption mechanism (mostly adsorption) at Low and high initial P conc. The real form of Langmuir Model is not well represented.

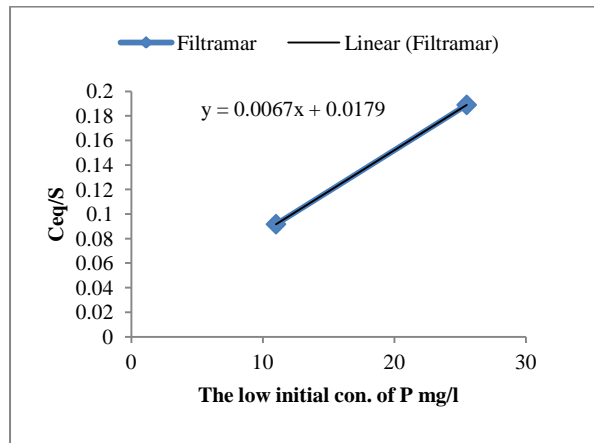
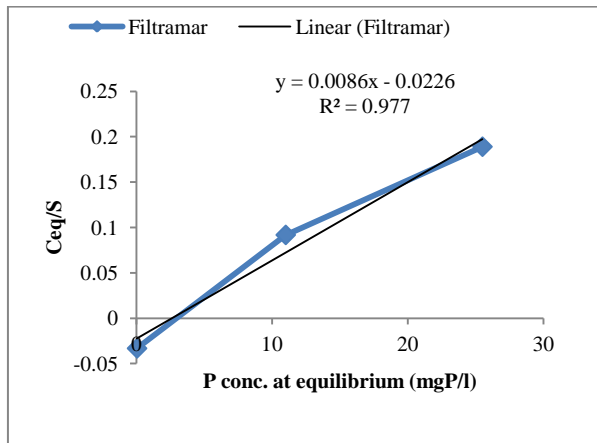


H: S_{max} values of Sand in function of P. con. Eq. The linearity of Langmuir is not absolutely present due to the irregular form of the isotherm.



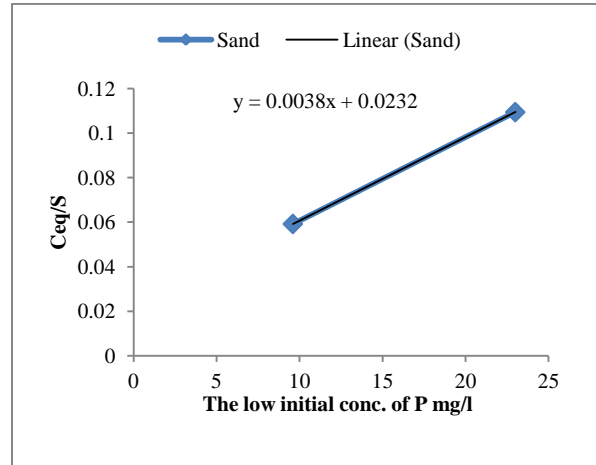
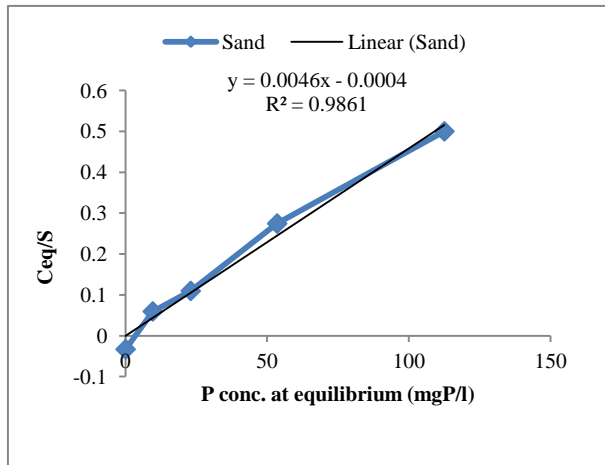
I: S_{max} values of Filtralite P in function of P. con. Eq
 For concentration 480mg/l which gives S_{max} of
 Filtralite P 1428 mg/kg, this S_{max} was obtained from the linear
 equation $Y=0.0007X+0.0458$ which gives
 $S_{max}=1/0.0007=1428$ mg/kg, and $1/K_2 S_{max}=0.0458$
 which gives $K_2=0.015$ l/mg P (K_2 to show how much P
 is adsorbed to the surface of a given filter material).

J: the S_{max} of Filtralite P was almost 476 mg P/kg. This was
 obtained from $y = 0,0021x + 0,017$, which gives $S_{max}=1/0.0021$
 $=476$ mg/kg



K: the S_{max} was found to be 116 mg P/kg
 with $1/K_2 S_{max}=0.0226$, which gives $K_2=0.38$ l/mg P.
 This 116 is less than Sorption (S) calculated from
 mass balance after Batch experiment which is 8220 mg P/kg.

L: the S_{max} the Filtramar (shellsand) was around 149 mg P/kg.
 This was obtained from $y = 0,0067x + 0, 0179$,
 which gives $S_{max}=1/0.0067=149$ mg P/kg.



M: S_{max} was found to be 217 mg P/kg with $1/K_2 S_{max} = 0.0004$, which gives $K_2 = 11.5$ l/mg P. This 217.39 is also less than sorption (S) 600 mg P/kg obtained from mass balance equation after Batch experiment and at high initial conc. 480mg p/l.

N: S_{max} of Sand was around 263 mg P/kg. This was obtained from $y = 0,0038x + 0, 0232$, which gives $S_{max} = 1/0.0038 = 263$ mg P/kg.

Fig. 14 (A-N): P adsorption as a function of P equilibrium concentrations in the batch experiment. The details are given below for each figure.

Fig.14 (A-N) shows the P sorption of the tested filter materials as a function of P equilibrium concentrations in the batch experiment as well as the maximum retention capacity of P: S_{max} (C_{eq}/S as a function of initial P concentrations at equilibrium (mg P/l)), which is plotted according to Langmuir model at both low initial P concentrations (10-15 ppm) and at high initial P concentrations (0-480 ppm).

The sorption isotherms show different behavior at high and low initial P concentrations, and did not fit the Langmuir or Freundlich isotherms (linearity of the curves especially for Filtramar). The Fig. 14(A) shows the entire isotherm of the filter materials i.e. for initial concentrations between 0 and 480 ppm P and Fig. 14(B) shows the isotherm for filter materials for initial concentrations between 0 and 50 ppm of P. With an initial concentration of 480 ppm, Filtramar (shellsand) has a P sorption capacity of 8.22 g P/kg (Fig.14 (E)), while Filtralite P was found to have a P sorption capacity of 1.23g P/kg (Fig.14 (C)), and sand was found to have a low P sorption capacity of 0.6g P/kg (Fig. 14(G)).

In a real situation the wastewater including toilet waste has a P concentration of about 10–15ppm. In this concentration interval the Filtralite P showed almost three times better removal capacity

than the sand and Filtramar (shellsand) did. This maximum P retention has been estimated from Figures 14 (J) and 14(L) and 14(N), and by taking the range (0-15) mg P/l which represents the first low initial concentrations of P in solution. These figures are plotted according to Langmuir model. The Langmuir equation (the linear equation ($Y=a*X \pm b$)), allows the calculation of S_{\max} (the Langmuir sorption maximum) and the binding energy constant K_2 as it is illustrated in the following equation: $C/S=1/K_2S_{\max} + C/S_{\max}$.

The aim is to compare the maximum retention capacity of filter materials being used in our system with the real conditions of field investigations of wastewater regarding phosphorus, and using the same interval of P concentrations in wastewater. Thus, the S_{\max} of Filtralite P was around 476 mg P/kg [$S_{\max}= 1/0.0021= 476$] and that of the Filtramar (shellsand) was 149 mg P/kg [$S_{\max}= 1/0.0067=149$], and for Sand was around 263mg P/kg [$S_{\max}= 1/0.0038=263$]. On the other hand at higher initial P concentrations (between 50 and 480 ppm) Filtramar (shellsand) removed significantly higher amounts of P (Fig. 14(A)). This means that it is difficult to say that the P-sorption capacity is better for certain materials, but we can deduct for the batch experiment that at lower P-concentrations Filtralite P has higher P-sorption capacity than Filtramar and in higher concentrations, Filtramar has higher P-sorption than Filtralite P. However, a batch experiment with phosphate solution and duration of 24 hours is very different from the full scale field situation with real wastewater. Full scale experiments are needed to supplement the batch experiments to verify if the differences observed also are present under field conditions.

The nature of the P solution used in batch experiments differs considerably among studies. Potassium dihydrogen phosphate is generally used and the most common solvent is water. However, many authors use a certain concentration of electrolyte to maintain a constant ionic strength. The type and concentration of the supporting electrolyte affects the interactions in solution. The presence of ions other than phosphate ions and the material under investigation may interfere with the sorption process and, consequently, the sorption capacity (Cucarella and Renman, 2009).

The P sorption capacity of the materials was measured with short-term batch experiments, with 24 hours shaking. In the batch experiment, the sorption capacity (8.22gP/kg) found for Filtramar is consistent with earlier findings by Roseth (2000) and Sjøvik and Kløve (2005) (Adam et al.,

2007), and some other investigations for retention capacity of Filtramar (Vohla et al., 2011). According to Roseth (2000), the calculated adsorption of phosphorus for the different qualities of Filtramar was very high, varying from 14-17g P/kg Filtramar (Roseth, 2000, Jenssen et al., 2005, Jenssen et al., 2006). According to Sjøvik and Kløve (2005), the maximum retention capacity was about 8000 and 800 mg P/kg depending on the ratio soil-water (Sjøvik and Kløve, 2005).

The maximum P sorption capacities of Filtralite P and Filtramar (shell sand) from previous investigations using Batch Experiments, long term laboratory experiments and field studies are illustrated in Annex 05. Comparing with our results, the sorption capacity found for Filtralite P was only 1.23gP/kg and that found for Sand was only 0.6g P/kg, which are much lower than previous the 12gP/kg for Filtralite P found by Jenssen and Krogstad (2003). According to Jenssen and Krogstad (2003), using P-solutions with concentrations of 320 and 480 ppm may give a P-Sorption of 8000 and 12000mg P/kg Filtralite P, respectively. Our results are quite consistent with those reported by Zhu (1998) for Filtralite P (first generation) with P sorption capacity range between 0.4 and 3.5 g P/kg material. However, Zhu used the very first generation of Filtralite without dolomite addition (Zhu, 1998). In brown sand containing much oxidized iron compounds, a phosphorus binding capacity over 1000 mg/kg was reported (Jenssen et al., 2005, Jenssen et al., 2006).

Phosphorus transformations in wetlands include adsorption/desorption, precipitation/dissolution, plant/microbial uptake, fragmentation and leaching, mineralization and burial. Thus when evaluation a wetland ecosystem considering P retention, all these components should be quantified (Vymazal, 2007) Within a constructed filter bed system, P is involved in a complicated biogeochemical cycle, which involves many pathways and different temporary and permanent sinks (Sjøvik and Kløve, 2005).

“Adsorption can be defined as the net accumulation of matter at the interface between a solid phase and an aqueous solution phase. The matter accumulates at the surface is a two-dimensional molecular arrangement in contrast to precipitation that includes the development of a three-dimensional molecular structure” (Johansson, 1998). Precipitation is the removal of two or more components from solution by their mutual combination into a new solid-phase compound (Holtan et al., 1988). Hence, adsorption and precipitation reactions will be the main sinks for P in the long

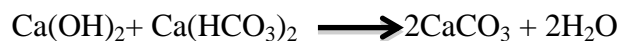
term. These reactions depend on the metal content of the filter material as well as ambient conditions such as pH, redox conditions and ionic strength. It is also well known that in acidic soils, phosphorus is precipitated by iron, aluminium and manganese ions. In alkaline soils, Ca^{2+} ions in the soil solution will react with P and form insoluble calcium P compounds which are slowly converted to apatite (Brady and Weil, 2002).

Batch experiment results showed the shape of the sorption isotherm for Filtramar as in (Fig. 14 (A) & (B)) which indicated the following: for initial P concentrations between 0-50 mg/l, the retention process occurs as adsorption processes. For high initial phosphorus concentrations between 50-480 mg/l, the precipitation of Ca-P minerals probably dominated. The precipitation was favored by the metal content of the filter material such as calcium and magnesium. According to Roseth (2000), chemical analyses performed on shellsand showed a high concentration of CaCO_3 measured as CaO and smaller variable concentrations of MgCO_3 measured as MgO contributed in phosphorus precipitation.

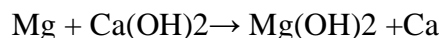
Concerning Filtralite P, the sorption (precipitation due to high pH) is the dominant retention mechanism for all initial phosphorus concentrations in the solution (Fig. 14 (C)). With an initial concentration of 480 ppm, the Filtralite P had a sorption capacity of 1.23 g P/kg which is almost consistent with the previous findings about the sorption isotherms for Filtralite P, with a sorption 2 mg P/g with initial concentration of 480mg P/l (Erstad, 2011). This precipitation was favored by the dramatic increase of pH (Fig: 14, 15). This increase in pH is probably due to the calcium (CaO) content which will create the alkaline conditions when the water comes into contact with the filter material (Zhu et al., 1997).

At high pH, calcium and magnesium are considered as the very important elements regarding the P sorption processes. At high pH values, P exists as HPO_4^{2-} in soils (Brady and Weil, 2002). The general view is that retention occurs as a result of adsorption of HPO_4^{2-} on to calcite by replacement of water and bicarbonate (HCO_3^-) or OH^- ions present on the calcite particles. In alkaline conditions at high P concentrations the presence of reactive Ca causes precipitation of calcium phosphates (Ahmed, 2007).

Lime (CaO) reacts with bicarbonate alkalinity of wastewater to form calcium carbonate and also reacts with orthophosphate to precipitate hydroxyapatite as shown in the following equations:



The apatite precipitate is a crystalline precipitate of variable composition represented by $\text{Ca}_5(\text{OH})(\text{PO}_4)_3$ in the equation above. As pH is increased above 9.5, precipitation of magnesium hydroxide begins:



Magnesium precipitation will not be complete until pH reaches 11.0.

The oxides of Al and Fe are moderately soluble at high PH, and they tend to react with H_2O forming hydroxides. The primary P-removal via Fe is by the formation of solid FeOOH-PO_4 complexes, for which the optimum PH is 5-7 (Lijklema, 1977). Aluminium forms Al(OH)_3 , which is a colloidal, amorphous floc, which combines strongly with P. At PH 6-8, insoluble Al(OH)_3 is predominant whereas at $\text{PH} < 6$, various soluble intermediate forms occur (Zhu et al., 1997).

A study was done by Zhu (1997) to illustrate the relationship between P-sorption and the chemical characteristics of the filter media. The relationship assumed that the P-sorption capacity was affected by total metal content, Fe-Al oxides, and CEC of the different filter media tested. The tested filter media which had high total metal content values, also exhibited the highest CEC, approximately 10-20 times greater than the others. The regression analysis of Ca, Al, Fe, Mg, and the P-sorption capacity showed that, among these four elements, Ca had the highest correlation with the P-sorption capacity (Zhu et al., 1997).

Despite the highest correlation of Ca with the P- Sorption capacity of filter material, this metal is responsible of some problems that can reduce the performance of the filter material. Among these problems are the clogging and leaching from filter media. An earlier study by Adam (2005) showed that Ca loss from Filtralite P material could be as much as 30% in the case of horizontal subsurface flow small-scale systems. The Ca loss from constructed wetland systems causes clogging of the effluent pipe and white precipitate around the discharge point (Adam et al., 2007) but not many has reported .

The sorption mechanism in Filtramar occurring at low initial concentrations is more close to the real conditions in the field than the precipitation taking place at high initial phosphorus concentrations. Thus, the presence of such discrepancy between realistic and unrealistic conditions in the phosphorus retention in Filtramar has created some difficulties to distinguish between the two retention processes of phosphorus in shellsand (Søvik and Kløve, 2005).

The initial P concentration in a batch test can be set in the range in which the material is expected to remove P for a given material to solution ratio. Typical concentrations of P in wastewater range from 5 to 10 mg p/l but can be as high as 20 or 30 mg p/l in some cases (Cucarella and Renman, 2009). Using much higher concentrations may lead to erroneous results (Drizo et al., 2002). Higher P concentrations give a lower pH value, which certainly influences the sorption reaction. Very high concentrations create a new and probably different equilibrium situation that might not reflect what happens at lower concentration (Adam et al., 2007, Søvik and Kløve, 2005). It is also known that precipitation reaction usually occur at high P concentrations, while adsorption dominates at low concentrations (Søvik and Kløve, 2005). Isotherm graph for Filtramar shows adsorption process occurs at low P concentration and precipitation occurs at high P concentration. The Fig. 14 (E& F) shows the mixture of adsorption and precipitation mechanism which means Langmuir model is not confirmed.

Since Filtramar consists ten times more calcium than Filtralite P (Roseth, 2000, Erstad, 2011), it could be the possible reason that the precipitation of calcium minerals is much greater in Filtramar. During the production of Filtralite P, 10-15% dolomite (CaMgCO_3) is added to clay prior to heating. Addition of dolomite is the main cause of the high P sorption capacity of Filtralite P produced in Norway (Jenssen and Krogstad, 2003, Mander and Jenssen, 2003). Dolomite is a calcium magnesium carbonate found in carbonate minerals and rocks. Reactions that will occur between clay and dolomite during the heating process will lead to an increase of pH when the water comes into contact with the filter material (Jenssen and Krogstad, 2003, Mander and Jenssen, 2003). Thus at the first phase (1-2 years) of a Filtralite P the pH of the system will be high (Skjønberg, 2010). The heating during the manufacturing process will create a high porosity of Filtralite P. This high porosity combined with high phosphorus removal and

good insulation properties, have characterized Filtralite P made in Norway (Jenssen and Krogstad, 2003, Mander and Jenssen, 2003, Skjønsberg, 2010).

The life time of filter bed systems consisting of Filtralite P is estimated to be 10-15 years depending on the loading rate (Jenssen et al., 2005).. From the table (7), it shows that the life time for the Filtralite P and Filtramar is 2.45 years and 26.2 years respectively. This means, the replacement of Filtralite P is needed after 2.45 years. This also means that Filtralite P is very close to saturation within a short period of time. The reason to have such low life time is due to using of only 4 m³ of Filtralite P. In a system sized according to VA/Miljøblad nr.49 the amount of filter material would have been 80 m³ minimum for similar treatment system which justifies that treatment system in Høyås farm is quite reasonable.

However these results are inconsistent with batch experiment and Langmuir equation regarding the S_{max} and the saturation point of the filter media. Since batch experiment does not give the real conditions of filter media saturation point, there is necessity of full scale field situation with real wastewater. Full scale experiments are needed to supplement the batch experiments to verify if the differences observed also are present under field conditions (Jenssen et al., 2010, Vohla et al., 2011). The life time of filter materials is shown in the table 7.

Table (7): Life Time of filter materials

Properties	Filtralite P	Filtramar
Bulk density (kg/m ³)	500	800
Volume (m ³)	4	4
Weight (kg)	2000	3200
Maximum P-sorption (S _{max}) (g/kg)	1.23	8.22
Maximum P-sorbed (kg)	2.46	26.30
Assume, *daily production of wastewater = 125l/d/Pe Annual production by 8 Person (l) = 125x8x365 =365000		
Volume of wastewater flow (l)	182500	182500
Orthophosphate concentration in bio-filter effluents -from lab results (mg/l)	5.5	5.5
Orthophosphate production (kg)	1.00375	1.00375
Life years	2.45	26.2

*200l/Pe.d design flow is used in the system but calculate life time using only 125 l/Pe.d considering average population 8 Pe has hardly reached during our field visit period. This means water consumption is reduced than designed.

7.2 Saturation of filter materials:

From batch experiment results seen in Fig. 14 and Annex 06 the saturation of filter materials is calculated using Langmuir equation. For concentration 480mg/l which gives S_{max} of Filtralite P 1428 mg/kg. This S_{max} was obtained from the linear equation $y=0.0007x+0.0458$ (Fig. 14. I). which gives $S_{max}=1/0.0007=1428$ mg/kg, and $1/K_2 S_{max}=0.0458$ which gives $K_2=0.015$ l/mg P. This calculated S_{max} at high initial P concentration has showed that Filtralite P still has some capacity to bind and sorb phosphorus, compared to that obtained from batch experiment, which is 1230mg/kg filter material (sorption isotherm of Filtralite P Fig.14 C) using mass balance equation. The mass balance equation can be written as follows:

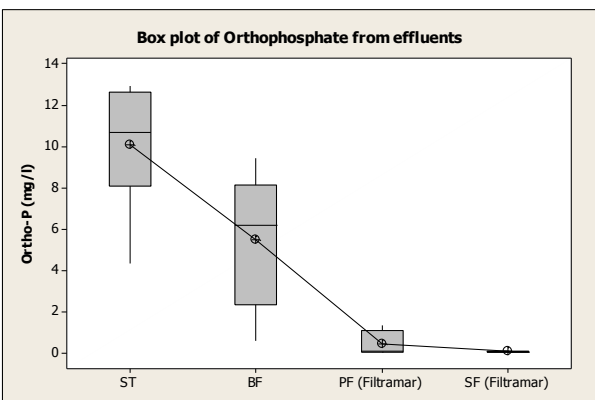
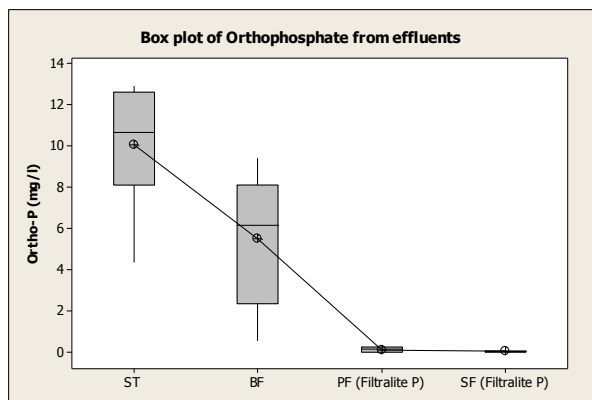
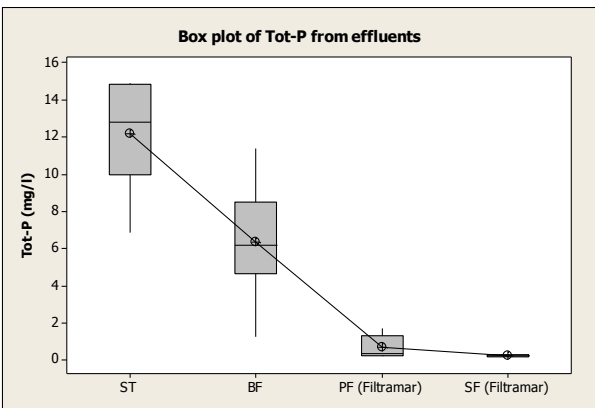
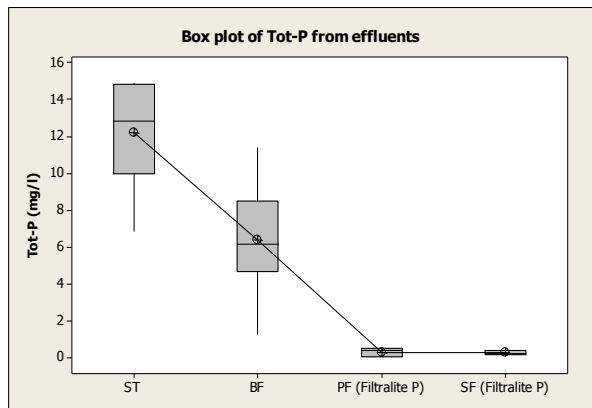
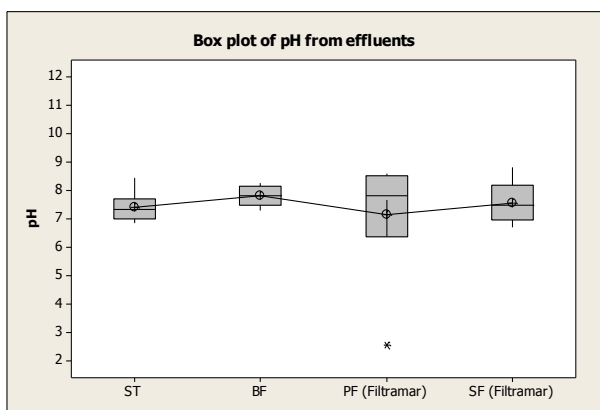
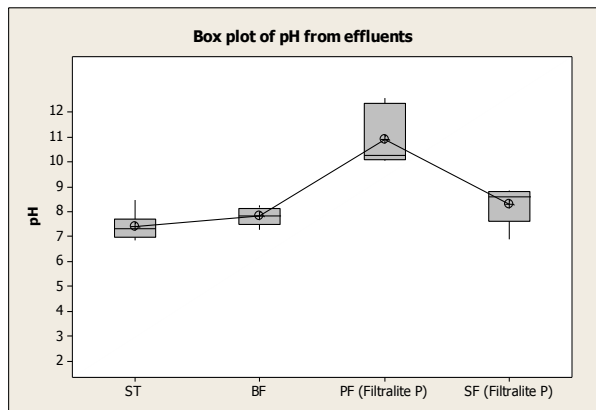
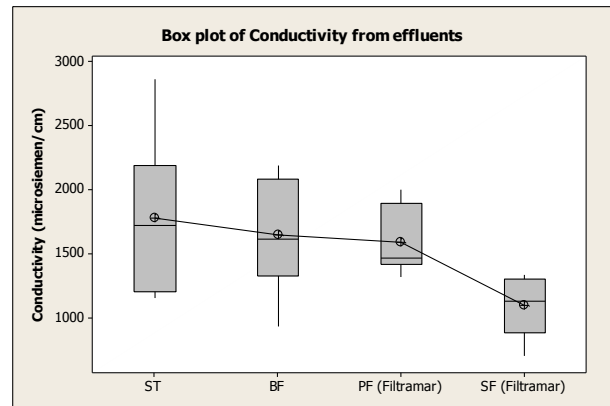
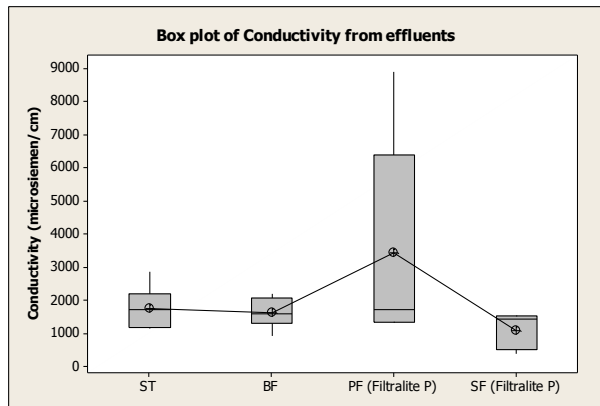
(C_0-C_{eq}) (mg P/L)* (0.09L)/3g = S, sorption in mg P/g material; Where C_0 is the initial concentration of phosphate in the solution and C_{eq} is the phosphate concentration at the end of the experiment (equilibrium concentration) in mg P/l. 0.09l is the total volume and 3g is the material mass added to the solution.

Similarly, the S_{max} of both Filtramar and Sand was also estimated. For Filtramar, the S_{max} was 116 mg P/kg ($y=0.0086x-0.0226$, Fig. 12. K), with $1/K_2 S_{max}=0.0226$, which gave $K_2=0.38$ l/mg P, and for Sand S_{max} was 217mg P/kg ($Y=0.0046X-0.0004$, Fig. 14. M), with $1/K_2 S_{max}=0.0004$, which gave $K_2=11.5$ l/mg P.

For Filtramar the $S_{max}=116$ was lower than the sorption calculated from mass balance (8220 mg P/kg at high initial P concentration 480 ppm). This means that the 480mgP/l applied to the Filtramar has saturated this filter material. For Sand, $S_{max} = 217$ was also lower than Sorption=600mg P/kg obtained from mass balance equation at high initial concentration 480mg P/l, which means that the sand has reached saturated too.

7.3 The removal efficiencies of wastewater parameters

The removal efficiencies are calculated from the difference between influent and effluent concentrations. They are shown in table 8.



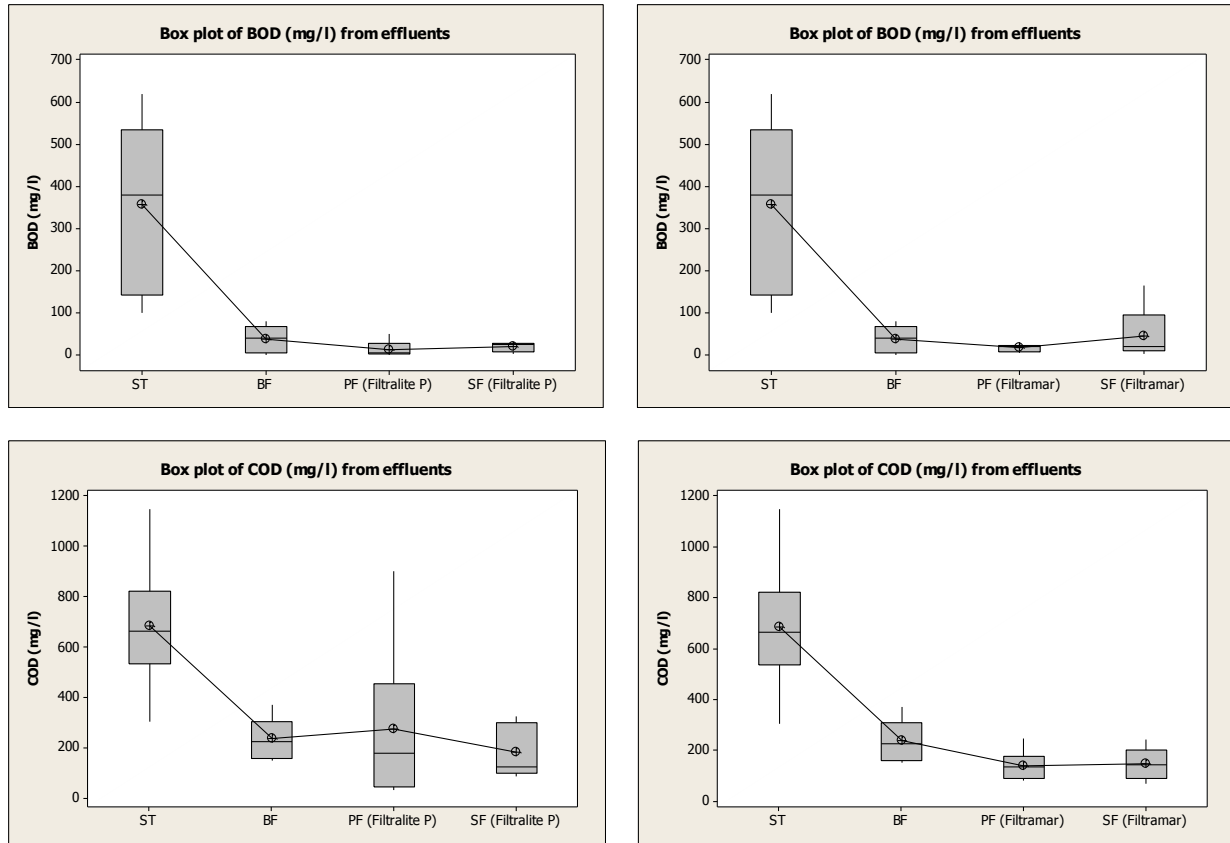


Fig. 15: Box plots of effluent concentrations at Høyås farm system: ST (septic tank), BF (biofilter), PF (phosphorus filter), SF (sand filter). The figures show the mean values; SD (standard deviation), and medians for all the observations (n=number of samples= 6) including the parameters COD mg/l, BOD mg/l, pH, conductivity $\mu\text{s}/\text{cm}$, Tot- P mg P/l, and Ortho-phosphate mg P/l.



 Mean box;
  Median

Table 8: removal efficiencies for different parameters

Components	BOD Removal Efficiency		COD Removal Efficiency		Tot-P Removal Efficiency		Ortho-Phosphate Removal Efficiency	
	Mean Value (mg/l)	Removal (%)	Mean Value (mg/l)	Removal (%)	Mean Value (mg/l)	Removal (%)	Mean Value (mg/l)	Removal (%)
Septic tank effluent	357.70		685.00		12.190		10.07	
Bio-filter effluent	36.80	89.71	237.50	65.33	6.380	47.66	5.50	45.38
Phosphorus filter effluent								
<i>Filtralite P</i>	13.00	96.37	275.00	59.85	0.333	97.27	0.15	98.48
<i>Filtramar</i>	19.44	94.57	141.40	79.36	0.688	94.36	0.46	95.45
Sand Filter effluent								
<i>Filtralite P</i>	23.82	93.34	186.40	72.79	0.276	97.74	0.08	99.26
<i>Filtramar</i>	45.10	87.39	145.80	78.72	0.262	97.85	0.10	99.01
Recipient		90.36		75.75		97.79		99.13

The table 8 shows that overall removal efficiencies for different parameters are >80% except for COD. For the phosphorus, the removal efficiency is above 90% and less than 0.5mg P/l which satisfies the guidelines and regulations of Norway. The removal efficiency for COD is comparatively lower than other parameters which may be due to the leaching of humic substances from the bark used for insulation.

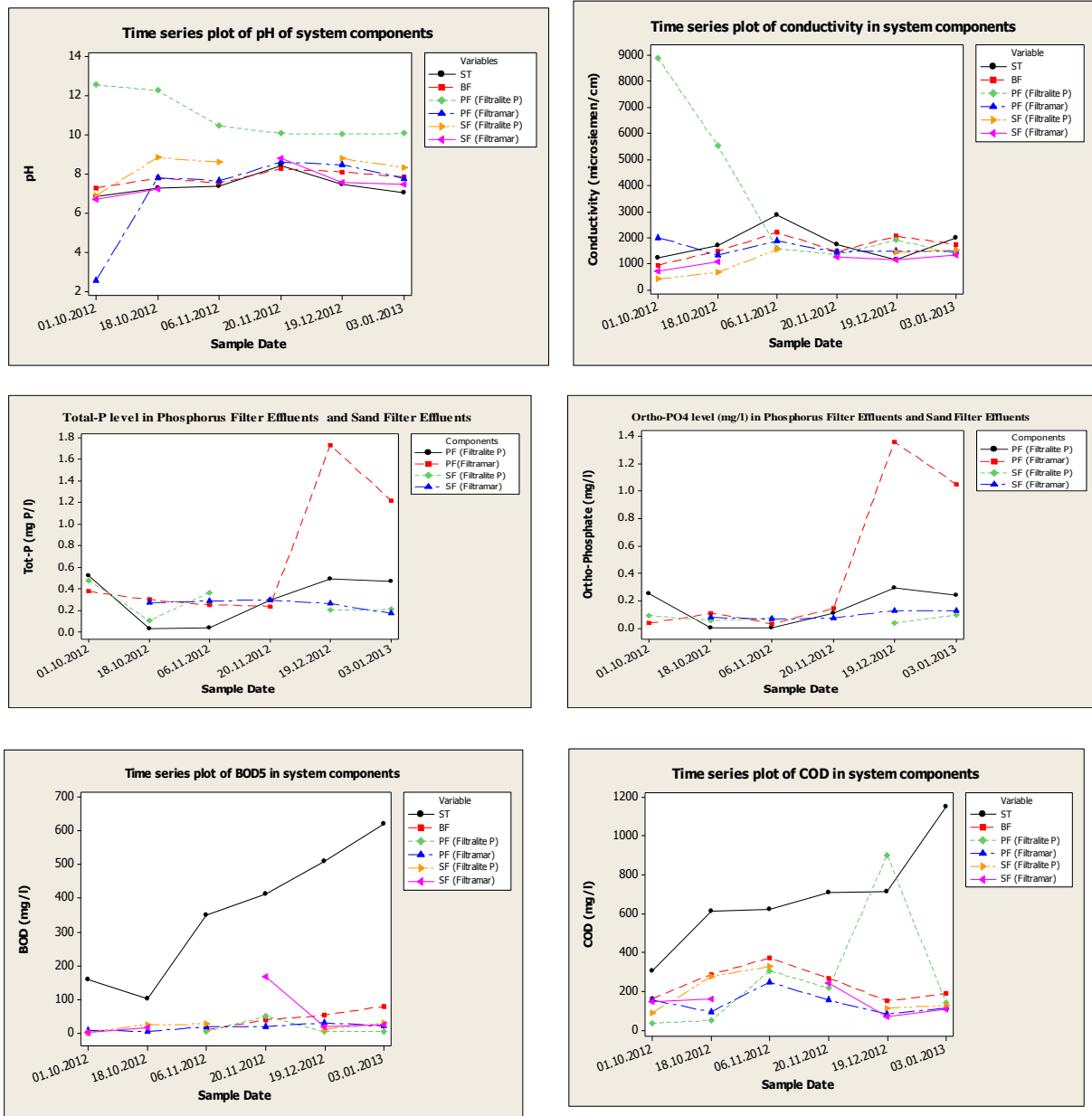


Figure 16: Time series of water concentrations in the effluents at Høyås farm treatment system.

Total Phosphorus and orthophosphate:

The system has performed excellently with respect to Tot-P and orthophosphate throughout the experiment with more than 90%. The average reduction in the final effluent with respect to Tot-P and Orthophosphate is 97.79% and 99.13% respectively (table 8). The final effluent has a value less than 0.5 mg/l. However, an increase of phosphorus concentration in PF (Filtramar) up to 1.730 mg P/l for Tot-P and 1.360 mg P/l for orthophosphate has been detected before the last measurement in December 2012 (Fig 16). It may be due to some technical problems or something wrong with the samples.

BOD: From table 8 the average value of BOD₅ for septic effluent is 357.7 mg/l and bio-filter effluent has 36.80 mg/l which shows the maximum BOD removal with an around of 90%. The phosphorus effluent has BOD level less than 25 mg/l which means around 95% removal was observed after phosphorus filter. But slight increase after the sand filter has been observed which may be due to leaching of humic substances from tree bark used for insulation of sand filter.

The time series graph (Fig. 16) shows continuous increase in BOD value in septic tank after the months October which may be due to probable reactions taking place in it releasing organic matter.

COD: Table 8 shows the average COD removal to around 75%. The septic tank effluent has an average COD concentration of 685.00 mg/l and the final effluent has an average value of 165 mg/l. The maximum reduction of COD occurs after septic tank which accounts for about 65%. Time series graph (Fig. 16) shows a continuous increase of COD concentration in septic tank effluent. Also sudden unexpected result of COD concentration (900 mg/l) was observed in December 2012 from phosphorus filter (Filtralite P) but phosphorus filter (Filtramar) shows only 82.20 mg/l COD in the same month. The increase of COD value after phosphorus filter may be due to the leaching of humic substances originating in the bark used as insulation in the sand filter.

pH: The mean effluent box plot for pH (Fig.15) shows high pH in phosphorus filter (Filtralite P) effluent with 10.91, while there is a decrease after sand filter (Filtralite P) effluent with 8.292. From the box plot, there is a decrease of pH after bio-filter effluents and increase after sand filter (Filtramar) effluents. The final effluent has pH around 8 (Table 8). A very low pH of 2.55 was

recorded in the phosphorus filter (Filtramar) in October 2012 as seen from time series graph (Fig. 16). A probable reason may be the hydrochloric acid used for preservation which may have exceeded than the required amount to be used.

Conductivity: The mean conductivity after septic tank recorded was 1776 siemen/cm and the maximum mean value of 3437 siemen/cm was recorded from phosphorus filter (Filtralite P). The final effluent has the mean conductivity of around 1100 siemen/cm. The maximum value recorded in the phosphorus filter (Filtralite P) effluents may be due to leaching of calcium from phosphorus filter. Skjønsberg (2010) explained that the leaching of calcium and magnesium increases the conductivity. The conductivity graphs are shown in Fig. 15 & Fig. 16.

8.0 Conclusion

Filter bed wastewater treatment system was designed at Høyås farm based on same principles and components of constructed wetland systems but with smaller phosphorus unit and additional post polishing sand filter. The results from laboratory experiment of samples for first three months of operation have shown 90% BOD removal, 76% COD removal, 98% total phosphorus and 99% orthophosphate removal. The low removal rate for COD may be due to leaching of humic substances from bark used as insulation. Hence bark should be replaced by other insulating material.

From batch experiment, the maximum P-sorption for Filtralite P and Filtramar was found 1230 mg/kg and 8220 mg/kg respectively based on initial concentration of 0-480 mg P/l. But at low initial concentration of 10-15 ppm, that is similar to the concentration in wastewater, Filtralite P showed P retention capacity (476 mg/kg) almost three times more than Filtramar (149 mg/kg). Similarly, the maximum sorption capacity (S_{max}) for Filtralite P (1428 mg/kg) was higher than Filtramar (116 mg/kg) when calculated from Langmuir equation. The use of Langmuir equation to calculate the saturation points of filter materials showed that Filtramar has theoretical life time (26.2 years) ten times more than service life of Filtralite P (2.45 years) before complete saturation. Thus it seems Filtramar is better than Filtralite P regarding sorption capacity, but it is not wise to determine replacement time of filter materials based on batch experiment results only.

Despite the small P-filter volume, system performs good enough comparable to CWs designed according to current guidelines. The main drawback is to replace filter materials earlier but the cost is still reasonable as CWs designed based on VA/miljøblad need large area and huge amount of filter materials.

Finally the combination of sand filters succeeding the phosphorus filter increases the phosphorus removal from about 90 to 98% with less than 0.5 mg P/l in final effluent during first three months of operation.

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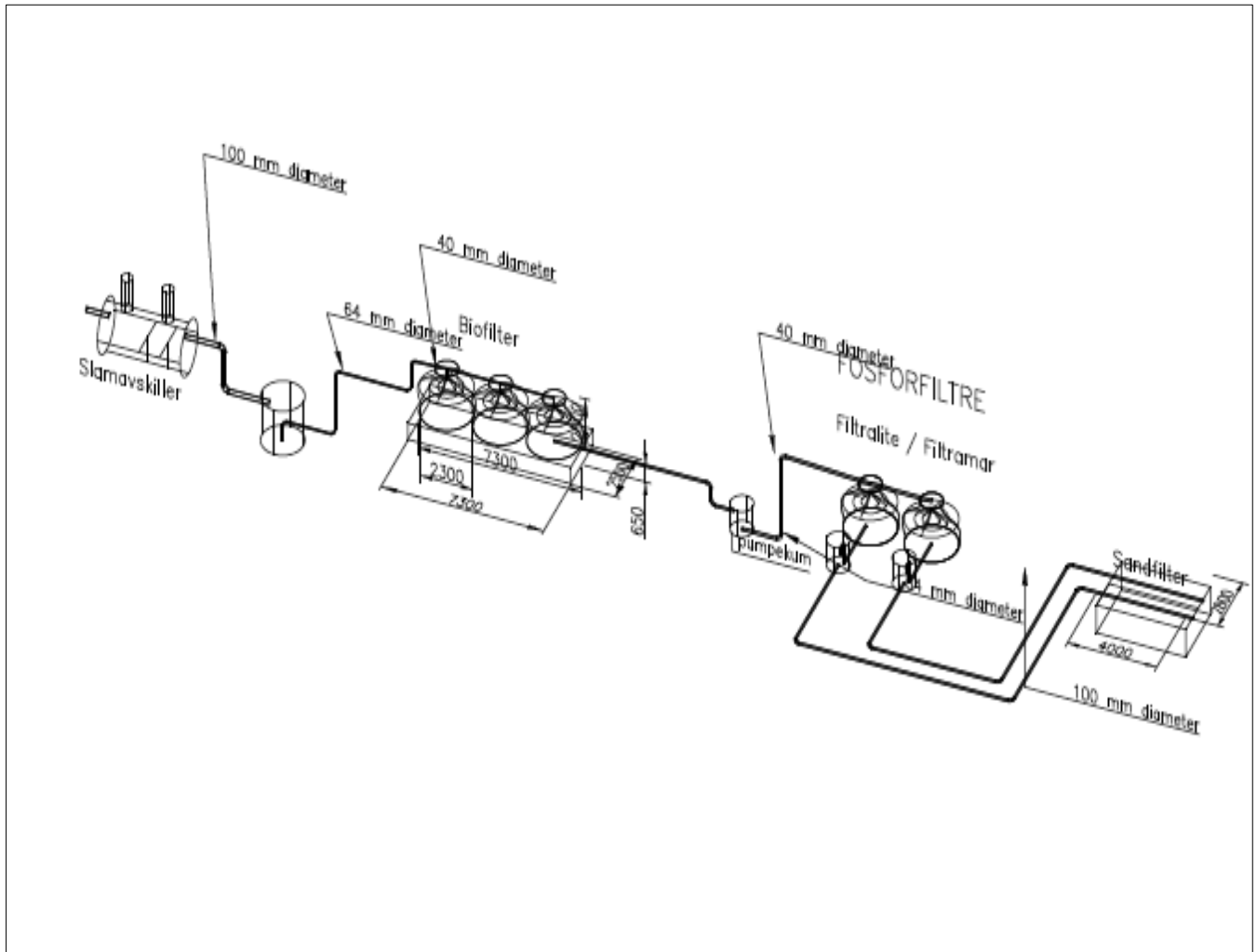
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10.0 Annexes

Annex01



Drawing of system components in 3D .

Annex02

Main group	Number of houses	Size of the tank (m ³)	Size of each chamber (m ³)		
			1	2	3
Residential unit with WC	1	4.0	3.0	0.5	0.5
	2	7.0	5.2	0.9	0.9
	3	9.5	7.1	1.2	1.2
	4	12.0	9.0	1.5	1.5
	5	14.0	10.4	1.8	1.8
	6	15.5	11.5	2.0	2.0
	7	16.5	12.1	2.2	2.2
Residential unit without WC	1	2.0	1.5	0.5	
	2	3.5	2.6	0.9	
	3	4.7	3.5	1.2	
	4	6.0	4.5	1.5	
	5	6.9	5.1	1.8	
	6	7.8	5.8	2.0	
	7	8.4	6.3	2.1	
Cottages with WC	1	2.0	1.5	0.5	
	2	3.5	2.6	0.9	
	3	4.7	3.5	1.2	
	4	6.0	4.5	1.5	
	5	6.9	5.1	1.8	
	6	7.8	5.8	2.0	
	7	8.4	6.3	2.1	
Cottages without WC	1	1.0	0.7	0.3	
	2	1.7	1.2	0.5	
	3	2.3	1.7	0.6	
	4	3.0	2.2	0.8	
	5	3.5	2.6	0.9	
	6	3.9	2.9	1.0	
	7	4.2	3.1	1.1	

Source: VA/Miljø-blad nr. 48. 2001

Volume of septic tanks for number of houses with/without WC, (Jenssen et al., 2006)
(VA/Miljø-blad nr.48. 2001)

MÅL:

Volum m ³	Totalhøyde mm	Lengde mm
7	2700	2800
8	2700	3160
9	2700	3520
10	2700	3880
11	2700	4240
12	2700	4600
13	2700	4960
14	2700	5320
15	2700	5680
16	2700	6040
17	2700	6400
18	2700	6760
19	2700	7120
20	2700	7480
21	2700	7840
22	2700	8200
23	2700	8560
24	2700	8920
25	2700	9280
26	2700	9640
27	2700	10000
28	2700	10360
29	2700	10720
30	2700	11080

Dimension of the septic tanks related to the given wet volume (**BOKN PLAST AS NS-EN 12566-1**)

Annex03

Product specification of Filtralite

Revisjon: 04

PRODUCT SPECIFICATION OF FILTRALITE® Filter media

FILTRALITE P 0-4

Commercial name	FILTRALITE® P 0-4 mm
Density	Bulk density: 500 kg/m ³
Type of material	Expanded clay
Appearance	Crushed particles, porous surface structure
Manufactured by	Weber Leca Rælingen, Norway

Size and weight	Value	Deviation	Comments
Effective size	0,3 mm		d_{10} , Approximately value
Particle size range	0-4 mm	> 4 mm max. 5 %	
Coefficient of uniformity	< 15		d_{60} / d_{10}
Bulk density, dry	500 kg/m ³	± 75 kg/m ³	EN 1097-3
Particle density, dry (PDD)	950 kg/m ³	± 200 kg/m ³	Exclay Norm

Other properties	Value	Comments
Floating particles	< 20 %	Approximately volume floating particles after 2 days in water.
Particle porosity	65%	Approximately value. Porosity internal particle: $(1-PDD/2700 \text{ kg/m}^3) * 100 \%$
Voids	42 %	Approximately value. EN 1097-3
pH	12	Exclay Norm
Alkalinity	35 mekv/l	New material. NS 4754
Water adsorption 1 day	31 %	Approximately value. Exclay Norm
<u>Hydraulic conductivity:</u>		
K	100 m/d	9 °C, Clean water
K dim	25 m/d	9 °C, Filter media with wetland plants, pre-treatment in septic tank and aerobic biofilter or equivalent system

The sewage water has to be pre-treated in septic tank and aerobic biofilter (or equivalent system) before the Filtralite P filter bed. Recommended loading of prefiltered municipal wastewater: 7-10 m³ Filtralite P / p.e. (p.e. = 0,6 kg P /year)

The material will leak some lime in the start-up period.

All values are based on assumption of use of the filtermaterial in saturated reed bed / constructed wetlands with long retention time and use of typical municipal wastewater. We strongly recommend use of consultants or system suppliers for sizing and design of wetland systems.

This material shall not be pumped.

Weber Saint-Gobain Byggevarer AS P.O. Box 216 Alnabru 0614 Oslo, Norway	Further information: www.filtralite.com E-mail: info@weber-norge.no	Telephone: +47 22 88 77 00 Telefax: +47 22 64 54 54
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filtralite

weber
SAINT-GOBAIN

Revisjon : 01

PRODUCT SPECIFICATION OF FILTRALITE® Filter media

FILTRALITE® HC 2,5-5 mm

Commercial name	FILTRALITE® HC 2,5-5 mm
Density	Bulk density: 800 kg/m ³ particle density: 1550 kg/m ³
Type of material	Expanded clay
Appearance	Crushed particles, porous surface structure
Manufactured by	Weber Leca Rælingen, Norway

Size and weight	Value	Deviation	Comments
Effective size	2,7 mm	± 0,2 mm	d ₁₀
Particle size range	2,5-5 mm	< 2 mm max. 4 % +Δ < 0,125 mm > 5,0 mm max. 5 %	
Coefficient of uniformity	< 1,5		d ₆₀ / d ₁₀
Bulk density, dry	800 kg/m ³	± 75 kg/m ³	EN 1097-3
Particle density, dry (PDD)	1550 kg/m ³	± 150 kg/m ³	Exclay Norm

Other properties	Value	Comments
Floating particles	< 2%	Maximum volume floating particles after 2 days in water.
Particle porosity	43%	Porosity internal particle: (1-PDD/2700 kg/m ³)*100
Voids	48 %	EN 1097-3
Acid solubility	< 5 %	EN 12902
Friability loss	< 5 %	EN 12902
Water adsorption 24 hours	16 %	Approximately value. Exclay Norm
Water adsorption 28 days	28 %	Approximately value. Exclay Norm
Water adsorption 1 year	30 %	Approximately value. Exclay Norm
Mohs' hardness	5	

Chemical composition, average values:

SiO ₂	Al ₂ O ₃	FeO ₃	K ₂ O	MgO	CaO	Na ₂ O	C _{tot}
62%	18%	7%	4%	3%	3%	2%	0,02%

Weber

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Annex04

Descriptive Statistics of Data

Septic Tank Effluent (ST)

Variable	Mean	SE Mean	StDev	Coef Var	Minimum	Median	Maximum
pH	7.415	0.226	0.553	7.46	6.870	7.335	8.450
Cond (µs/cm)	1776	253	620	34.89	1152	1725	2863
BOD (mg/l)	357.7	81.6	199.9	55.89	101.0	380.0	620.0
COD (mg/l)	685	111	272	39.66	306	666	1148
Temp (°C)	15.32	1.89	4.63	30.22	9.80	15.15	20.50
Tot-P (mg/l)	12.19	1.24	3.03	24.88	6.86	12.80	14.90
PO4-P (mg/l)	10.07	1.26	3.10	30.77	4.36	10.65	12.90

Bio-Filter Effluent (BF)

Variable	Mean	SE Mean	StDev	CoefVar	Minimum	Median	Maximum
pH	7.812	0.146	0.358	4.58	7.290	7.825	8.270
Cond (µs/cm)	1644	186	456	27.72	936	1613	2193
BOD (mg/l)	36.8	14.5	32.5	88.20	0.0	39.5	80.3
COD (mg/l)	237.6	35.2	86.2	36.27	151.0	227.6	372.0
Temp (°C)	14.57	2.18	5.34	36.63	8.40	14.15	20.50
Tot-P (mg/l)	6.38	1.33	3.27	51.22	1.25	6.18	11.40
PO4-P (mg/l)	5.50	1.32	3.23	58.71	0.60	6.18	9.43

Phosphorus Filter Effluent (Filtralite P)

Variable	Mean	SE Mean	StDev	CoefVar	Minimum	Median	Maximum
pH	10.907	0.476	1.166	10.69	10.030	10.270	12.520
Cond (µs/cm)	3437	1273	3119	90.77	1339	1745	8890
BOD (mg/l)	13.00	9.45	21.12	162.47	0.00	4.80	50.60
COD (mg/l)	275	132	323	117.43	35	179	900
Temp (°C)	15.40	2.09	5.12	33.27	8.10	15.40	20.90
Tot-P (mg/l)	0.3133	0.0924	0.2263	72.23	0.0390	0.3875	0.5280
PO4-P (mg/l)	0.1527	0.0526	0.1289	84.41	0.0050	0.1785	0.2950

Phosphorus Filter Effluent (Filtramar)

Variable	Mean	SE Mean	StDev	CoefVar	Minimum	Median	Maximum
pH	8.068	0.196	0.439	5.44	7.650	7.830	8.610
Cond (µs/cm)	1594	110	270	16.96	1320	1467	2002
BOD (mg/l)	19.44	3.99	8.91	45.84	5.90	19.90	30.90
COD (mg/l)	141.4	24.6	60.2	42.54	82.2	134.5	248.0
Temp (°C)	16.35	1.73	4.24	25.95	11.90	16.50	20.40
Tot-P (mg/l)	0.688	0.258	0.632	91.84	0.242	0.341	1.730
PO4-P (mg/l)	0.458	0.240	0.588	128.47	0.037	0.131	1.360

Sand Filter Effluent(Filtralite P)

Variable	Mean	SE Mean	StDev	CoefVar	Minimum	Median	Maximum
pH	8.292	0.362	0.810	9.77	6.890	8.610	8.840
Cond (µs/cm)	1112	240	536	48.21	403	1433	1530
BOD (mg/l)	23.82	3.99	7.98	33.50	12.10	26.60	30.00
COD (mg/l)	186.4	48.3	108.0	57.93	88.2	125.8	328.0
Temp (°C)	16.32	2.26	5.06	31.00	10.00	17.10	21.10
Tot-P (mg/l)	0.2756	0.0661	0.1478	53.64	0.1090	0.2130	0.4810
PO4-P (mg/l)	0.0750	0.0107	0.0238	31.76	0.0430	0.0770	0.0990

Sand Filter Effluent(Filtramar)

Variable	Mean	SE Mean	StDev	CoefVar	Minimum	Median	Maximum
pH	7.556	0.344	0.770	10.18	6.710	7.480	8.800
Cond (µs/cm)	1102	111	249	22.57	702	1131	1339
BOD (mg/l)	45.1	30.5	68.2	151.37	0.0	19.7	166.0
COD (mg/l)	145.8	29.2	65.3	44.78	69.6	145.4	244.0
Temp (°C)	17.02	1.80	4.04	23.71	12.70	17.20	21.30
Tot-P (mg/l)	0.2618	0.0225	0.0503	19.22	0.1750	0.2750	0.3010
PO4-P (mg/l)	0.0994	0.0143	0.0319	32.06	0.0700	0.0820	0.1340

WATEWATER PARAMETERS OF SYSTEM COMPONENTS

Date (Months)		Tot-P mg PO ₄ ³⁻ /L					
Lab Exp Date	Sample Date	S1	S2	S3	S4	S5	S6
21-11-12	01.10.2012	6,860	1,250	0,039	0,303	0,109	0,275
27-11-12	18.10.2012	11,000	5,870	0,040	0,256	0,369	0,291
09-11-12	06.11.2012	12,000	6,480	0,528	0,379	0,481	****
20-12-12	20.11.2012	13,600	5,780	0,301	0,242	***	0,301
04-01-13	19.12.2012	14,900	7,500	0,498	1,730	0,206	0,267
04-01-13	03.01.2013	14,800	11,400	0,474	1,220	0,213	0,175

Date (Months)		PO4-P PO ₄ ³⁻ /l					
Lab Exp Date	Sample Date	S1	S2	S3	S4	S5	S6
21-11-12	01.10.2012	4,360	0,597	0,005	0,113	0,060	0,082
27-11-12	18.10.2012	11,000	2,940	0,006	0,037	0,077	0,070
09-11-12	06.11.2012	9,340	7,670	0,253	0,040	0,096	****
20-12-12	20.11.2012	10,300	5,700	0,115	0,148	***	0,077
04-01-13	19.12.2012	12,900	6,660	0,295	1,360	0,043	0,134
04-01-13	03.01.2013	12,500	9,430	0,242	1,050	0,099	0,134

Date (Months)		COD mg/l					
Lab Exp Date	Sample Date	S1	S2	S3	S4	S5	S6
21-11-12	01.10.2012	306,00	161,60	35,20	153,80	88,20	145,40
27-11-12	18.10.2012	610,00	286,00	50,00	94,40	276,00	161,40
09-11-12	06.11.2012	622,00	372,00	306,00	248,00	328,00	****
20-12-12	20.11.2012	710,00	268,00	216,00	155,00	***	244,00
04-01-13	19.12.2012	714,00	151,00	900,00	82,20	114,00	69,60
04-01-13	03.01.2013	1148,00	187,20	142,00	115,20	125,80	108,80

Date (Months)		BOD mg/l					
Lab Exp Date	Sample Date	S1	S2	S3	S4	S5	S6
21-11-12	01.10.2012	158,00	0,00	0,00	8,10	3,40	2,80
27-11-12	18.10.2012	101,00	*	*	5,90	26,40	15,70
09-11-12	06.11.2012	349,00	10,70	4,80	19,40	26,80	****
20-12-12	20.11.2012	411,00	39,50	50,60	19,90	***	166,00
04-01-13	19.12.2012	507,00	53,50	4,80	30,90	12,10	19,70
04-01-13	03.01.2013	620,00	80,30	4,80	21,10	30,00	23,90

Date (Months)		Cond µs/cm					
Lab Exp Date	Sample Date	S1	S2	S3	S4	S5	S6
21-11-12	01.10.2012	1223,00	936,00	8890,00	2002,00	403,00	702,00
27-11-12	18.10.2012	1705,00	1484,00	5540,00	1320,00	668,00	1064,00
09-11-12	06.11.2012	2863,00	2193,00	1577,00	1859,00	1530,00	****
20-12-12	20.11.2012	1745,00	1457,00	1339,00	1449,00	***	1272,00
04-01-13	19.12.2012	1152,00	2051,00	1913,00	1475,00	1433,00	1131,00
04-01-13	03.01.2013	1969,00	1741,00	1361,00	1458,00	1527,00	1339,00

Date (Months)		pH					
Lab Exp Date	Sample Date	S1	S2	S3	S4	S5	S6
21-11-12	01.10.2012	6,87	7,29	12,56	2,55	6,89	6,71
27-11-12	18.10.2012	7,28	7,80	12,27	7,83	8,84	7,24
09-11-12	06.11.2012	7,39	7,55	10,46	7,65	8,61	****
20-12-12	20.11.2012	8,45	8,27	10,08	8,61	***	8,80
04-01-13	19.12.2012	7,46	8,11	10,03	8,47	8,80	7,55
04-01-13	03.01.2013	7,04	7,85	10,08	7,78	8,32	7,48

Symbols:

*: undefined BOD value

***: No sample for sand/Filtralite P

****: No sample for sand/Filtramar

Annex 05

Batch experiment results

P-solutions concentration P (mg/l)	P- solution concentration after experiment mg/l					
	Filtralite P	Filtralite P	Sand	Sand	Filtramar	Filtramar
0	0.03	0.03	0.01	0.00	0.04	0.04
15	7.6	7.3	10	9.2	11	11
30	19	19	23	23	25	26
60	44	43	54	53	51	50
120	98	92	111	114	70	71
240	205	204	228	224	107	120
480	438	440	462	458	197	215

P-solutions concentration P (mg/L)	P sorbed mg P/kg					
	Filtralite P	Filtralite P	Sand	Sand	Filtramar	Filtramar
0	-0.9	-0.9	-0.3	0	-1.2	-1.2
15	222	231	150	174	120	120
30	330	330	210	210	150	120
60	480	510	180	210	270	300
120	660	840	270	180	1500	1470
240	1050	1080	360	480	3990	3600
480	1260	1200	540	660	8490	7950

	P- sorption (mgP/kg)		P- sorption (mgP/kg)		P- sorption (mgP/kg)
Avg. P conc. at equilibrium (mg/l)	Filtralite P	Avg. P conc. at equilibrium (mg/l)	Filtramar	Avg. P conc. at equilibrium (mg/l)	Sand
0.03	-0.9	0.04	-1.2	0.01	-0.3
7.45	226.5	11	120	9.6	162
19	330	25.5	135	23	210
43.5	495	50.5	285	53.5	195
95	750	70.5	1485	112.5	225
204.5	1065	113.5	3795	226	420
439	1230	206	8220	460	600

	Ave. Ceq/S		Ave. Ceq/S		Ave. Ceq/S
Avg. P conc. at equilibrium (mg/l)	Filtralite P	Avg. P conc. at equilibrium (mg/l)	Filtramar	Avg. P conc. at equilibrium (mg/l)	Sand
0.03	-0.0333	0.04	-0.0333	0.01	-0.0333
7.45	0.0329	11	0.0917	9.6	0.0593
19	0.0576	25.5	0.1889	23	0.1095
43.5	0.0879	50.5	0.1772	53.5	0.2744
95	0.1267	70.5	0.0475	112.5	0.5
204.5	0.192	113.5	0.0299	226	0.5389
439	0.3569	203	0.0247	460	0.7667

Annex 06

Filtralite P [®]		Shellsand	
Experiment	P sorption capacity (mg P kg ⁻¹)	Experiment	P sorption capacity (mg P kg ⁻¹)
<i>Batch experiments</i>			
Ádám et al. 2005 Filtralite P [®]	3300	Roseth (2000) Einar Øgreid AS	17000
Ádám et al. (2007) Filtralite P [®]	2500	Fosen skjellsand	15000
		Hordaland tørkeri	16000
		Korall AS	17000
		Brødrene Nilsen AS	16000
		Søvik and Kløve (2005) Korall AS	8000
		Ádám et al. (2007) Hordaland tørkeri	10000
<i>Box experiments^a</i>			
Ádám et al. (2006)	3900 (1000)		
<i>Trench experiments^b</i>			
Ádám et al. (2006)	4500 (1048)	Søvik et al. (2005) Korall AS	330 (130)
		Søvik and Kløve (2005) Korall AS	1300 / 420 ^e (330)
<i>Column experiments^c</i>			
Ádám et al. (2007)	950 (635)	Ádám et al. (2007) Hordaland tørkeri	300 (136)
		Roseth (2000) ^f Hordaland tørkeri / Korall AS	3500
<i>Field studies^d</i>			
Zhu (1998) ^e	800		
Ádám et al. (2006)	250		

^a Flow experiments in boxes (26x9x7 cm³) filled with filter material. Inlet at top and outlet at bottom of boxes.
^b Flow experiments in trenches (3x0.75x0.5 m³) filled with filter material. Inlet at top and outlet at bottom of trench
^c Flow experiments in columns (d: 14 cm, length: 1.5 m) filled with filter material. Inlet at bottom of column.
^d Field studies – collection of samples of filter material from an on-site constructed wetland treating wastewater from a group of houses.
^e The results are for the pre-filter and main filter, respectively
^f The P sorption capacity is based on mass balance
^g The field scale system referred to was constructed with light-weight aggregate

The maximum P sorption capacities of Filtralite P and Filtramar (shellsand) table from Batch Experiments, long –term laboratory experiments and field studies. The data from the long-term laboratory and field experiments are based on extraction of total P from the material, except for Roseth (2000). Values between brackets show the average extracted content of Tot-P (Ádám et al., 2007).