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SMALL SCALE WASTEWATER TREATMENT SYSTEM AT HØYÅS FARM IN ÅS, NORWAY

Field Scale Study Comparing Phosphorus Sorption of Two Filter Media and Evaluating General Treatment Performance of Treatment Components

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A Thesis submitted in partial satisfaction of the requirements for the degree
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Environment and Natural Resources - Specialization Sustainable Water and
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By

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ABSTRACT

Phosphorus (P) removal in small scale wastewater treatment systems (SSWWTSs) to achieve P discharge limit of 1mg/l requires P filters with high P sorption capacity. For comparison purposes, two P filters are used at Høyås SSWWTS. The system comprises of a septic tank and biofilter for pre-treatment. This is followed by two P filter units installed parallel to each other where one is filled with P filter Filtralite® P (PFFP) while the other with P filter Filtramar® (PFFM) also called Shellsand. Finally, two sand filter units are also installed parallel to each other as a polishing step. One sand filter (SFFM) receives effluent from PFFM and the other sandfilter (SFFP) receives PFFP effluent. This work compared P sorption capacity between PFFP and PFFM. This is by taking WW samples from effluent in each treatment unit and analyse for P in form of total P (TP) and orthophosphate (Ortho-P). At the same time, the general treatment performance and effect of replacing insulating tree bark with light weight aggregates (LWA) (Leca® ISO 10-20mm) was monitored. The tree bark leached organic substances into treatment components and this changed WW effluent colour. The colour changes were monitored before and after tree bark replacement.

Treatment performance other than phosphorus was monitored by analysing for nitrogen (N) in form of total nitrogen (TN), ammonium ions (NH_4^+), and nitrates, as well as 5-day biochemical oxygen demand (BOD_5), conductivity, and pH. In addition, one-time sample was taken and analysed for bacteria. The comparison of P sorption was described by t-test that showed that PFFP has higher P sorption capacity than PFFM at 95% confidence level. Regarding treatment performance, the Høyås system has a removal efficiency of >95% for TP, >95% for Ortho-P, 50-60% for TN, 65-80% for NH_4^+, and >98% for BOD.

The final effluent has mean TP effluent concentration of 0.6mg/l and 0.95mg/l from SFFP and SFFM respectively and mean BOD concentration of 3.8mg/l and 3mg/l from SFFM and SFFP respectively. The treatment system meets the discharge limits of 1mg/l for P and 20mg/l for BOD set by the Ås municipality. Organic substances from tree bark affected WW colour. WW effluent from treatment components had a yellow-brown colour before tree bark replacement and became clearer after tree bark replacement. Replacing tree bark showed a positive effect on P and BOD treatment performance. The one-time sampling of bacteria shows that the final effluent has 31 *E. coli/*100ml and 13*E. Coli/100ml* from SFFM and SFFP respectively, hence, the treatment system meets the European standard for swimming water of <500*E. Coli/100ml.*

ACRONYMNS

ADP adenosine diphosphate

ATP adenosine triphosphate

BF biofilter

BFE biofilter effluent

BOD_5 : 5-day biochemical oxygen demand

CTPs centralized treatment plants

CWs constructed wetlands

DNA deoxyribonucleic acid

DO dissolved oxygen

DWW domestic wastewater

E. coli Escherichia coli

Eh redox potential

FHC Filtralite HC 2.5-5mm

Fig. figure

HLR hydraulic loading rate

HRT hydraulic retention time

K hydraulic conductivity (m/day)

Max. maximum value

Min. minimum value

MPN most probable number

N nitrogen

NH_3 ammonia

NH_4^+ ammonium ions

NKF ‘Norsk Kommunalteknisk Forening’

NORVAR Norsk VA-verkforening

NO_3^- : nitrates

O_2 oxygen

OM organic matter

Ortho-P orthophosphate

P Phosphorus

Pe persons equivalent

PFFM phosphorus filter Filtramar®

PFFP phosphorus filter Filtralite® P

PTPs package treatment plants

Q volumetric flow rate (m^3/day)

RNA ribonucleic acid

SFFM sand filter Filtramar®

SFFP sand filter Filtralite® P

SSWWTSs small scale wastewater treatment systems

ST septic tank

Std.Dev standard deviation

STE septic tank effluent

SuSanA Sustainable Sanitation Alliance

TCB total coliform bacteria

TN Total nitrogen

TW Tap water

UNEP United Nations Environmental Program

USEPA United States Environmental Protection Agency

USGS United States Geological Survey

WCED World Commission on Environment and Development

WHO World Health Organization

WW wastewater

WWT wastewater treatment

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1. INTRODUCTION

Use of small scale wastewater treatment systems (SSWWTSs) to treat domestic wastewater (DWW) is common in Norway where around 340,000 SSWWTSs are in use (Berge and Mellem, 2011). These treatment systems are categorized into three treatment technologies namely natural systems, package treatment plants, and low performance solutions. Examples of low performance solutions include septic tanks (ST), sand filters, enclosed black water holding tanks, and direct discharge. Package treatment plants (PTPs) are downsized centralized treatment plants (CTPs) hence use process configurations similar to CTPs. Natural systems include soil infiltration systems and constructed wetlands (CWs) (Johannessen, 2012). Traditional ST-soil infiltration systems are few due to stringent local regulations while PTPs have difficulties to meet discharge limits especially for P.

Subsurface flow CWs with biofilters as pre-treatment have shown excellent performance in Nordic climate conditions. However, they occupy larger space compared to PTPs and also their investment costs are high due to space and use of light weight aggregates (LWA) for P-sorption (Jenssen et al, 2010). CWs enable P reuse by reusing LWA saturated with P in agriculture. This is particularly in LWA rich in calcium (Ca) and magnesium (Mg) as opposed to LWA rich in aluminium (Al) and iron (Fe). P bonded with Ca and Mg is easily extracted by plants as opposed to P bonded to Al and Fe (Krogstad et al., 2005). P extraction from wastewater (WW) and reuse in agriculture may reduce scarcity of P fertilizers. P is a scarce non-renewable resource and current reserves are near depletion (Cordell et al., 2009). Its recovery from WW and reuse in agriculture may reduce rate of P extraction from P natural sources. P recovery and reuse may also close the loop between sanitation and agriculture which is the main principle of ecological sanitation (Fig. 1) (Esrey et al., 2000).

Fig. 1: *Basic principles of ecological sanitation* (Lapid, 2010).

Ecological sanitation systems are designed and constructed according to ecological engineering techniques. Ecological engineering is a holistic perspective on engineering where not only technical aspect, but also interactions between technology, nature and society are important in the engineering process and design (Mitsch and Jørgensen, 1989). Ecological engineering hence promotes sustainability which is important in all aspects in the society. Sustainable development was defined by Brundtland commission as 'Development that meet the needs of the present without compromising the ability of future generations to meet their own needs'' (World Commission on Environment and Development (WCED), 1987). In sanitary engineering, sustainability evaluation of sanitary systems is used where a sustainable sanitation system has to be economically viable, socially acceptable, technically and institutionally appropriate, and able to protect the environment and its natural resources. The criteria for evaluating such systems include sustainability aspects, namely protecting health, environment, and natural resources, ease in constructing, operating, and monitoring of technology and operation, financial and economic issues, and finally fitting socio-cultural and institutional aspects (Sustainable Sanitation Alliance (SuSanA) (2007); Guterstam, 1991).

To be regarded as sustainable therefore, SSWWTSs used in Norway should meet above evaluation criteria. Particularly for the sustainability aspect of protecting health, environment, and natural resources, these SSWWTSs are monitored by discharge guidelines. The SSWWTSs should have capacity to reduce contaminants to concentrations that comply with discharge guidelines. The guidelines vary from one municipality to another depending on WW recipient sensitivity to particular contaminant. Fresh water sources in Norway are sensitive to phosphorus (P) a limiting nutrient in fresh waters while nitrogen (N) is a limiting nutrient in marine waters. Discharging WW containing high P concentrations into fresh waters in Norway may therefore lead to eutrophication problem (Heistad et al., 2006).

Eutrophication refers to increase in nutrient input, primarily P and N, to surface waters to extent of overenrichment leading to increase in primary productivity and other related negative effects (Prepas and Putz, 2014). Eutrophication effects include algae blooms of noxious, foul-smelling phytoplankton that reduce water clarity and harm water quality (Chislock et al., 2013). Reduced surface water quality reduces possibilities for water use such as drinking, fishing, swimming, and other recreational uses (United Nations Environmental Program (UNEP), n.d). To protect fresh waters from eutrophication, Norway has set strict discharge limits for P ranging from 0.5mg/l to 1mg/l depending on location and size of treatment plant. In most municipalities, P discharge limit is 1mg/l (NKF and NORVAR, 2001). This means P-filter material in CWs has to be replaced when P discharge concentration reaches 1mg/l. For this reason, P removal from DWW is the chief criteria when designing and installing CWs in Norway (Adam, 2006; Roseth, 2000).

P removal in CWs is achieved by using P-filter materials (also called P substrates) which can be soils, rocks and minerals, marine sediments, industrial by-products, and man-made products. The P substrates have a P-sorption capacity in which P is removed from WW and retained in the P substrate through adsorption and/or precipitation (Westholm, 2006). P-sorption capacity of soils hence of P-filters varies depending on physical and chemical properties of material and environmental factors that influence P-sorption (Sekhon, 2002). This means some P-filters have higher P-sorption capacity than others in the field scale. To meet 1mg/l P discharge limit in Norway therefore, it is necessary to select P-filter with high P-sorption capacity for use in CWs. P-filter materials with high P-sorption capacity are used in a SSWWTS installed at Høyås farm in Ås municipality, Norway. The system receives WW from an average of 8persons per day throughout a year and can treat WW from a maximum of 25persons per day (Ganesh and Nabelsi, 2012). It is a CW system designed for contaminants removal in general and for P removal to meet the P discharge limit of 1mg/l. It is comprised of a ST, an equalizing pump chamber, a BF, followed by two P-filter units, and finally there are two sand filter units as polishing step after each P-filter (Section 3.2). The two P-filter units are installed parallel to each other. One is filled with P-filter Filtralite® P (PFFP) while the other unit is filled with P-filter Filtramar® (PFFM) also called Shellsand.

PFFM and PFFP have high P-sorption capacity (Cucarella and Renman, 2009). Their physical and chemical properties differ (Section 3.2.4) and each P-filter can be affected differently by environmental factors that influence P-sorption in the field scale (Sekhon, 2002). Hence, one P-filter may be better in P-sorption than the other in the field scale although laboratory experiments may show the opposite. The main purpose of this field study therefore was to compare P removal capacity between PFFM and PFFP used at Høyås SSWWTS. This is by taking WW samples from effluent in each treatment unit and analyse for P in form of total P (TP) and orthophosphate (Ortho-P). At the same time, general treatment performance of the system was monitored by analysing for N inform of total nitrogen (TN), ammonium ions (NH_4^+), and nitrates (NO_3 as well as 5-day biochemical oxygen demand (BOD_5), conductivity, and pH. For BOD, Ås Municipality has discharge limit of 20mg/l (NKF and NORVAR, 2001). In addition, one-time sample was taken and analysed for indicator bacteria namely, total coliform bacteria (TCB) and *Escherichia coli* (*E. coli*) to monitor WW hygienic quality.

Analyses of data for these parameters have then been statistically analysed and results evaluated before compared to a pioneer study on the same system by Ganesh and Nabelsi (2012). The pioneer study which also included a batch experiment compared P-sorption capacity between PFFM and PFFP. Results from the study indicated that PFFP has higher P-sorption capacity than PFFM. However, PFFM was estimated to have longer lifetime of 26.2 years than PFFP that was estimated to have 2.45 years lifetime. The same study recommended replacement of the insulating tree bark that leached organic substances which in turn competed with P for sorption sites in P-filters. The tree bark was used for insulation in BF, SFFM, and SFFP treatment components (Ganesh and Nabelsi, 2012).

The tree bark is natural organic matter and its decomposition leaches organic substances that can increase BOD concentration in water (Dalahmeh, 2013). Dissolved organic substances can produce yellow or brown colour in water (Hessen, 1998). In addition to competition with P for sorption sites, organic substance from insulating tree bark at Høyås system affected colour of the treated WW. For these reasons, the tree bark was replaced on 17th August 2013 with Leca ISO® 10-20mm medium (Section 3.2.3). Then, effects of tree bark replacement was monitored throughout this study. This is by monitoring WW colour change and also by comparing TP and Ortho-P concentration trends before and after tree back replacement. Monitoring tree bark replacement effect on P-sorption was one of the objectives when evaluating experimental results in this study.

Other objectives included, first, understand inlet contaminant load into the treatment system and by using removal efficiencies and final mean effluent concentrations understand whether treatment components reduce such contaminants to lower concentrations. This includes whether the system meets the discharge limits of 1mg/l for P and 20mg/l for BOD. Secondly, understand whether the P-filters have significantly different P-sorption capacities and if so, which one has higher P-sorption capacity. Thirdly, evaluate trend of estimated life time for P-filters by assessing TP and Ortho-P effluent concentration change with time in the P-filters. Finally, assess whether there are needs for innovation to improve general treatment performance of the treatment system as a whole to ensure that final effluent has qualities that do not change water qualities in the recipient. This hence protects organisms that might be in the recipient environment. The organisms are hence one of the beneficiaries of this study.

This study may also be beneficial to Ås municipality, SSWWTSs engineers, producers of PFFP and PFFM, SSWWTSs owners, and the society at large. The municipality may use results from this study to evaluate whether Høyås system meets discharge limits for P and BOD. For PFFM and PFFP producers, this study may motivate them to solve faults of each P-filter medium that hinder P-sorption. This may hence improve filter media quality production. Increasing P-filter medium quality may lead to increased sales for producers and might also lead to increased P removal and recovery from WW and reuse in agriculture. Ecological engineers may use this study to evaluate and choose P-filter medium with better P-sorption capacity when designing and constructing CWs with P medium for P-sorption. Engineers may also develop and apply recommended innovations suggested in the study so as to improve general treatment performance of SSWWTSs. Good treatment performance and increased P removal at Høyås treatment system may have regional and global benefits in the sense that other SSWWTSs owners may adopt design and layout of Høyås treatment system hence capture P from DWW in larger scales. P proportion in DWW is relatively high as explained in the background information section.

2. BACKGROUND INFORMATION

2.1 Domestic Wastewater Composition

DWW is collection of brown, yellow, and grey waters. Brown water is WW containing faeces, yellow water is WW containing urine, while grey water is WW generated from households excluding toilet wastes i.e. WW from laundry, dish washing, showers, cleaning containing detergents, kitchen sinks, etc. The term black water is used if WW contains both urine and faeces (Wilderer, 2003). In composition, DWW contains physical, biological, and chemical contaminants that may become hazardous to environment and health. Examples of physical contaminants include pH, temperature, conductivity, odour, colour, and solids. Examples of biological characteristics include pathogens like bacteria, viruses, helminths, and parasitic protozoa. The pathogens are shallowly dealt with in this work although they are significant in WWT because of their ability to cause waterborne diseases (Heistad et al., 2006; McCray et al., 2009).

Examples of chemical contaminants include P, N, K, trace and heavy metals, organic matter (OM), ions, dissolved oxygen (DO), chemicals from personal care products, pharmaceuticals, and so on. Most of the chemical contaminants are labile meaning that they can be physically, biologically, or chemically transformed from one species to another hence these contaminants exist in different forms in WW. These forms can then be used as parameters to monitor these contaminants in WW (Tchobanoglous et al., 2003; Tjandraatmadja et al, 2010; Gray and Becker, 2002). Importantly, contaminants P, N, and K are essential nutrients for plants while OM can be used as soil conditioner. It is therefore necessary to recover these nutrients and OM from WW and reuse in agriculture (Esrey et al., 2000).

The nutrients and OM originate from faeces, urine, and grey water produced in households. Study in Sweden by Vinnerås et al. (2007) concluded that in daily average, each person produces approximately 140g faeces, 1.5L urine, and 100L grey water. This implies that out of 100% DWW volume, grey water has the highest proportion compared to urine and faeces. However, urine has the highest nutrient proportions compared to feces and grey water (Fig. 2). In addition, urine contains more ions and metals compared to faeces as Kirchmann and Pettersson (1995) studied that stored urine with pH8.9 contained >90% N with ammonium bicarbonate (NH_4HO_3) as the dominant form.

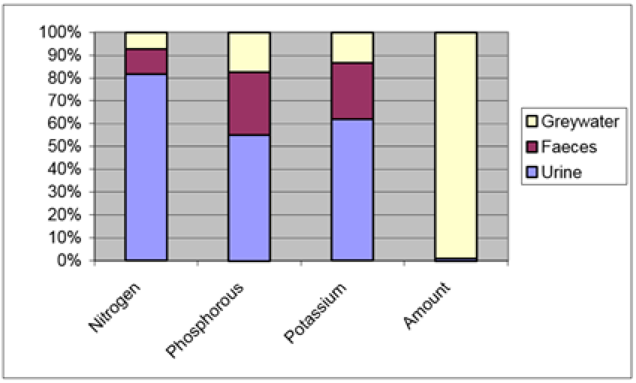

Fig. 2: *Proportion of nutrients nitrogen (N), phosphorus (P), and potassium (K) in grey water, faeces, and urine and their volume in domestic wastewater (DWW) (*Jönsson et al 1999).

The urine also contained cations of sodium (Na^+), potassium (K^+), NH_4^+, and calcium (Ca^{2+}), anions chlorides (Cl^-), sulphates (SO_4^{2-}), PO_4^{3-}, and bicarbonates (HCO_3^-), and heavy metals with concentrations of mercury (Hg), copper (Cu), nickel (Ni), and zinc (Zn) at 10-500 times higher in urine than in precipitation and surface waters. N and P must be reduced to discharge guidelines before WW discharge because of their ability to cause eutrophication problems. Other chemical as well as biological and physical contaminants also need to be removed from WW to avoid adverse effects on environment and health. Removal of these contaminants from Høyås treatment system were monitored through WW sampling and analysis.

2.2. Contaminants Monitored at Høyås Treatment System

2.2.1 Phosphorus

2.2.1.1 Physicochemical Properties of Phosphorus

P is multivalent non-metallic element of N family in group 15 in the periodic table. It has oxidation states ranging from -3 to +5 but common oxidation states are +5, +3, and -3. P has 23 isotopes going from ^{24}P to ^{46}P with ^{31}P as the only stable isotope while rest are radioactive with short half-lives (Paytan and McLaughlin, 2011). Elemental P exists in various allotropes common ones being white P (P_4), red P (P_5), and black P (P_6). White P is dangerously toxic while red and black P are non-toxic (Wulfsberg, 2000). In nature, elemental P readily reacts with air to form phosphates (PO_4^{3-}) hence P exists in nature majorly as mineral and organic compounds (Paytan and McLaughlin, 2011). There are various PO_4^{3-} minerals the common being apatite forms. Fluoroapatite ($Ca_5(PO_4)_3F$) deposits are the most extensively mined minerals with world production of 153 million tonnes per year. The major Fluoroapatite mining countries include Russia, USA, Morocco, Tunisia, Togo and Nauru (LENNTECH, 2014). There are concerns on depletion of P deposits. P is a non-renewable resource and its reserves are estimated to be depleted in 50 to 100 years (Cordell et al., 2009).

P depletion is due to high demand for P minerals and compounds that are used in different applications. P minerals and compounds are used in agriculture as fertilizers, toothpaste, baking soda, matches, pesticides, nerve gases, buffer solutions, and food (Paytan and McLaughlin, 2011). P compounds were once used in manufacturing household laundry detergents but were banned in 1970’s by various countries and later industries voluntarily stopped manufacturing such detergents due to P pollution and eutrophication. The ban applied to household laundry detergents only and not dishwashing detergents and commercial cleaning products (USEPA, 2002; Emsley, 2000; Likte, 1999). This means detergents and cleaning products used in households contribute P in DWW.

P is important for all living organisms. Particularly P in form of PO_4^{3-} are part of biological molecules adenosine diphosphate (ADP), adenosine triphosphate (ATP), deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and phospholipids. PO_4^{3-} together with calcium play important role in formation of bones and teeth where 85% of P in human body occurs. P also helps in kidney functioning and acts as buffer for acid-base balance in the body. PO_4^{3-} aid in muscle contraction, heartbeat regulation, support proper nerve conduction, and support niacin and riboflavin conversion to their active coenzyme form (Haas, n.d). Thus, PO_4^{3-} are dietary requirement for humans of minimum 800mg/day (LENNTECH, 2014) and are not only essential but also the only P form available for plants in soil (Brady and Weil 2008).

2.2.1.2 Sources of Phosphorus into domestic wastewater

Human excreta are the main source of P into DWW and some proportions come from other source through grey water. On daily average, each person produces 1.6g P (Yri et al., 2006). Human excreta contain 30-70% P excreted in form of nucleic acids and ATP given that P is one of the components in biological molecules. The rest 30-70% P comes from grey water containing laundry detergents, dishwashing soaps, food residues in sinks, garbage disposal, toothpastes, cleaners, shampoos, cosmetics, and other personal care products (Tjandraatmadja et al., 2010; USEPA, 2002). All these P sources root back to P applications and uses as provided in section 2.2.1. Amount of P into DWW varies according to number of people in household, their water use habits, their diet, and their habits of using chemicals containing P e.g. detergents, shampoos, personal care products etc. (Schönning, 2001).

About diet, P is higher in animal-based food products like meat, milk, poultry, fish, eggs, and dairy products compared to plant-based foods (Moe et al., 2011). Hence, inlet P concentration is higher in households where people consume animal-based diet than in households where people consume plant-based diets. P concentration may however be affected by water use habits. More water volume use per capita per day may lead to lower inlet P concentration due to dilution (Chang and Overby, 2011). Regarding number of people in household, amount and concentration of inlet P into the treatment system can vary according to number of users and their water use habits (Schönning, 2001). The Høyås system serves between 8 – 25 persons equivalent (Pe) per day (Section 3.2.1). Considering all sources of P into DWW, each person produces 2.7g of P every day (USEPA, 2002). Amount of inlet P per day into Høyås system can then be around 22g (i.e. 2.7g P/Pe.day * 8Pe) from WW produced by 8 people and around 68g from WW produced by 25 people (i.e. 2.7g P/Pe.day * 25Pe). The inlet P concentration is high when water use per person is low (Schönning, 2001; (Tjandraatmadja et al., 2010). At Høyås system, black water and grey water is collected in a ST and inlet concentrations of different parameters are measured in the septic tank effluent (STE). This includes TP which is the sum of all forms of P in WW (USEPA, 1997). P occurs in various forms in WW as explained next.

2.2.1.3 Forms of Phosphorus in wastewater

Forms of P in WW can be categorized into organic P (OP) and inorganic P (IP). OP is formed by biological processes hence represents P bound to plants and animal tissues. In WW, OP includes P in human excreta, in food residues, and in microorganisms present in WW (McCray et al, 2009; USEPA, 1997). OP contributes smallest fraction of TP influent. It can be soluble, colloidal or particulate OP. These can further be subdivided into biodegradable or non-biodegradable fractions. The particulate and colloidal OP are removed as particles with sludge after settling and precipitating out respectively (USEPA, 2010). They are included in the TP proportion removed in ST where approximately 20-30% of TP is removed as particles (Lusk et al., 2013). The other OP fractions are the soluble biodegradable and soluble non-biodegradable OP. During biodegradation, microorganisms consume the soluble biodegradable P for energy in cells. This hence reduces P in WW. Some of the soluble biodegradable OP can also be hydrolysed into orthophosphate (Ortho-P) while soluble non-biodegradable OP flows with WW to final effluent (USEPA, 2010; Metcal and Eddy, 2003). Converting OP to Ortho-P increases Ortho-P concentration in treatment components. Ortho-P is one of the IP forms.

IP include P forms not associated with organic material from plants and animals. This includes Ortho-P and polyphosphates. Ortho-P is soluble, most reactive, and abundant form of P. It is therefore hazardous in the environment because of its availability for biological metabolism without further breakdown. Hence Ortho-P, in addition to TP, is the commonly used parameter to monitor P concentration in WWTSs (McCray et al., 2005; USEPA, 1997). Ortho-P can be in form of one or several species in WW including orthophosphoric acid (H_3PO_4), dihydrogenphosphate ion ($H_2PO_4^-$), hydrogen phosphate ion (HPO_4^{2-}), and PO_4^{3-} ions. The form present depends on pH (Fig. 3) (USEPA, 2010; Thomason, 2002).

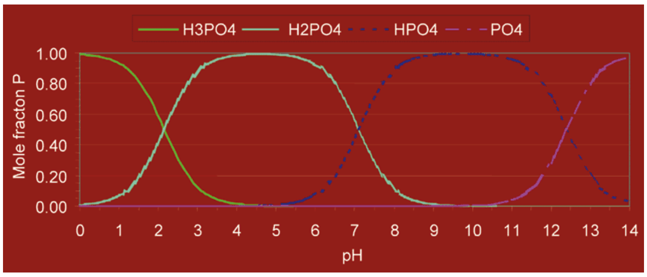

Fig. 3: *pH influence on distribution of orthophosphate forms orthophosphoric acid (H_3PO_4), dihydrogenphosphate ion ($H_2PO_4^-$), hydrogen phosphate ion (HPO_4^{2-}), and phosphate ion (PO_4^{3-})* (Thomason, 2002).

Considering pH levels in P-filters at Høyås system where pH in PFFP ranges between pH 8.7-9.5 (Annex 04) and in PFFM ranges between pH 8- 8.8 (Annex 03), it implies that HPO_4^{2-} ions are the main P forms in these P-filters.

IP is polyphosphates which are high-energy condensed phosphates meaning Ortho-P molecules are linked together in chain. Large polyphosphate fractions are in detergents and cleaners. Common examples include pyrophosphate ($P_2O_7^{4-}$) and triphosphate ($P_3O_{10}^{5-}$) (Lusk et al, 2013; McCray et al., 2009). Polyphosphates are soluble but unstable in water hence are converted to Ortho-P through biological activity or through hydrolysis before removed from WW (USEPA, 2010; Averbuch-Pouchot and A Durif, 1996). Polyphosphates hence increase Ortho-P concentrations hence going back to the point that Ortho-P is commonly used WW parameter for P analysis. Ortho-P together with small fraction of other P forms flow to subsequent treatment units after ST and removed through physical, biological, and chemical processes that include sedimentation, biological assimilation, and sorption mechanisms (Hamdan and Mara, 2013). In CWs optimized for P removal, use of reactive filter media also called P-sorbents or reactive substrates which have a high P affinity, is common (Vohla et al, 2011; Westholm, 2005). At Høyås, PFFM and PFFP are examples of such P-sorbents that remove and retain P from WW through sorption as provided next.

2.2.1.4 Phosphorus Sorption in Reactive Filter Media

P-sorption involves P removal from solution by concentrating it in or on a solid phase. It is a continuous reaction involving adsorption followed by precipitation processes (Reddy et al., 1999). Precipitation refers to process by which insoluble solid substance (precipitate) is formed and separated from solution after chemical reaction between ionic compounds in a solution. Precipitation is favoured by more availability of necessary ions in solution and precipitates do not form if the solution is under-saturated with respect to the new solid phase (Chang and Overby, 2011; Lusk et al., 2013; Reddy et al., 1999). In theory, precipitation is not limited provided there is sufficient space for the formed mineral to ‘grow’ and sufficient aqueous concentration of mineral components in the solution. Precipitation process is irreversible but the reversibility depends on factors like pH, reduction-oxidation conditions, and solubility product of P-bearing minerals (Robertson et al., 1998). In P removal, Ortho-P anions form metal complexes with cations present in P-filter media. Particularly, Ca and Mg are important elements for P precipitation due to their reactivity at high pH (Søvik and Kløve, 2005: Adam et al., 2007a).

Adsorption refers to removal of compound (adsorbate) from solution to solid phase (adsorbent) and accumulation of such compound at solid-liquid interface. It can either be physisorption or chemisorption. In physisorption, adsorbate molecules are physically fastened to adsorbent molecules as a result of energy differences and/or electrical attractive forces (weak van der Waals forces). These adsorbate molecules form multimolecular layers on the adsorbent and the layers are proportional to contaminant concentration. Unfortunately, physisorption is reversible depending on strength of attractive forces between adsorbate molecule and adsorbent. Chemisorption involves reaction between adsorbed molecule and adsorbent that produce a chemical compound. Chemisorption forms one thick layer and is irreversible because of energy requirement to form new chemical compound at adsorbent surface. The energy would otherwise reverse the process. Chemisorption is favoured by high temperatures unlike physisorption that occur at low temperatures (Cheremisinoff, 2002; Reddy et al., 1999). Adsorption is limited by amount of available sorption sites hence rate of sorption decreases as a function of time. It is not limited by adsorbate concentration in the solution hence P adsorption can occur even at low Ortho-P ions concentration in the solution (McCray et al, 2005; Lusk et al., 2013; Reddy et al., 1999).

In P-filters, P-sorption involves both adsorption and precipitation processes. Ca and Mg are important elements for P-sorption in P-filters. At pH>8, P exists as HPO_4^{2-} (Fig.3). These $HPO4^{2-}$ ions first displace water and bicarbonate (HCO_3^-) or hydroxide ions (OH^-) present on calcite ($CaCO_3$) particles, and then adsorb on the positively charged surfaces of the $CaCO_3$ particles. At alkaline conditions and high P concentration, precipitation of calcium phosphate ($Ca_3(PO4)_2$) occurs due to presence of reactive Ca (Adam et al., 2007a). The Ca and Mg elements in P-filter media become reactive after reacting with WW (equation 1).

$$Ca + H_2O \longrightarrow Ca^{2+} + OH^- \qquad \textit{Equation 1.}$$
$$Mg + H_2O \longrightarrow Mg^{2+} + OH^-$$

Due to high pH in P-filters, reactive Ca precipitates to $Ca_3(PO4)_2$ at high P concentrations (equation 2) (Adam et al., 2007a; Søvik and Kløve, 2005).

$$Ca(OH)_2 + PO_4^{3-} \longrightarrow Ca_3(PO4)_2 + H_2O \qquad \textit{Equation 2.}$$

The above precipitation process is different from coagulation and precipitation using lime. When lime is added to WW, it reacts with bicarbonate alkalinity ($Ca(HCO_3)_2$) in WW to form $CaCO_3$ (equation 3) and also reacts with Ortho-P species HPO_4^{2-} to form hydroxyapatite precipitates (equation 4).

$$Ca(OH)_2 + Ca(HCO_3)_2 \longrightarrow 2CaCO_3 + 2H_2O \qquad \textit{Equation 3.}$$
$$5Ca^{2+} + 4OH^- + 3HPO_4^{2-} \longrightarrow Ca_5OH(PO_4)_3 + 3H_2O \qquad \textit{Equation 4.}$$

Precipitation of magnesium hydroxide ($Mg(OH)_2$) occurs as pH increases above 9.5. At pH>9.5 reactive Mg starts to form precipitates of $Mg(OH)_2$ (equation 5) and the precipitation process completes at pH11 (Adam et al, 2007a).

$$Mg^{2+} + Ca(OH)_2 \xrightarrow{\qquad\qquad} Mg(OH)_2 + Ca \qquad \textit{Equation 5}$$

Equation 5 may also explain Ca leaching in PFFP because the Ca in the equation reacts with CO_2 in WW to form $CaCO_3$ that are then deposited in outlet pipes. Due to Ca leaching, pH in the PFFP decreases gradually. After a certain period, the pH in the PFFP will be governed by WW pH (Adam et al, 2007a). pH is one of various factors affecting P-sorption in P substrates. These factors are categorised into (1) physical and chemical properties of adsorbent, (2) physical and chemical properties of adsorbate, (3) characteristic of liquid phase, and (4) hydraulic loading rate (HLR) and hydraulic residential time (HRT) (Cheremisinoff, 2002).

Physical and chemical properties of adsorbent; main factors related to filter medium properties that promote P adsorption include (a) pH in terms of point of zero charge (pH_{pzc}) where at medium's pH_{pzc} its surface has zero net charge, then the surface has net positive charge at value below pH_{pzc} while has net negative charge at value above pH_{pzc}. Filter media with pH_{pzc} greater than 6-8 mostly develop net positive charge on their surfaces hence increase in P-sorption, (b) high mineral composition particularly Ca, Mg, and (oxyhydr-) oxides of Fe, Al, and Mn that provide cations for Ortho- P-sorption, and high clay content that provide large surface area for P-sorption sites (c) grain size, texture, and pore size. For instance, small and rough grains have large surface area hence higher adsorption capacity compared to adsorbents with large and smooth grains (Lusk et al, 2013; McCray, 2005; Cheremisinoff, 2002; Armenante, n.d).

Physical and chemical properties of adsorbate; some examples of these include (a) molecular size of adsorbate with respect to sizes of pores in adsorbent; the larger the size, the lower the adsorption capacity if the adsorbent pore sizes are smaller (b) adsorbate solubility meaning that compounds with low solubility are easily removed from WW than compounds with high solubility. Similarly, nonpolar substances are easily removed from WW compared to polar substances which have high water affinity, (c) adsorbate affinity for the adsorbent. For instance, negatively charged adsorbate will have affinity for positively charged adsorbent surfaces. Similarly, non-polar compounds will have affinity for polar adsorbent surfaces (Tchobanoglous et al., 2003; Cheremisinoff, 2002; Armenante, n.d).

Characteristic of liquid phase; this includes WW quality with physical, chemical, and biological characteristics. Examples of WW characteristics that have impact on P-sorption include pH, organic matter (OM), oxygen (O_2) availability, temperature, content and concentration of other anions and cations. To illustrate, solution pH affects degree of ionization of adsorbate (Fig. 3) consequently affecting adsorption rate (Cheremisinoff, 2002; Armenante, n.d). For temperature, more P is removed during higher that lower temperatures (Mæhlum and Jenssen, 2003). Concerning content and concentration of anions, other anions like NO_3^-, SO_4^{2-}, bicarbonates (HCO_3^-), carbonates (CO_3^{2-}), and chlorides (Cl^-) together with organic substances in WW may compete with Ortho-P anions for ion exchange and sorption sites hence reducing P-sorption. For instance PO_4^{3-} and SO_4^{2-} compete for the same sorption sites. However, SO_4^{2-} adsorb less compared to PO_4^{3-} (Sparks 2013; Tchobanoglous et al., 2003; Chen et al., 2002). For O_2 availability, aerobic conditions promote P-sorption while anaerobic conditions reduce P-sorption. Anaerobic conditions can cause reduced ferric compounds, increased ionic strength, reduced pH, and displacement Fe and Al phosphates by organic anions (Reddy et al, 1999).

High concentration of OM in WW can have positive and negative impacts on P-sorption. For positive impacts, organic carbon (OC) can immobilize phosphates as organic bound complexes hence removing P from solution. This P removal mechanism is however minimal (Brady and Weil, 2008). About negative impact, organic acids can form complexes with metal ions in filter medium leading to competition for sorption sites on adsorbent surfaces and decrease P-sorption (Chen et al., 2002: Ganesh and Nabelsi, 2012). The organic acids can also trap reactive Al and Fe in stable organic complexes called chelates hence make them unavailable for P-sorption (Brady and Weil, 2008).

Excess organic substances can form insoluble complexes with metal ions and oxides and deposited in sorption sites of filter medium hence either block sorption sites for reactive P (Jenssen et al, 2010; Guppy et al., 2005; von Wandruszka, 2006) or inhibit $Ca_3(PO4)_2$ precipitation (Song et al., 2006) consequently reduce P-sorption and removal from WW. Negative effects of OM on P-sorption may lead to shorter than estimated lifetime of treatment components filled with P-filter medium. Hence, treatment components with P-filter may pass longevity early and violate P discharge guidelines. Longevity refers to time during which contaminant concentration is under discharge limit. In this study, P discharge limit is 1mg/l so longevity is that period within which treatment system operates and able to discharge <1mg

P/l. However, the filter medium still has P-sorption capacity after longevity is reached since longevity is shorter than lifetime (Heistad et al., 2006).

Hydraulic loading rate (HLR) and hydraulic residential time (HRT); HLR refers to volume of water applied over unit area per unit time while HRT is average time for volumetric flow (Q) to occupy volume (V) of a given treatment component. HRT is calculated as volume divided by volumetric flow rate (Q) (Tchobanoglous et al., 2003). P-sorption decreases with increase in HLR. When WW contacts filter material, it is postulated that calcium ions (Ca^{2+}) hydrolize through weathering of Ca-containing compounds in the material, then react with PO_4^{3-} and form precipitates which are physically/mechanically retained in the filter material. High HLR then increasingly wash out these precipitates hence reduce Ca content that would otherwise enhance P-sorption in filter medium. Moreover, reactive Ca^{2+} can also be washed out by increased HLR hence reduce P-sorption (Herrmann et al., 2013; Cheremisinoff, 2002). However, Adam et al. (2005) discovered that HLR does not affect P removal in Filtra P. HLR is closely connected to HRT and there is relationship between these two parameters and P-sorption. High HLR implies short HRT due to increased preferential flow and less porosity used for active flow. Reduced HRT means reduced contact time between WW and filter material hence low P adsorption. Longer HRT may however need large space for treatment system installation (Vohla et al., 2011; Adam et al., 2007b; Christos and Tsihrintzis, 2006; Cheremisinoff, 2002; Armenante, n.d). Space may however not be an issue in rural areas. Besides, the treatment system simultaneously removes other contaminants other than P.

2.2.2. Nitrogen

N is an essential nutrient for plants and animals and supports life because it is one of the key elements in proteins and cells (USEPA, 2010). It has seven possible oxidation states hence it occurs in the environment as organic nitrogen (organic-N), ammonia (NH_3), NH_4^+, nitrogen gas (N_2), nitrous oxide (N_2O), nitric oxide (NO), nitrite ion (NO_2^-), nitrogen dioxide (NO_2), and NO_3^-. These N forms are governed by fixation, ammonification, synthesis, nitrification, and denitrification mechanisms in the environment (Fig.4) (USEPA, 1993).

N and its compounds are used in various applications like in fertilizer, explosives, food packaging, light bulbs, electronics, high voltage equipment, and so on (Krebs, 2006). Discharging WW containing excess N to the environment can cause eutrophication in marine waters, deteriorated water quality, high O_2 demand because of nitrification process, groundwater contamination from NO_3^-, and toxicity to aquatic organisms from NH_3.

Consuming water containing excess NO_3^- can cause miscarriages, carcinogenesis, methemoglobinemia (also called ‘‘blue baby syndrome’’) in infants, and birth defects. Due to health effects, NO_3^- concentration limit in drinking water is 10mg/L (USEPA, 2010; Patterson, 2003; USEPA, 1997; USEPA, 1993).

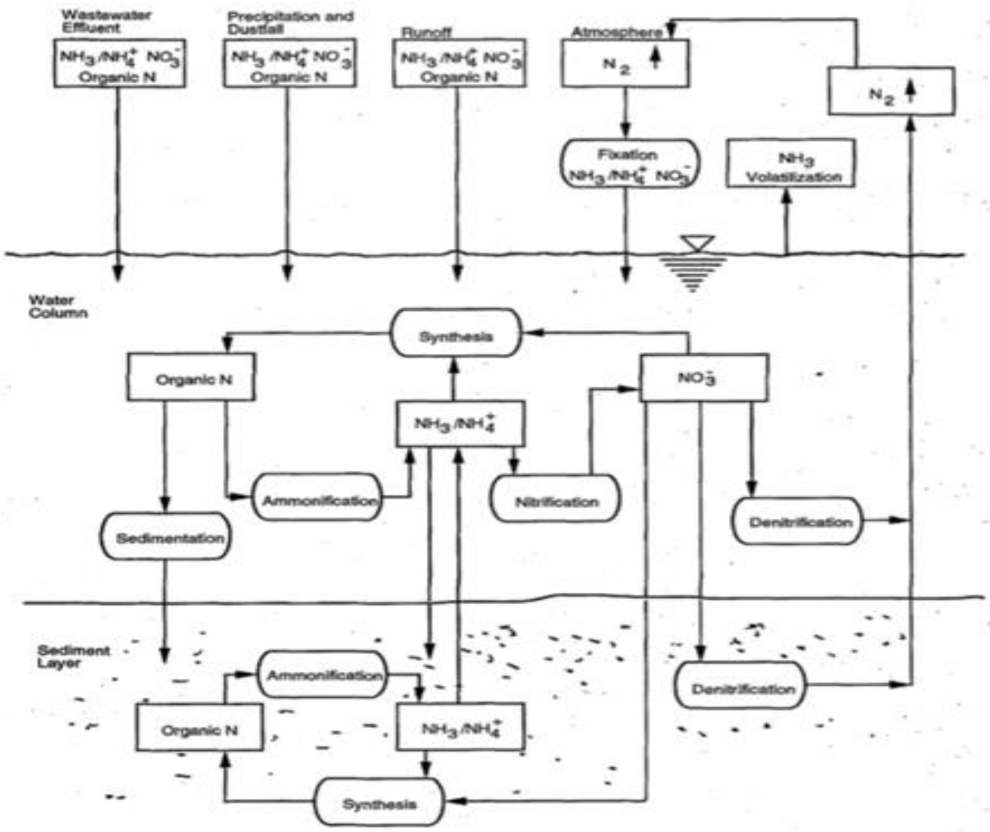

Fig. 4: *Nitrogen cycle and its transformation mechanisms in the environment (*USEPA, 1993)

N into DWW originates from urine, faeces, and grey water. Each person produces around 12g of N per day mostly in form of urea $[CO(NH_2)_2]$ (Yri et al., 2006). Urine contains >80% N (Fig. 2) and daily urine production per person is 1.0 - 1.5L depending on fluid intake (Patterson, 2003). The urea rapidly breaks down to ammonia which is further converted to ammonium ions depending on WW pH (USEPA, 2010). In faeces, N is waste product of protein metabolism. In grey water, N comes from food residues in kitchen sinks, shampoos, detergents, personal care products, sweat, and other body wastes like skin, hair, body oils and greases (Patterson, 2003). N forms in WW include organic-N, NH_3, NH_4^+, and NO_3^- (Fig. 4). Inlet concentrations of each of these N forms can be measured in the STE. The sum of these N-forms in the inlet can also be measured as TN concentration in the STE (USEPA, 2010; USEPA, 1993).

TN is sum of nitrate-nitrogen (NO3-N), nitrite-nitrogen (NO2-N), ammonia-nitrogen (NH_3-N) and organic-N. TN is different from Total Kjeldahl Total Nitrogen (TKN) which is the sum of NH_3-N and organic-N. DWW has inlet concentration ranges of 12-453mg/l for TN, 17-178mg/l for NH_4^+, 0-1.94mg/l forNO_3^-, and 9.4-15mg/l for organic N. NH_4^+ is the most dominant form compared to other N forms in DWW. The presence and concentration of N forms in STE vary according to number of users, their WW generating behaviour, biological activities in the ST including sludge and scum accumulation degree (McCray et al., 2005; Patterson, 2003). The change of effluent concentrations of TN, NH_4^+ and NO_3^- from ST and consecutive treatment components depend on rates of ammonification, nitrification, and denitrification mechanisms. These mechanisms in addition to volatization, plant uptake, filtration, sedimentation, cation exchange, adsorption, and microbial assimilation are related to how N is removed from DWW (Albuquerque et al, 2009; USEPA, 1993). Ammonification refers to biochemical conversion of organic material to NH_3 or NH_4^+. It is evident in hydrolysis reaction of urea in urine (equation 6). Ammonification occurs when animal and plant tissue and animal fecal matter decompose according to equation 7 (USEPA, 1993).

$$\underset{\text{(Urea)}}{H_2NCONH_2} + 2H_2O \xrightarrow[\text{(Urease)}]{\text{Enzyme}} \underset{\text{(ammonium carbonate)}}{(NH_4)_2\,CO_3} \qquad \textit{equation 6.}$$

$$\underset{\text{(proteins, amino acids, etc.)}}{\text{Organic nitrogen}} + \text{microorganisms} \longrightarrow NH_3/NH_4^+ \qquad \textit{equation 7.}$$

Ammonia nitrogen (NH_3-N) is the first N form that does not contain C. This N form breaks down rapidly to NH_3. The NH_3 formed is very soluble in water forming NH_4^+ and hydroxyl ion (OH^-) hence raising pH (Equation 8). The equilibrium of the equation depends on pH and temperature (Weiner, 2000).

$$NH_3 + H_2O \longleftrightarrow NH_4^+ + OH^- \qquad \textit{equation 8.}$$

Concentration of either NH_3 or NH_4^+ in a treatment unit is pH and temperature dependent because these factors affect the equilibrium in equation 8. At pH>9.6, NH_3 dominates while at pH<9.6, NH_4^+ dominates (USEPA, 2010; Weiner, 2000). Nitrification refers to biological oxidation of NH_4^+ to NO_3^- under aerobic conditions. The process involves two stages (equation 9) (USEPA, 1993).

$$\begin{array}{l}
\text{Stage 1: } NH_4^+ + 1.5O_2 \xrightarrow{\textit{Nitrosomonas}} NO_2^- + 2H^+ + H_2O \\
\text{Stage 2: } NO_2^- + 0.5O_2 \xrightarrow{\textit{Nitrobacter}} NO_3^- \\
\hline
\qquad NH_4^+ + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O
\end{array} \qquad \textit{equation 9.}$$

Nitrification process produces nitrous acid (HNO_2) hence drop in WW pH (Kemira, 2003). This is evident in this study where pH decreases in BF effluent (BFE) (Section 4.7). The optimum pH range for nitrifying bacteria is pH 7.5-8 (Henze et al., 2008). Nitrification process stops if pH drops below 5.5 because low pH inhibits the nitrifying bacteria. Nitrification does not occur at high pH because then large amount of N occurs as NH_3 hence readily taken up by the bacteria. The pH should not be too high during nitrification process because oxidation of nitrite is favoured by a lower pH (Kemira, 2003). pH plays important role in nitrification process. Other conditions that favour nitrification include temperature between 15^0C to 30^0C, >2mg/l DO, low food to microorganism ratio, adequate buffering, and long contact time (Komorowska-Kaufman et al., 2005; Tchobanoglous et al., 2003; Shu-guang et al., 2003).

Denitrification refers to biological reduction of NO_3^- to N_2 gas under anaerobic or anoxic conditions and C source (equation 10). The N_2 gas produced diffuses back to the atmosphere and completes the N cycle (USEPA, 1993).

$$2NO_3^- + H^+ + \text{organic matter} \longrightarrow N_2 + HCO_3^- \qquad \textit{equation 10.}$$

Denitrification process results in increased alkalinity due to HCO_3^- produced. This therefore increases WW pH. Optimum pH range for denitrification process is between 7and 9. Conditions must be anoxic during denitrification meaning WW must not contain DO, but O_2 bound up as NO_3^-. In case of aerobic conditions, microorganisms will prefer to use DO because it yields higher energy. The microorganisms are heterotrophic thus need organic C as substrate. This is provided from either OM in WW or especially in CTPs, adding external C source like methanol, ethanol, etc. to the process (Henze et al., 2008; Kemira, 2003).

2.2.3. Biochemical Oxygen Demand (BOD)

BOD indirectly measures amount of OM in water and WW. It involves measuring DO microorganisms use to oxidize OM for specified period usually five days (BOD_5) or seven days (BOD_7) at constant temperature. It excludes O_2 used for nitrification and denitrification processes. In WWT, BOD_5 test at 20^0C is the most commonly used (Tchobanoglous et al., 2003). OM contains biodegradable material composed of mainly proteins, carbohydrates and fats which are energy source to organisms. Microorganisms retrieve this energy from OM by using DO in WW to decompose OM into carbon dioxide (CO_2), water, and energy (equation 11) and reuse the energy for growth and reproduction (Hach et al.1997).

Equation 11.

$$\text{Organic Matter} + O_2 + \text{Microorganisms} \longrightarrow CO_2 + H_2O + \text{Energy}$$

OM can be in dissolved or undissolved form in water and WW. The dissolved form is further divided into soluble and insoluble OM. In BOD_5 test, microorganisms mainly oxidize soluble

OM during the five days incubation period because it requires longer time to oxidise insoluble OM (Hach et al., 1997). The undissolved form is removed either as settleable solids or biodegraded if in suspended solid form. Both dissolved and undissolved forms are subject to biodegradation provided there are suitable conditions in treatment component. The dissolved form play major role in transport of contaminants in water and WW systems (Illani et al., 2005; USEPA, 2002). Decomposed OM contains inorganic elements essential for soil amendment and plant growth (Guppy et al., 2005; Gondar et al., 2004). Therefore, decomposed OM from WW can be reused in agriculture.

OM in DWW originates from human excreta, food residues from kitchen sinks, laundry, soaps, shampoos, and personal care products (Gray and Becker, 2002; USEPA, 2002). Each person produces 46g OM per day and the typical inlet BOD concentration in DWW ranges from 200mg/l to 260mg/l (Yri et al., 2006). Høyås system has a slightly higher range (Section 4.5). Conditions favorable for BOD removal include enough O_2 supply, temperature range of 15-30^{0}C, pH range 6-9, time varying input loading and not steady input loading, sufficient contact time, sufficient DO concentration, relative low hydraulic loading rate (HLR), and relatively large sized medium granules for biofilm development and simultaneously allow sufficient porosity (Mæhlum and Stålncke, 1999; USEPA, 1997; Palm et al., 1980; Young and McCarty, 1969).

Discharging WW containing high BOD concentrations can hinder WW reuse and can cause O_2 depletion in ecosystems receiving treated WW and lead to adverse ecological effects. High BOD concentration needs high O_2 for OM degradation. Consequently, microorganisms use DO in aquatic WW recipients to decompose OM and this can deplete O_2 required by biota in the same WW recipient. This can affect the biota that depends on O_2 for survival in that ecosystem (USEPA, 1997). Other effects of discharging WW with high BOD concentration into aquatic systems include; reduced river water movement, lakes become abiotic due to lack of O_2, foul-smell due to population increase of anaerobic bacteria, production of toxic gases like methane (CH_4), NH_3, and hydrogen sulfide (H_2S) due to anaerobic conditions, and pollution of ground water sources which affect human health (Delzer and McKenzie, 2003; Marshall, 1978).

2.2.4 pH

pH is a measure of acidity or basicity of an aqueous solution. Its scale ranges from 0 to 14. A solution with pH7 is neutral, with pH>7 is basic and with pH<7 is acidic. pH is calculated as negative logarithm of H^+ concentration (i.e. $pH= -Log_{10} [H^+]$). A pH change from one value to another thus represents 10-fold change in acidity or basicity of a solution (United States Geological Survey (USGS), 2013). Typical WW pH in the inlet ranges from 6 to 9 (Gross, 2005). The pH varies in treatment components due to physical, chemical, and biological activities within or outside the treatment components. Examples of activities that can influence pH change in treatment components include nitrification and denitrification processes, interaction between WW and filter medium (Adam et al., 2007a; Muirhead, 2005; Luklema, 1969).

By monitoring WW pH in treatment components one can understand and control proceedings of different chemical and biological processes. This is particularly biological processes where microorganisms' survival depends on pH levels. Monitoring and controlling pH in the final effluent can enable WW reuse and also protect organisms in the environment including humans. Most organisms flourish in pH range 6.5-8.5 hence this is recommended pH discharge range (USEPA, 1997). Discharging WW with pH out of this range to recipients with organisms can reduce rates of survival, growth, and productivity of such organisms. Discharging WW with low pH can increase mobility of toxic elements and compounds hence bioavailable for uptake by aquatic organisms. This may affect health of aquatic organisms and organisms in higher food chain including humans due to biomagnification of heavy metals (Fairbrother et al., 2007; Muirhead, 2005; Tchobanoglous et al., 2003; USEPA, 1997). DWW should therefore be discharged with suitable pH according to recipient user interests.

2.2.5 Conductivity

Conductivity refers to water ability to pass electric current. It indirectly measures inorganic cations and anions present in water or WW. High conductivity value indicates accumulation of such cations and anions. It is measured in micromhos per centimetre (µmhos/cm) or microsiemens per centimetre (µS/cm) or related units (USEPA, 1997). Inorganic cations like magnesium (Mg^{2+}), calcium (Ca^{2+}), iron (Fe^{2+}), potassium (K^+) and sodium (Na^+) and anions like SO_4^{2-}, Cl^-, NO_3^-, HCO_3^-, CO_3^{2-} and PO_4^{3-} are constituents of different organic and inorganic materials. They enter into DW from different sources ranging from human excreta to detergents and personal care products. The ions are natural constituents in the environment hence are not harmful unless levels are under or above tolerable range of organisms (USEPA, 1997; Gray and Becker, 2002).

WW conductivity level in the inlet depends on dissolved solids containing inorganic ions from different sources. Presence of organic compounds like oils, phenol, sugar, and alcohol lowers conductivity levels in water and WW (USEPA, 1997; USGS, 2013). The conductivity also varies in treatment components according to temperature, geology of filter material, and biological and chemical activities that convert inert inorganic ions to free soluble inorganic ions. High temperature increases conductivity because warm water is less viscous hence high electronic movement which allows free flow of electric current. For that reason, conductivity is reported at constant temperature of 25^0C (USEPA, 1997) while drinking water conductivity is limited to 2500μS/cm at 20^0C (COUNCIL DIRECTIVE, 1998).

Regarding geology of filter medium, some filter media contain materials that ionize when washed into water hence increase water conductivity (USEPA, 1997). Other filter media have sorption capacity to remove ions from water and hence reduce water conductivity. Examples of biological and chemical activities in treatment components that can lead to change in WW conductivity include conversion of biodegradable OP to Ortho-P (Section 2.2.1.3), oxidation of NH_3 to NO_3^- ' conversion of organic N to NH_4^+, reduction of NO_3^- to N_2 gas (Section 2.2.2), and adsorption of NH_4^+ , Ortho-P, and other inorganic ions (USEPA, 1997).

2.2.6 Hygiene Parameters

To check the microbial quality of the treatment system one sample was taken and analysed for Total Coliform Bacteria (TCB) and the common indicator bacteria *E. coli*. TCB is a collection of bacteria of different origins in the environment and is no longer recommended as an indicator of fecal contamination for recreational waters because it is difficult to know the sources of TCB detected in a sample. However TCB is used as an indicator for fecal contamination in drinking water supply (USEPA, 1997). *E. coli* are enteric in humans and other warm blooded animals. Their presence in a sample indicates contamination specifically from human faeces or other warm-blooded animals.

Due to their specificity and ease of detection, *E. coli* is recommended as indicator when analysing health risks associated with water contact in recreational waters (World Health Organization (WHO), 2001; USEPA, 1997). The discharge limit to recipients for swimming purposes is <500 *E. coli/*100ml (COUNCIL DIRECTIVE, 2006). Most strains of *E. coli* are harmless but some are as *E. coli* 0157:H7 which can cause severe diarrhoea, long term illness, and death (Hayhurst, 2004). *E. coli* and other bacteria removal from DWW using filter bed systems is achieved by physical straining and filtration, sorption, natural death, predation, and inactivation at air-water interfaces (Hendriks, 2010; Siegrist et al., 2000). Results from the one-time hygiene parameters analysis indicate that the microbial reduction in the system is high and the effluent from the day sampling met water quality for swimming purposes (Section 4.8).

3. MATERIALS AND METHODS

3.1 Study Area

This part provides Høyås general information on geographical location, geology, climate, and anthropogenic activities all of which directly or indirectly impact the treatment system's performance. To start with, Høyås is a farm area with geographical coordinates 59° 38' 5.5''N and 10° 47'13''E. The farm is in a location termed as "marine limit" which means the area was covered by sea after the last glaciation period around 10,000 years ago (Ganesh and Nabelsi, 2012). The farm is situated in Ås municipality (*kommune*), Akershus County (*fylke*), Norway. Although most regulations are controlled by the state, matters regarding water and WW quality are monitored and controlled by Ås municipality. This includes setting standards for WW discharge in relation to different contaminants (Heistad et al. 2006; NKF and NORVAR, 2001).

Main anthropogenic activities at Høyås farm include subsistence farming, commercial honey production, commercial lumbering, guesthouse services, and office for administrating farm activities. Although some activities occur throughout the year, most of them are intense during summer. Farming for instance, many people are present at the farm for land preparation, weeding, and farm maintenance. The same case with accommodation of guests is higher during summer especially when international students come for summer school. These activities at the farm impact the treatment system. Number of people present at the farm affects not only nature of WW quality but also determines value of Q. About number of people and nature of WW quality, as explained in section 2, diet preference by different people may lead to variation in concentration of contaminants in WW. Hence, the variation increases as the number of people increases and vice versa. Regarding number of people and Q, the more people present at the farm the higher the Q value and vice versa.

Concerning geology, soil at Høyås farm is mainly silty clay although there might be patches of sand and gravel as a result of glaciation (Ganesh and Nabelsi, 2012). Clay has effective porosity (n_e) often <10% and a hydraulic conductivity (K) below 0.1m/day (Scwartz and Zhang, 2003). This means this area is not suitable for a soil infiltration system since WW flow down the soil matrix is limited by both n_e and K. The low n_e and K has however an advantage that in case of WW leakage from treatment system or as final effluent flows into a creek, chances of groundwater contamination are reduced. About climate, the area has winter, spring, summer, and autumn seasons a year. Hence, temperature, precipitation, and humidity vary greatly. During this study period, temperature varied with winter having coldest day -14.7^{0}C and summer with hottest day 27.6^{0}C. See Annex 09 for weather conditions during sampling dates and Annex 10 for monthly average temperatures and precipitation for different months within the study period 2013 to 2014 (Yr.no, 2014).

Climatic conditions may impact performance of Høyås treatment system. For instance, high temperatures increase rate of biological and chemical processes hence high removal and retention of contaminants while low temperatures may lead to lower rates of such processes (Mæhlum and Jenssen, 2003). Precipitation in form of rainfall may increase leaching rate of organic substances into treatment components consequently increasing BOD concentrations, and so on (Jury et al., 1983). Climatic impacts on treatment performance at Høyås may not be easily seen in current results because normal performance of the system has been disturbed for instance by leaching of organic substances that may affect microorganisms due to changes in pH, digging out of the tree bark may have mobilized and increased transport of substances into treatment components, and so on.

3.2 Treatment System Layout and Design Parameters

The Høyås SSWWTS was designed and constructed from March 2012 until September 2012 the same month it started operating. This means the system is after 18 months of operation i.e. September 2012 until the last sampling period in March 2014. Design and construction details are documented in Ganesh and Nabelsi (2012) who also monitored the system's general treatment performance and its capacity to remove P using PFFM and PFFP. The system comprises of WW source, WW treatment components, conveying pipes, as well as control and pumping chambers for WW dosing and sampling. WW comes from guesthouse and main house, conveyed with pipes to and treated in treatment components ST, BF, PFFM, PFFP, SFFM, and SFFP. The treatment system is divided into two lines of treatment after the BF treatment component (Fig. 5). The final effluent flows into a creek. The WW source and treatment components ST, BF, PFFM, PFFP, SFFM, and SFFP alongside with conveying pipes, pumping and control chamber units are described in relation to size, structure, function, and design parameters Q, HLR, HRT, hydraulic conductivity (K), hydraulic gradient, and WW dosing where applicable.

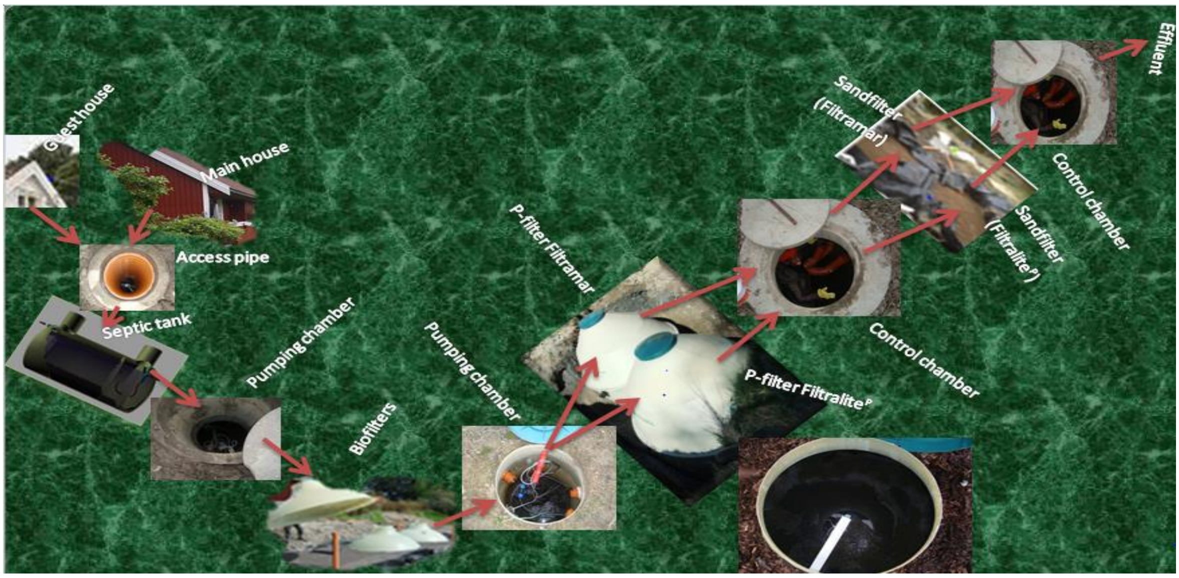

Fig. 5: *Høyås small scale wastewater treatment system (SSWWTS) components Layout.*

3.2.1 Wastewater source

WW into Høyås treatment system originates from one household (main house) occupied by an average of three persons per day and a guest house occupied by up to six persons per day in addition to two small flats in the barn continuously rented to two persons. It is therefore estimated that there is an average of eight persons every day throughout a year and each produces a daily load of 150L of WW into the treatment system. NKF and NORVAR (2001) specify 150L/Pe.day as a standard for designing SSWWTSs. The system is therefore designed for an average of 8 person equivalent (Pe) per day and maximum capacity of 25Pe per day which corresponds to 7 residential units according to NKF and NORVAR (2001).
This gives an average Q design value of 1.2m^3/day (i.e 150L/Pe.day * 8Pe) or 438m^3/year (i.e 1.2m^3/day * 365 days a year). However, the actual Q value is <1.2m^3/day because people are not 100% present at the farm.

To estimate actual Q, WW production was monitored by a device installed at the pumping chamber after ST. The device recorded and stored daily, weekly, and monthly average energy (kWh) used by the pump. The values were then used to calculate number of dosing cycles per day, week, and month given that the pump uses 0.007kWh per dosing cycle. The numbers of dosing cycles are then determined by the formula;

$$\text{Dosing Cycles per day/week/month} = \frac{\text{Average energy (kWh) per day/week/month}}{\text{0.007kWh per dosing cycle}}$$

To estimate Q, dosing cycles per day/week/month values are multiplied by 30L/dose because the pumps are designed to pump 30L every 20minutes to complete the 72 doses/day. The calculated daily, weekly, and monthly Q values are provided in Annex 11. According to data from monitoring device, Q is around 1m^3/day which gives 125L/Pe.day (i.e. 1000l/8Pe). This is around 80% of the design Q value of 1200L/day.

The hydraulic gradient in WW flow pipes in the whole treatment system are adjusted to 1-2% to enable WW flow by gravity wherever possible. WW flows by gravity through pipes from WW sources into main inlet pipe into ST for pre-treatment (Ganesh and Nabelsi, 2012). During this flow, some suspended solids are deposited in the inlet pipe. The deposited solids can be flushed out via access pipe. The access pipe is also designed to change WW flow direction from source to ST. The joint between inlet pipe and access pipe has >90^0 turn hence WW flow direction from source is changed at this point (Ganesh and Nabelsi, 2012).

3.2.2 Septic tank Treatment Component

The ST is a 9.5m^3 fiberglass tank divided into three chambers with volumes 6.9 m^3, 1.3 m^3 and 1.3 m^3 in chambers 1,2, and 3 respectively (Ganesh and Nabelsi, 2012). Fig. 6 illustrates size specifications of this treatment unit at Høyås treatment system.

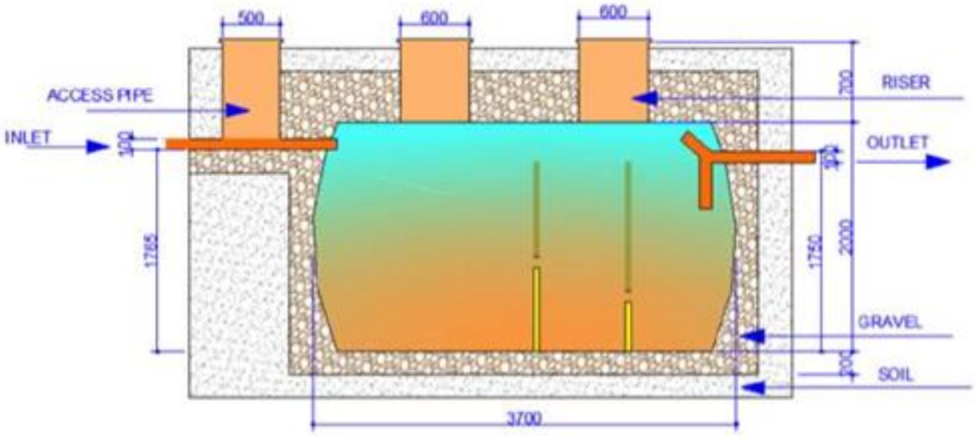

Fig. 6: *Cross-sectional view of septic tank unit including components and dimensions* (Ganesh and Nabelsi, 2012)

The total volume of 9.5m^3 corresponds to ST for three residential units (Annex 18) meaning that the ST at Høyås is oversized relative to actual Q value of 1m^3/day (Ganesh and Nabelsi, 2012). The total volume includes both solid volume (V_s) and wet volume (V_w). The V_w size is calculated by the following formula given that HRT is 18hours in the ST (Jenssen et al 2006).

$$V_w = Q * 18/24 = 1m^3/day * 18/24 = 0.75m^3$$

The V_s corresponds to sludge and scum accumulating in the three chambers which are designed to enable sedimentation and retention of sludge and scum in the ST (Jenssen et al., 2006). At Høyås the ST is scheduled for emptying after every two years. Removal of settleable solids as sludge and floatable solids as scum are the main functions of ST. ST can also remove small proportions of other contaminants in WW. This treatment component can remove 95% settleable and floatable materials, 5-10% TP, 5-10% TN, 25-35% BOD_7), 30-60% suspended solids (SS). The component however has low capacity to remove pathogens (Jenssen et al., 2006). The STE at Høyås therefore mainly contains less particulate contaminants hence reduced loading of these contaminants into consecutive treatment components.

The STE flows by gravity through 110mm-diameter PVC pipe to a $2m^3$ holding tank which is also a pumping and a control chamber. STE sample is taken from this chamber where also STE is held and pumped to BF. The pump is mounted with alarm, floating switch and timer automated to pump 72 doses per day discharging 30L per dose provided there is sufficient water. The pump stops running when there is insufficient water in pumping chamber. This means there are 72doses per day during peak periods while fewer doses per day when Q is low. Assuming peak period when there is sufficient water in pumping chamber throughout the day, the pump runs after every 20 minutes within a day hence able to discharge $2.16m^3$/day (72doses/day *30L). This is higher than the actual Q value $1m^3$/day. In actual sense the pump runs <72 dosages/day because mostly there is insufficient water in the pumping chamber tank (Ganesh and Nabelsi, 2012).

High WW level in pumping chamber either due to pump failure or during high peaks is detected by the mounted alarm. The alarm emits light signals particularly in case of pump failure (Ganesh and Nabelsi 2012). During this study period, WW level in pumping chamber right after BF raised in three occasions and led to pump failure three times. All three occasions were caused by insects and particles that blocked nozzles that distribute WW in P-filters. In case of pump failure, WW flows continuously by gravity through the consecutive treatment component as opposed to intermittent dosage.

3.2.3 Biofilter Treatment Component

The BF is aerobic vertical flow system comprised of $12.5m^2$ filter bed with three 2.3m-diameter domes filled with Filtralite® HC (FHC) 2.5-5mm grains up to 0.6m deep. There are two access pipes for flushing out solid deposits as well as a perforated drainage pipe installed at the bottom along the filter bed (Fig. 7a). The perforated drainage pipe is for aerating the system and for collecting and transmitting BFE by gravity to pumping and control chamber unit. The domes have nozzles from which WW into BF is equally and evenly distributed over FHC medium in the filter bed (Ganesh and Nabelsi, 2012).

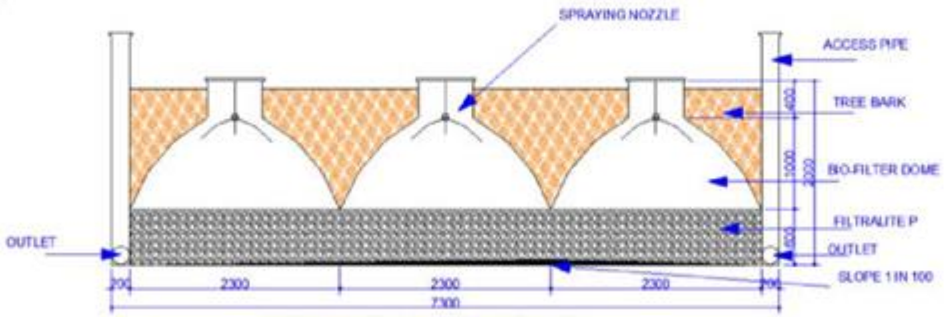

Fig. 7a: *Cross-sectional view of biofilter unit including components and dimensions.* (Ganesh and Nabelsi, 2012)

OM and bacteria form biofilm that attach on grain surfaces of FHC medium and enable OM biodegradation. Biofilm formation on grain surfaces may however reduce P-sorption (Mæhlum and Jenssen, 2003) and may also reduce permeability in the filter material (Brady and Weil, 2004). It is therefore necessary to remove degraded OM deposited on filter material. The bottom and walls of bed are sealed with one millimetre thick PVC liner to avoid leakages from natural soil into treatment component. The top part of bed was initially covered with insulating tree bark (Fig. 7a).

The tree bark was replaced on 17th August 2013 with LWA (Leca® ISO 10– 20mm). I was part of the workers who dug out tree bark from BF, SFFM, and SFFP beds using excavation tractor, then added and spread the Leca evenly (Fig. 7b). The insulation depth is 40cm. This medium has dry density of 220 kg/m^3 and thermal conductivity of 0.11W/m.K properties suitable for insulation. More description and properties of this filter material see Annex 13 (Weber, 2014a). Excavation increases mobility of substances in soils hence of filter media (Jury et al., 1983). Therefore, higher effluent concentrations of contaminants were expected in the following sampling date just after tree bark replacement. Although efforts were made to remove as much tree bark as possible, there were some left that were mixed with filter media and removing them meant removing also the filter media. This was avoided otherwise filter media volume would have been reduced. Thus, the left tree bark may leach organic substances and gradually decrease with time as decay process of tree bark completes.

Fig. 7b: *Replacement of insulating tree bark with light weight aggregates (Leca) at Høyås.*

The BF is designed according to VA-Miljøblad nr.49 which specifies HLR 20cm/day (i.e 200L/m^2.day) and HRT 10 days (NKF and NORVAR, 2001). The designing Q value in BF is 1200L/day calculated from the recommended WW production standard of 150L/Pe per day (150L/Pe.day *8Pe). However the actual Q value used for calculations is 125L/Pe per day as estimated by water monitoring device. Estimating HLR from the designing Q value by dividing Q with surface area of filter bed (1200L/day ÷ 12.5m^2), it gives HLR of 96L/m^2.day or 9.6cm/day. The BF is oversized when comparing HLR of 20cm/day from VA-Miljøblad nr.49 with calculated HLR of 9.6cm/day from designing Q value. The oversizing can be utilized during peak period hence good treatment performance of BF (Ganesh and Nabelsi, 2012).

The BF has suitable conditions for microorganisms to carry out nitrification process and to decompose OM. The microorganisms are attached to filter material grains as biofilm. These microorganisms decompose organic matter in WW using supplied O_2 from the vertical unsaturated flow in the BF (Jenssen et al., 2006). Therefore BOD and NH_4^+ reduction majorly occurs in BF (Sections 4.4 and 4.5). BF can also remove P through adsorption, as well as bacteria. The degree of removal depends on type and properties of filter material, HLR, and WW dosage (Jenssen et al, 2006).

WW treatment in BF occurs in the FHC filter material. FHC is a clay expanded material with crushed particles and porous surface structure manufactured in Norway by burning clay at 1200^0C. These properties improve filter efficiency through reduced backwash frequency and improved water velocity. It contains 63% $SiO_{2,\ 17}$% Al_2O_3, 7% Fe_2O_3, 4% K_2O, 2% CaO and 2% Na_2O. The metal oxides enable P-sorption. These and other properties (see Annex 12) make FHC to be regarded as a high quality filter medium for contaminants removal (Weber, 2014b). To monitor contaminant levels in BFE, WW samples were taken from pumping and control chamber installed after the BF. This pumping and control chamber is the same as the pumping and control chamber after the ST. This includes size, Q value, dosage, and pump properties (Section 3.2.2). It pumps BFE equally to PFFM and PFFP which are the next treatment components after the BF. This means the average Q value of 1m^3/day is divided into 2 and flows to two lines. That is, one of the Q value 0.5m^3/day flows to PFFM and the other 0.5m^3/day flows to PFFP (Ganesh and Nabelsi, 2012).

3.2.4 Phosphorus Filter Treatment Components

PFFM and PFFP units are installed parallel to each other (Fig. 8a). The P-filters have the same size, HRT, HLR, and Q. What differentiate them is filter materials filled in each unit. In size, each unit encompasses 6m^3 fiberglass tank with approximately 2.3m diameter where in PFFM unit the tank is filled with 4m^3 Filtramar® 0-7mm grains and in PFFP unit the tank is filled with 4m^3 PFFP 0.5-4mm grains.

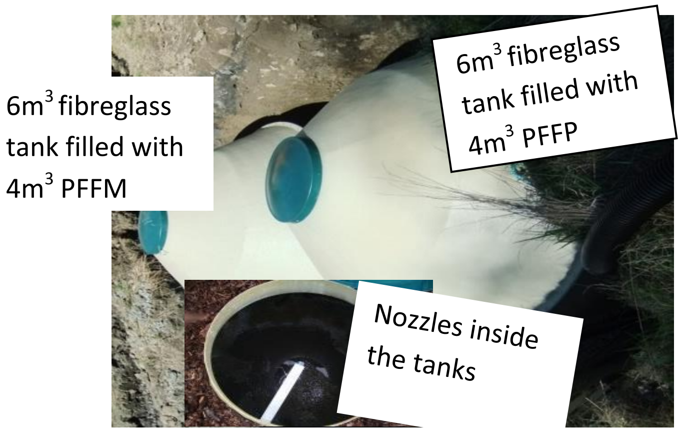

Fig. 8a: The *phosphorus filter Filtramar® (PFFM) and phosphorus filer Filtralite® P (PFFP) treatment components at Høyås treatment system.*

Both tanks have nozzles which are supposed to distribute WW equally and evenly over 4m^2 surface area filter material (Fig. 8b). This was not the case during this study period. The nozzles mostly sprayed WW over less than half the surface area of filter material (Fig. 8c). Therefore there might be preferential flow as well as ‘dead zones’ in the P-filters. On each sampling date, the nozzles were adjusted to spray WW over the whole 4m^2 but the spraying did not last long until the next sampling date. Throughout this study, the inlet Q to P-filters has been treated over <4m^2 surface area and 1m depth of filter medium.

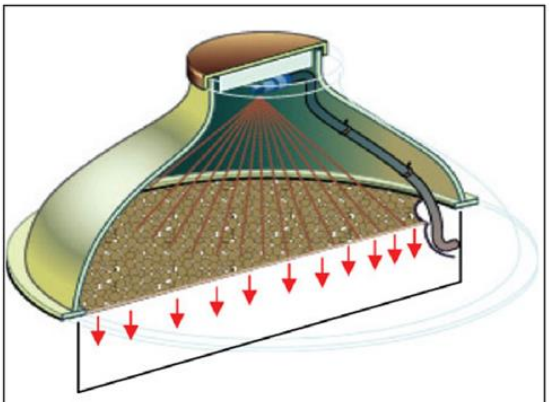

Fig. 8b: *Nozzle distributing wastewater (WW) evenly over surface area of filter medium* (Jenssen et al., 2006).

Fig. 8c: *Nozzles in P-filters at Høyås treatment system.*

Assuming equal and even WW distribution by the nozzles in P-filters, inlet Q value of 500L/day from BFE pumping chamber gives HLR in each P-filter as 125L/m^2 per day or 12.5cm/day (500L/day ÷ 4m^2). However, each P-filter unit is designed with HLR of 20cm/day hence the P-filters are oversized. The oversizing allows good treatment performance during peak loads and also achieves good performance of the P-filters. The P-filters remove and retain P as well as other contaminants from WW. The P-filters have vertical unsaturated flow in the upper 20cm and saturated flow in the lower 80cm (Ganesh and Nabelsi, 2012).

To estimate HRT, average inlet Q value of 0.5m^3/day flowing through each P-filter medium of volume 4m^3 gives HRT of eight days (i.e 4m^3 ÷ 0.5m^3/day) in each P-filter. Although PFFM and PFFP units receive the same amount of Q with the same WW quality, the results (Section 4) indicate that these P-filters have different treatment performance. One of the reasons can be due to different physical and chemical properties between PFFP and PFFM used at Høyås system. PFFP used at Høyås is a commercially produced medium from clay mixed with 10-15% dolomite ($CaMg(CO_3)_2$) and heated at 1200^{0}C. The heating expands the clay and forms porous particles. Due to high heating the dolomite dissociates according to equation 12:

$$CaMg(CO_3)_2 \xrightarrow{\text{heat}} CaO + MgO + CO2 \qquad \textit{Equation 12.}$$

PFFP contains Ca and Mg in form of CaO and MgO. It can also contain some $CaCO_3$ and magnesite ($MgCO_3$) because the metal oxides may react with CO_2 produced during the heating process. This medium contains 31gCa/Kg material, 7gMg/Kg material, 20gAl/Kg material, and 6gFe/Kg material (Heistad, 2008; Adam et al., 2007a; Adam et al., 2007b; Jenssen and Krogstad, 2003). The porous particles are crushed to grain size range 0.5-4mm, bulk density 370Kg/m^3, and pH 12. High pH in PFFP enhances P-sorption and substantial pathogen removal. However the high pH can hamper microbial activities of nitrification and denitrification hence low TN removal. This P-filter medium loses Ca which later clogs outlet pipes during first years of operation due to precipitation of $CaCO_3$ (Adam et al, 2007a: Heistad et al, 2006). For more properties of PFFP see Annex 14(Weber, 2014c).

PFFM used at Høyås system is natural carbonic material composed of crushed shells of snails, mussels, and coral alga deposited at and harvested from coastlines. Its chemical composition is dominantly $CaCO_3$ and $MgCO_3$ although it may contain minute CaO and MgO. It contains 300gCa/Kg material, 14gMg/Kg material, 0.3gAl/Kg material, and 0.6gFe/Kg material (Adam et al., 2007a: Adam et al., 2007b; Søvik and Kløve, 2005). The medium is crushed to particle size range 0-7mm, bulk density 800Kg/m^3, pH8-8.5, hydraulic conductivity 500m/day, and P adsorption capacity 4gP/Kg material. For more properties of PFFM see Annex 15 (BOSTON AS, n.d). PFFM is naturally available, has good P-sorption capacity measured in laboratory tests, and it is relatively cheap. However there is lack of full-scale experiences with PFFM. Another disadvantage is that this medium has relatively low pathogen removal capacity due to low pH range 8-8.5. This pH range however promotes nitrification and denitrification processes hence high TN removal in PFFM (Adam et al., 2007b). WW from P-filters flows by gravity through 110mm-diameter pipe to sand filter treatment components. PFFM effluent flows to SFFM unit while PFFP effluent flows to SFFP. The sand filter beds are polishing units as explained next (Ganesh and Nabelsi, 2012).

3.2.5 Sandfilter Treatment Components

SFFM and SFFP are filter beds installed parallel to each other where PFFM and PFFP effluents are treated respectively. Each filter bed has 7m^2 surface rea and has sand up to 0.8m deep. The bottom and walls of each bed is sealed with one millimetre thick PVC liner and on top was 0.2m deep insulating bark which was replaced with Leca. The beds have vertical unsaturated flow each with HLR of 8.9cm/day or 89L/m^2.day (i.e. 500l/day ÷ 7m^2) and 1-2 days HRT. HRT in these sand filters is shorter than the normal 2-4 days because of higher HLR (8.9cm/day) than the common 2-4cm/day for sand filters (Jenssen et al., 19.91). At the bottom of each bed there is drainage pipe to collect and transmit treated WW to control chamber where WW sampling is done. The SFFM and SFFP units are similar in size and dimensions (Fig. 9) together with similar hydraulic design parameters.

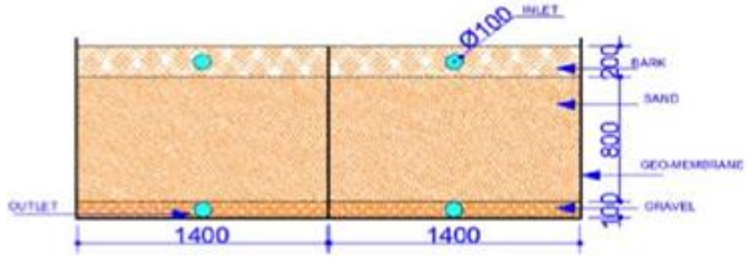

Fig. 9: *Cross-sectional view of sand filter Filtramar® (SSFM)and sand filter Filtralite P (SFFP)units including components and dimensions* (Ganesh and Nabelsi, 2012)

Size of each sand filter bed is 10m long 0.7m wide and 0.7m deep. Sand generally contains Ca, Mg, Fe, and Al and pH vary from 6.7 to 8.1. The metal content in sand can enable further P removal through adsorption and precipitation (Cucarella and Renman, 2009). At pH>6, physical adsorption of Ortho-P anions on Al and Fe oxides as well as precipitation of sparingly soluble $Ca_3(PO4)_2$ can occur in sand medium. At lower pH, Al and Fe phosphate precipitates may form. P removal in sand filter medium therefore depends on presence of the cations and pH changes. The P removal is usually high initially and decreases as P-sorption capacity of sand is exhausted (Vohla et al., 2011). The sand filters at Høyås system removes contaminants and stabilizes WW pH and conductivity before final discharge (Section 4). The SFFP and SFFM effluents flow separately through 110mm-diameter pipe by gravity to recipient via control chamber where SFFM and SFFP effluent samples are taken for analysis. The recipient of the final effluent is a creek that has no user interests (Ganesh and Nabelsi, 2012).

3.3 Wastewater Sampling and Analysis

WW sampling and analysis started from 12th June 2013 until 31st March 2014. WW samples were collected as grab samples from ST, BF, PFFM, PFFP, SFFM, and SFFP effluents, then stored in freezer and awaited for analysis. The one-time sample was collected on 10th March 2014 from BF, PFFM, PFFP, SFFM, and SFFP effluents and analysed the same day for TCB and *E. coli.* The other samples were taken once per month except in September when samples were taken twice to evaluate early effects of replacing tree bark with Leca on treatment performance. To assess whether there were 'dead zones' in the P-filters, four filter media samples were taken two from each P-filter. In PFFM unit, one sample of medium was taken from the centre where the nozzle mostly sprayed WW and another medium sample was taken far aside where WW sprayed by nozzle did not reach. Similarly, in PFFP unit, one medium sample was taken in the centre and another sample from the sides. Due to limited time, the samples are stored and wait for analysis hence the results are not included in this study.

Samples for each sampling date were taken out of freezer one day before analysis to allow melting. On the analysis day, first, photos of samples from each treatment component for every sampling date were taken to show WW colour so as to monitor WW colour change with time before and after tree bark replacement. Then, conductivity and pH in WW samples were measured before chemical analysis.

3.3.1 *Conductivity and pH Measurements*

Conductivity was measured using conductivity meter “Thermo Scientific Orion Star A329 Portable Conductivity Meter” while pH was measured using pH meter “Thermo Scientific Orion Star A329 Portable pH Meter”. Conductivity and pH data were collected for statistical analysis. Both pH and conductivity measuring instruments are in installed at the laboratory in the Department of Environmental Sciences (IMV) in Norwegian University of Life Sciences (NMBU). The chemical analyses were also performed in the same laboratory. In chemical analysis, the samples were analysed for P (in form of TP and Ortho-P), N (in form of TN, NH_4^+, and NO_3^-) and BOD_5. Except for BOD_5 measurement, chemical parameters TP, Ortho-P, TN, NH4+, and NO3- were analysed using HACH LANGE cuvette tests reagents. The results were read using barcode reading machine HACH LANGE DR 2800 where all cuvettes were first cleaned by serviette from the outside before inserted in the barcode reading machine. HACH LANGE LT200 thermostat was used where heating of samples in cuvettes was needed. Each chemical analysis was performed following procedures given in each reagent test kits for each parameter as explained below.

3.3.2. *Phosphorus Analysis*

The samples were analysed for TP and Ortho-P using reagents LCK 349 measuring range 0.5-5mg P/L and LCK 350 measuring range 2-20mg/l PO_4-P/ 6-60 mg/l PO_4/4.5-45mg/l P_2O_5. The concentration ranges in treatment components were determined during previous study by Ganesh and Nabelsi (2012). LCK 350 test kit that includes manual with test procedures was used to analyse for TP and Ortho-P in STE and BFE samples due to relatively high P concentrations in these treatment components. LCK 349 that also includes manual with test procedures was used to analyse for TP and Ortho-P in PFFM, PFFP, SFFM, and SFFP effluent samples because P concentration was relatively low in these treatment components. The principle of TP and Ortho-P tests using both LCK 349 and LCK 350 reagents is that antimonyl phosphomolybdate complex is formed after reaction between PO_4^{3-} ions with molybdate and antimony ions in an acidic solution. The antimonyl phosphomolybdate complex is then reduced by ascorbic acid to phosphomolybdenum blue (HACH LANGE, n.d$_{a)}$. TP and Ortho-P data for the analysed samples were collected for statistical analysis.

3.3.3. *Nitrogen Analysis*

The samples were analysed for N using reagents LCK 338 measuring range 20-100mg/l for TN test, LCK 303 measuring range 2.5-60mg/l NH_4 for NH_4^+ test, and LCK 339 measuring range 1-60mg/l NO_3 for NO_3^- test. Each test kit has one range meaning samples with concentrations above each range were diluted. Samples with concentrations below the ranges were measured undiluted and the barcode reading machine read the results as 'under measuring range' followed by concentration value. To determine concentration ranges in treatment components, three trial tests for each N form were performed prior to N analysis. In the first trial test, samples were analysed without dilution to check whether there was need for sample dilution. The samples that needed dilution could not be read by the HACH LANGE barcode reading machine. Such samples were diluted with distilled water and reanalysed in the second and third trial tests until dilution factor was determined. The dilution factors were then appropriately used in TN, NH4+, and NO3- analysis.

In TN analysis, reagent LCK 338 range 20-100mg TN/L was used in all treatment components. The STE samples were diluted by factor of two due to higher TN concentrations in ST than the reagent range. Samples from the rest treatment components did not need dilution. The samples were then analysed following procedures included in LCK 338 test kit. The principle of TN test is that peroxodisulphate digests inorganically and organically bonded N in the sample oxidising them to NO_3. Then the NO_3^- ions react with 2.6-dimethylphenol in sulphuric and phosphoric acid solution to form nitrophenol (HACH LANGE, n.d$_b$). Next, LCK 303 range 2.5-60mg/l NH_4 was used for NH_4^+ analysis in samples from all treatment components. Samples from STE were diluted by factor of three while samples from rest treatment components were diluted by factor of two. The samples were then analysed following procedures provided in LCK 303 cuvette test kit.

The principle of NH_4^+ test is that at pH 12.6, NH_4^+ ions react with hypochlorite ions and salicylate ions in presence of sodium nitroprusside as catalyst to form indophenol blue (HACH LANGE, n.d$_c$). Finally, LCK 339 range 1-60mg/l was used to analyse NO_3^- in samples from all treatment components. STE samples did not need dilution while samples from rest treatment components were diluted by factor of two. The samples were then analysed following procedures provided in LCK 339 cuvette test kit. The principle of NO_3^-

test is that NO_3^- ions in solution containing sulphuric and phosphoric acids react with 2.6-dimethylphenol forming 4-nitro-2.6-dimethylphenol (HACH LANGE, n.d_d). The TN, NH_4^+, and NO_3^- data for the analysed samples were collected for statistical analysis.

3.3.4 *BOD_5 Measurement*

BOD_5 was measured using OxiTop® OC100 system. The measurement is based on measuring pressure in closed system. Microorganisms in the sample consume O_2 forming CO_2 that is absorbed by NaOH hence create vacuum which is measured as mg/l BOD value. The sample volume regulates O_2 amount available for complete BOD (WTW, 2014). A single sample BOD_5 test using OxiTop system involves one brown measuring bottle where specific sample amount, a magnetic stirrer bar, and drops of nitrification inhibitor ($C_4H_8N_2S$) are added. The measuring bottle is brown to avoid algae growth while the $C_4H_8N_2S$ is added to inhibit nitrification process. Then, a rubber sleeve is inserted into the bottle with sample as leak proof and where 2-3 NaOH pellets are put to adsorb CO_2 produced during incubation period. Next, an OxiTop® measuring head is screwed tightly on the bottle with sample to avoid aeration and also where registration and results are stored and read using WTW OxiTop® OC100 controller. Finally, the bottle with contents is put in an incubator and left in darkness at 20^0C for five days. Some of the OxiTop® OC100 system components are illustrated in Fig. 10 (WTW, n.d).

Fig. 10: *OxiTop system "WTW OxiTop® OC100''components for biochemical oxygen demand (BOD) test* (WTW, 2014).

Samples from each treatment component at Høyås needed specific concentration range and sample volumes. These together with procedures and principles for BOD_5 measurement are described in the manual 'Determination of Biochemical Oxygen Demand (BOD)' provided by WTW (n.d). Following the manual, samples from STE were measured using range 0-800mg/l hence 97ml sample was poured in the measuring bottle with two drops $C_4H_8N_2S$ and one pellet NaOH. Samples from the rest treatment components were measured using range 0-40 mg/l hence 432ml sample was used in each test with 9-10 drops $C_4H_8N_2S$ and three pellets NaOH. Due to bottles limitation, 12 samples were measured at a time. Then the bottles were machine cleaned before they were used for the next BOD test. Result from each BOD_5 measurement was read after five days incubation period. All data for the analysed samples were collected for statistical analysis.

3.3.5 Hygiene Parameters Analysis

The one-time sample collected on 10th March 2014 was analysed the same day for TCB and *E. coli* using Colilert 18/Quanti-Trays2000 Method as described in IDEXX (2014). The analysis was performed in the *Bioforsk* [1]laboratory at Campus, Ås. The analysis was done with undiluted samples. TCB and *E. coli* were detected in all samples that were taken from BF, PFFM, PFFP, SFFM, and SFFP. The results were reported in most probable number per 100 millilitre sample (MPN/100ml) units.

3.3.6 Statistical Analysis

Minitab 15 statistical software and Microsoft excel 2010 were used to statistically analyse raw data and also to produce time series graphs and charts to represent the raw data. The analysis include two sample t-test and descriptive statistics namely mean, median, standard deviation (Std.Dev.), maximum value (Max.), minimum value (Min.), and range. The raw data, t-test outputs, and descriptive statistics for parameters conductivity, pH, TP, Ortho-P, TN, NH4+, NO3- , and BOD_5 for treatment components ST, BF, PFFM, PFFP, SFFM, and SFFP are provided in the Annexes. The data from the one-time sampling and analysis for TCB and *E. coli* were statistically analysed to determine log reductions in the treatment components BF, PFFM, PFFP, SFFM, and SFFP and the results also in the Annexes (Section 8). The mean and std.Dev values for each parameter in treatment components together with their time series graphs and charts are provided and discussed in the following section of results and discussion.

4. RESULTS AND DISCUSSION

This section first provides general results including effluent concentrations/levels of parameters, their descriptive statistics, and treatment efficiencies in treatment components. This is followed by a detailed discussion of each contaminant removal including comparison of results with previous study on Høyås system by Ganesh and Nabelsi (2012).

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[1] Bioforsk Jord og Miljø; Adam M. Paruch Seniorforsker (Dr. Ing.) Miljøteknologi og renseprosesser www.bioforsk.no

4.1 General Results

Effluent concentrations and levels as well as descriptive statistics of analysed parameters for WW effluent from treatment components ST, BF, PFFM, PFFP, SFFM, and SFFP are shown in Annexes 1, 2, 3, 4, 5, and 6 respectively. Table 1 shows the mean concentrations and Std.Dev values of parameters for each treatment component during the study period.

Table 1: **Mean Effluent Concentrations and levels of Parameters in Treatment Components as per Study Period June 2013 to March 2014. The numbers in brackets are Std.Dev values.**

	TREATMENT COMPONENTS					
PARAMETERS	ST	BF	PFFM	PFFP	SFFM	SFFP
TP (mg/l)	16.56 (2.2)	10.4 (3.38)	1.68 (0.45)	1.19 (0.32)	0.95 (0.43)	0.61 (0.31)
Ortho-P (mg/l)	14.35 (2.32)	9 (2.56)	1.6 (0.39)	1.12 (0.35)	0.82 (0.31)	0.57 (0.28)
TN (mg/l)	112.55 (10.78)	72.75 (12.22)	55.23 (14.14)	62.26 (14.59)	43.75 (11.9)	51.73 (17.17)
NH4+ (mg/l)	108.89 (11.17)	51.75 (20.6)	32.66 (18.42)	42.61 (19.14)	23.36 (14.31)	33.29 (17.3)
NO3- (mg/l)	0.99 (0.25)	19.38 (10.52)	27.94 (14.31)	22.46 (10.22)	29.35 (9.91)	24.73 (9.13)
BOD (mg/l)	254.18 (30.77)	10.59 (12.72)	4.58 (6.91)	5.17 (6.19)	3.83 (6.0)	3.11 (5.0)
Cond. (µS/cm)	1470 (168.24)	1189 (59.25)	1111 (90.99)	1266 (78.16)	975 (95.29)	1113 (88.26)
pH	8.07 (0.36)	7.79 (0.33)	8.44 (0.28)	8.99 (0.26)	8.15 (0.47)	8.49 (0.26)

As evident in table 1, Høyås SSWWTS meets discharge limits for P 1mg/l and for BOD 20mg/l. Mean inlet TP concentration of 16mg/l is reduced to final mean TP effluent concentration of 0.95mg/l and 0.6mg/l from SFFM and SFFP respectively. Also, mean inlet BOD concentration of 254mg/l is reduced to final mean effluent concentration of 3.8mg/l and 3mg/l from SFFM and SFFP respectively. This treatment system also reduces mean inlet TN 112mg/l to final mean effluent concentration of 43mg/l and 51mg/l from SFFM and SFFP respectively. Mean final effluent pH 8.2 from SFFM and pH8.5 from SFFP are within pH range 6.5-8.5 which is suitable for most aquatic organisms (USEPA, 1997). For conductivity, mean inlet level 1470 µS/cm is reduced to final effluent level of 975µS/cm and 1113µS/cm from SFFM and SFFP respectively.

Table 2 represents concentrations of TP, Ortho-P, and BOD along with pH and conductivity levels from previous study (Ganesh and Nabelsi, 2012). Comparably, the mean TP and Ortho-P concentrations were lower in the previous than in the current study while the mean BOD concentrations were higher in the previous than in the current study. The mean conductivity levels in the previous study were slightly higher particularly in BF and P-filters. The mean pH levels from both studies are relatively the same except in the PFFP that has higher pH in the previous study than in the current study.

Table 2: Mean Effluent Concentrations and levels of Parameters in Treatment Components as per Study Period October 2012 to January 2013. The numbers in brackets are Std.Dev values.

	TREATMENT COMPONENTS					
PARAMETERS	ST	BF	PFFM	PFFP	SFFM	SFFP
TP (mg/l)	12.19 (3.03)	6.38 (3.27)	0.688 (0.632)	0.313 (0.226)	0.262 (0.05)	0.276 (0.148)
Ortho-P (mg/l)	10.07 (3.10)	5.50 (3.23)	0.458 (0.588)	0.153 (0.129)	0.099 (0.032)	0.075 (0.024)
BOD (mg/l)	357.7 (199.9)	36.8 (32.5)	19.44 (8.91)	13 (21.12)	45.1 (68.2)	23.82 (7.98)
Cond. (µS/cm)	1176 (620)	1644 (456)	1594 (270)	3437 (3119)	1102 (249)	1112 (536)
pH	7.415 (0.553)	7.812 (0.358)	8.068 (0.439)	10.907 (1.166)	7.556 (0.77)	8.292 (0.81)

To monitor capacities of treatment components to remove different contaminants, treatment efficiencies of each treatment component with respect to P, N, and BOD removal was calculated using the formula;

$$\frac{\textit{Mean STE Concentration} - \textit{Mean Effluent Concentration of Treatment Component} *100}{\textit{Mean STE Concentration}}$$

The treatment efficiency values from each treatment component are presented in Annex 07. Treatment components have high removal efficiency particularly in respect to P and BOD (Fig. 11).

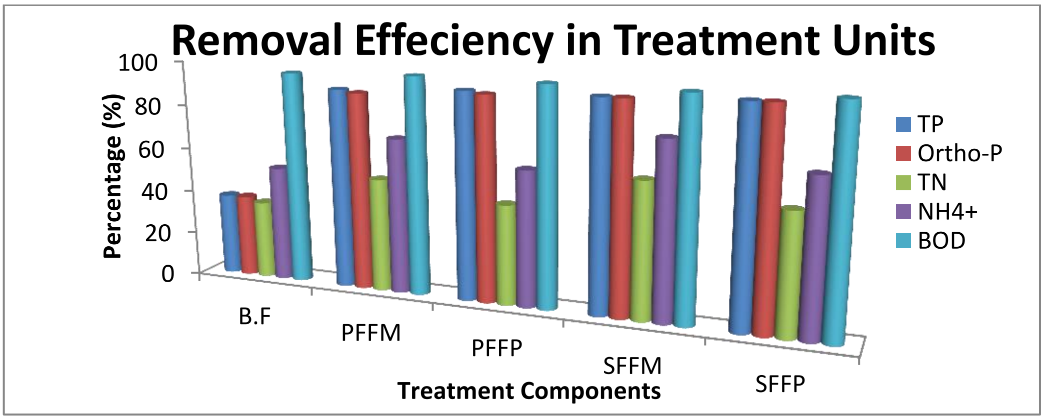


Fig. 11: *Removal efficiency (%) graphs for total phosphorus (TP),orthophosphate (Ortho-P), total nitrogen (TN), ammonium ions (NH_4^+), biochemical oxygen demand (BOD) in biofilter*

(BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) treatment components.

Fig. 12a, 12b, and 12c shows WW colour change monitoring before and after tree bark replacement. The WW effluent from BF, PFFM, PFFP, SFFM, and SFFP treatment components had yellowish and/or brownish colour before tree bark replacement. It is therefore apparent that tree bark leached organic substances into the treatment components as suggested by Ganesh and Nabelsi (2012).

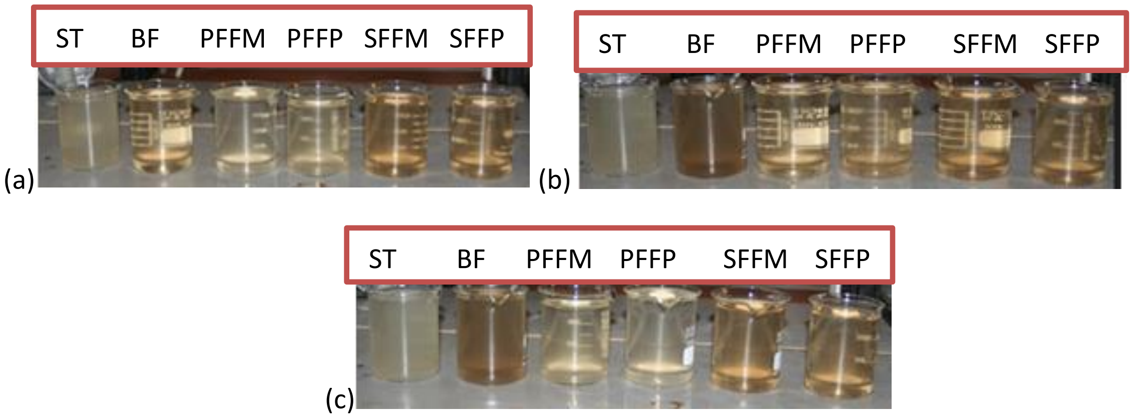


Fig. 12: *Wastewater (WW) effluent colours from treatment components septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) before tree bark replacement. The figures represent samples taken on (a) 12th June 2013, (b)13th July 2013, and (c) 7th August 2013.*

The tree bark was applied on the BF, SFFM, and SFFP-filter beds. Therefore, these are the directly affected treatment components compared to PFFM and PFFP that only received organic substances from BFE. The colour in STE is grey and not affected by organic substances. The WW samples taken two and half weeks after tree bark replacement also had a yellowish and/or brownish colour. The same was also evident in the consecutive two months although the WW effluent colours diminished gradually (Fig. 13a, 13b and 13c).

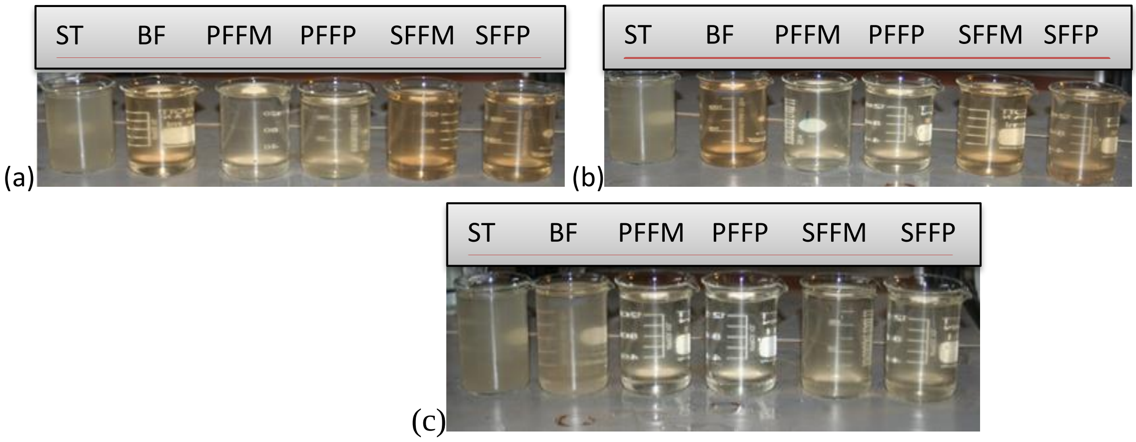


Fig. 13: *Wastewater (WW) effluent colours from treatment components septic tank*

(ST), biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) for samples taken on (a) 4th September 2013, (b) 21st October 2013, and (c) 20th December 2013 after tree back replacement.

Fig.14a, 14b, and 14c show effluents from BF and consecutive treatment components from January until March 2014. The effluents began to be clear from January 2014 and completely clear in February and March 2014. Fig. 14d compares tap water (TW) with the final effluents from SFFM and SFFP treatment components. Evidently, one may not easily tell the difference if the samples were not labelled.

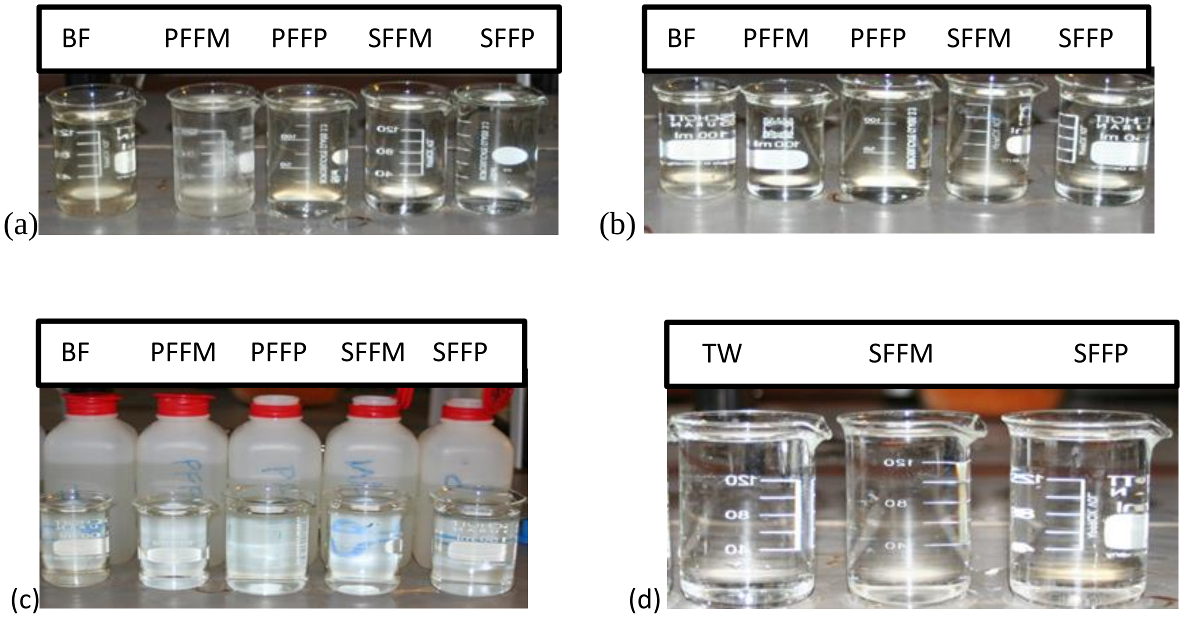


Fig. 14: *Wastewater (WW) effluent colours from treatment components biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) for samples taken on (a) 27th January 2014, (b) 18th February 2014, and (c) 31st March 2014 after tree bark replacement, whereas (d) compares tap water (TW) with the effluent samples from SFFM and SFFP taken on 31st March 2014.*

Considering WW colour of samples in Fig. 14, it can be concluded that tree bark leaching has stopped. Replacing insulating tree bark had also effect on P removal performance of treatment components as discussed in the next section.

4.2 Phosphorus Removal

Different P removal mechanisms (Section 2.2.1.4) have played important roles in reducing inlet P concentrations at Høyås treatment system. The mean inlet TP effluent concentration measured as STE is 16mg/l with Std.Dev of 2.2mg/l (Table 1) and is in the range 13-19mg/l (Annex 01). The range is higher than the common 8-11mg/l (Yri et al., 2006) probably because of no or little leakages of the local piping system. Other reasons may include water use habits, diet, and habits of using chemicals containing P (Section 2.2.1.2). During this study period, inlet concentration measured as STE varied with sampling dates where the highest inlet TP concentration is 19mg/l and the lowest concentration is 13mg/l (Annex 01). These variations in inlet TP concentrations are reduced as WW flows through consecutive treatment components as seen in curve shifts from ST to BF then BF to P-filters, and P-filters to sand filters in Fig. 15a.

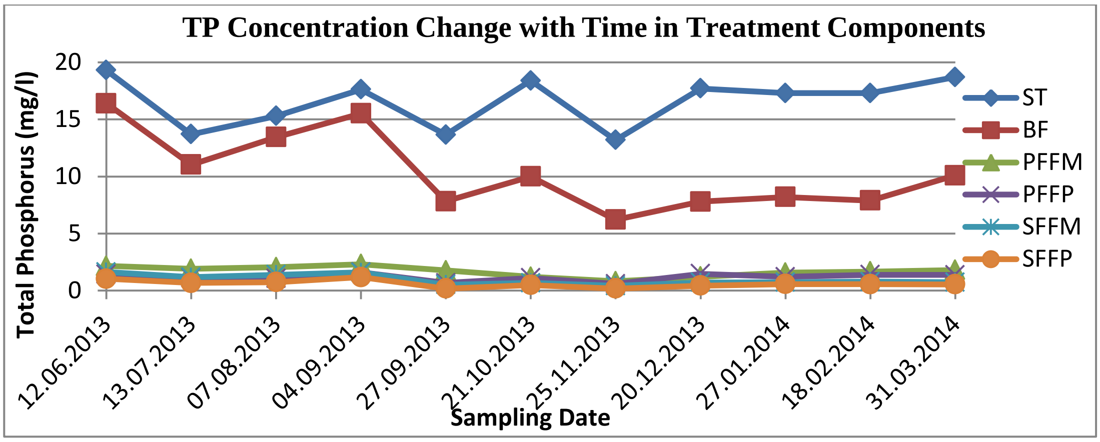
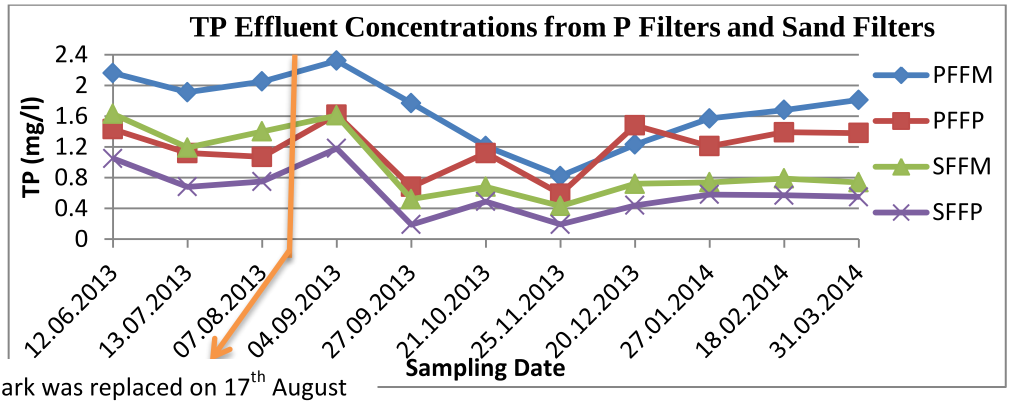


Fig. 15a: *Total phosphorus (TP) effluent concentrations (mg/l) versus time for the treatment components treatment units septic tank (ST), biofilter (BF), phosphorus filter Filtramar*$^{®}$ *(PFFM), phosphorus filter Filtralite*$^{®}$ *P (PFFP), sand filter Filtramar*$^{®}$ *(SFFM), and sand filter Filtralite*$^{®}$ *P (SFFP) during 2013-2014 study period.*

The major P reduction occurs in P-filters as seen in curve shift from BF to PFFM and to PFFP curves (Fig. 15a). The P removal efficiencies of the different treatment components increases from 36% after the BF, 90% after the PFFM, 93% after the PFFP, 94% after the SFFM, and 96% after the SFFP (Annex 07). These removal efficiencies are slightly lower than in the previous study with TP removal of 48% BF, PFFM 94%, PFFP 97%, SFFM 98%, and SFFP 98% (Ganesh and Nabelsi, 2012). In my opinion, the higher removal efficiencies in previous study may be explained by the fact that treatment components were new with fresh P-sorption sites at the same time tree bark decay and leaching of organic substances was in their early stages. Tree bark leaching therefore affected TP effluent concentrations more in this study than previous study.

The tree bark replacement impacted P removal at Høyås treatment system. The TP effluent concentrations were higher during the months before tree bark replacement in BF, P-filters, and sand filters than in the months after. This is mainly in the BF as indicated by increasing gap between STE curve and BFE curve (Fig. 15a). Furthermore, the maximum TP effluent concentration 16mg/l from BF is also before tree bark replacement while the minimum concentration 6mg/l is after tree bark replacement (Annex 02). The impact of tree bark replacement on P removal in P-filters and sand filters can be seen in Fig. 15b. TP effluent concentrations from the P-filters and sand filters were reduced one month after tree bark replacement. It is however necessary to perform batch experiment to assess effects of organic substances on P-sorption in PFFM and PFFP.



Tree bark was replaced on 17th August

Fig. 15b: *Total phosphorus (TP) effluent concentrations (mg/l) versus time for the treatment components phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) during 2013-2014 study period.*

According to Fig. 15b, TP effluent concentrations were relatively higher during the first four sampling dates then started decreasing as from 27th September until November and started to gradually increase again as from December. The gradual increase in P-filters is probably due to decreasing sorption sites which is a limiting factor for P-sorption (McCray et al, 2005; Lusk et al., 2013; Reddy et al., 1999). Another possible reason for the gradual increase is decreasing temperatures (Annex 10) which also affects P-sorption (Mæhlum and Jenssen, 2003). The increasing trends in TP effluent concentration from PFFM and PFFP in the current study (Fig. 15b) seem to continue from previous study where PFFM and PFFP curves show a gradual increase during the last two months of previous study (Fig. 15c).

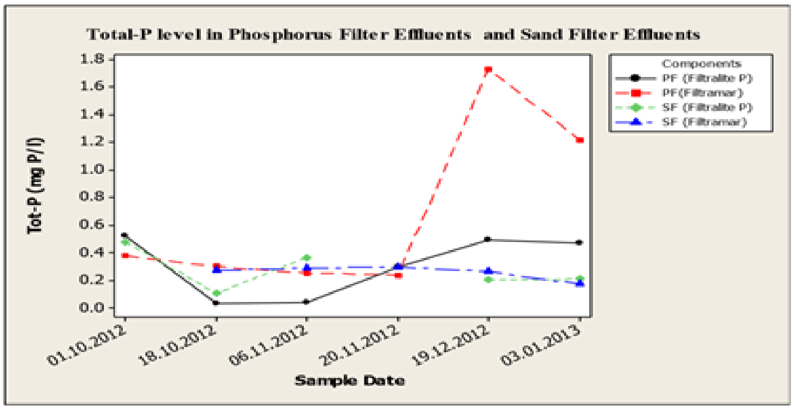


Fig. 15c: *Total phosphorus (TP) effluent concentrations (mg/l) versus time for the treatment components phosphorus filter Filtramar® (PF(Filtramar)), phosphorus filter Filtralite® P (PF(Filtralite P)), sand filter Filtramar® (SF(Filtramar)), and sand filter Filtralite® P (SF(Filtralite P))during study period 2012 to 2013* (Ganesh and Nabelsi, 2012).

The mean TP effluent concentrations 1.7mg/l for PFFM and 1.2mg/l for PFFP (Table 1) show that the P-filters had passed the 1mg/l limit by the end of this study period while final effluent mean concentrations 0.95mg/l for SFFM and 0.6mg/l for SFFP (table 1) were still <1mg/l. These mean effluent concentrations from P-filters and sand filters could be much lower if it were not that organic substances affected WW concentrations during tree bark leaching. Furthermore, the mean TP concentrations from P-filters could have been much lower if the nozzles in P-filters could distribute WW evenly on the whole surface area of filter media. The nozzles sprayed WW over less than half the surface area (Fig. 8c). The PFFM exceeded 1mg/l first time 12.06.2013 (Fig.15b) and also last sampling date of the previous study (in January) while PFFP and sand filters discharged <1mg/l during the whole previous study (Fig. 15c). From previous study, mean TP effluent concentrations were 0.7mg/l and 0.3mg/l from PFFM and PFFP respectively while final effluent concentration was 0.26mg/l and 0.27mg/l from SFFM and SFFP respectively (Table 2).

TP effluent concentrations from treatment components have relatively the same trend as Ortho-P effluent concentrations. Mean influent Ortho-P concentration measured as STE is 14mg/l (Table 1). This is about 87% of mean inlet TP given that mean TP influent concentration is 16mg/l (Table 1). This Ortho-P proportion was also concluded by Gold and Sims (2000) who studied that of the TP measured as STE, 85% is Ortho-P and rest 15% is in form of OP or IP suspended solids. Inlet Ortho-P concentrations at Høyås system are reduced to low final effluent concentrations as WW flows through consecutive treatment components

(Fig. 15d). The mean final effluent concentration is 0.8mg/l and 0.6mg/l from SFFM and SFFP respectively (Table 1).

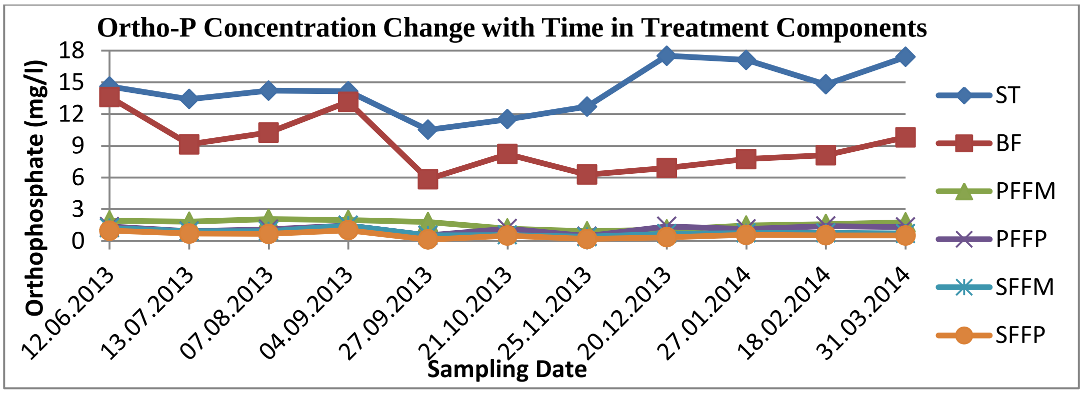


Fig. 15d: *Orthophosphate (Ortho-P) effluent concentrations (mg/l) versus time for the treatment components septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) during 2013-2014 study period.*

Similar to TP, major Ortho-P removal occurs in P-filters as indicated by shift of BF curve to P-filter curves (Fig. 15d). The mean Ortho-P concentration is 1.6mg/l and 1.2mg/l from PFFM and PFFP respectively (Table 1). Like in the TP trend, Ortho-P effluent concentrations from P-filters and sand filters show a gradual increase from December (Fig. 15e).

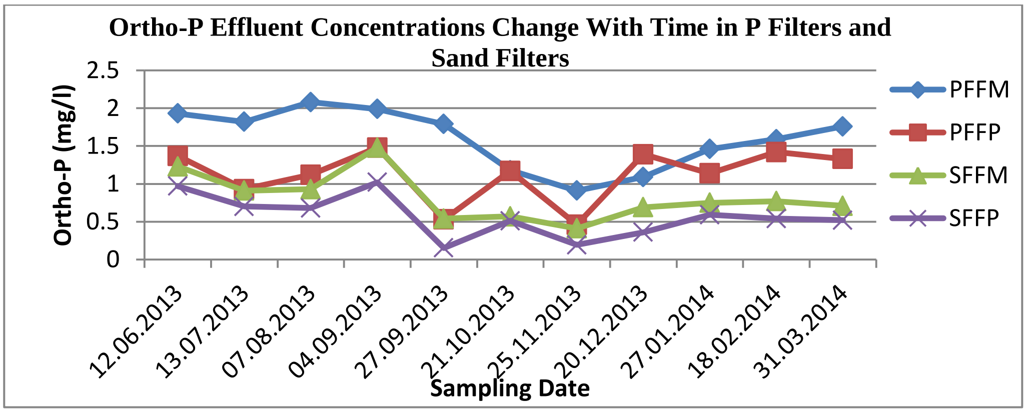


Fig. 15e: *Orthophosphate (Ortho-P) effluent concentrations (mg/l) versus time for the treatment components phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) during study period 2013-2014.*

The gradual increase in Ortho-PP effluent concentration from PFFM and PFFP in the current study (Fig. 15e) seem to continue from previous study where PFFM and PFFP curves show a gradual increase during the last two months of previous study (Fig. 15f).

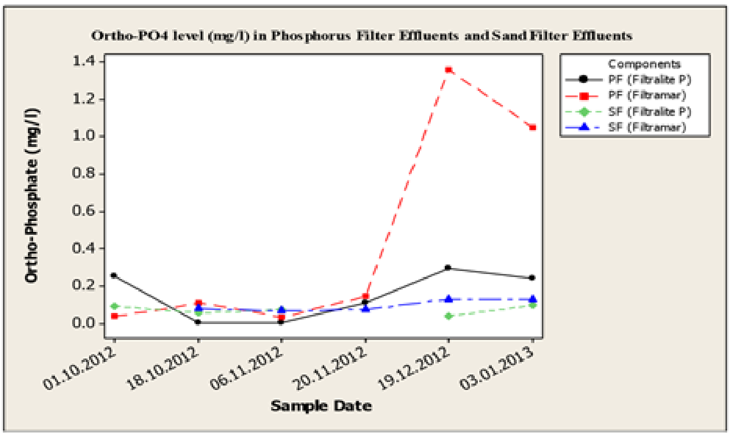


Fig. 15f: *Orthophosphate (Ortho-P) effluent concentrations (mg/l) versus time for the treatment components phosphorus filter Filtramar® (PF(Filtramar)), phosphorus filter Filtralite® P (PF(Filtralite P)), sand filter Filtramar® (SF(Filtramar)), and sand filter Filtralite® P (SF(Filtralite P))during study period 2012 to 2013* (Ganesh and Nabelsi, 2012).

P results from the current study suggest that although both P-filters have high P removal capacities, PFFP is better than PFFM medium. A t-test also confirms that PFFP has higher P-sorption capacity than PFFM at 95% confidence level (Annex 16). The same conclusion was made from batch experiment and field study in Høyås system by Ganesh and Nabelsi (2012). Comparison of P-sorption capacity between PFFP and PFFM used at Høyås system should not be transferred to another shell sand type because there are varieties of shell sand media with different physical and chemical properties. Besides, some shell sand media have been found to have better P-sorption capacity than PFFP (Adam et al., 2007b).

The higher P removal in PFFP than in PFFM is due to difference in properties of the two filter media (Section 3.2.4). The high pH in PFFP leads to more P adsorption (Adam et al., 2007a) in PFFP than in PFFM. However, PFFP may become saturated faster than PFFM since both receive the same amount of WW with similar P concentrations but PFFP retains more P than it does PFFM. The batch experiment from previous study estimated life time to be 2.45years and 26.2 years for PFFP and PFFM respectively (Ganesh and Nabelsi, 2012). This implies that longevity is <2.45 years and <26.2 years for PFFP and PFFM respectively since longevity is shorter than lifetime (Heistad et al., 2006). The P-filters in Høyås system have passed longevity because both discharge >1mg/l (Fig.15b).

The P-filters can remain operative until mean TP concentration in the final effluent from sand filters become 1mg/l. Until the last sampling date, TP mean final effluent concentration was

0.95mg/l and 0.6mg/l for SFFM and SFFP respectively (Table 1). The values however are approaching longevity meaning that the mean concentration in the final effluent is approaching the 1mg/l P discharge limit. The longevity at Høyås treatment system can be prolonged by adopting one of the various methods for regenerating P-sorption sites in P-filters as discussed next.

4.3 Regenerating Sorption Sites in Phosphorus Filter Media

Regeneration of P-sorption sites in P-filters leads to increase in P-sorption and reduced P concentrations from the P-filters (Adam et al., 2005; Drizo et al., 2002). P-sorption sites in P-filters at Høyås treatment system can be regenerated and hence prolong longevity of the P-removal part of the system. Common ways for regenerating P-sorption sites in P-filter medium include thermal process, treating media with chemicals, resting periods, and flow enhancement. Each is described below.

Thermal process; P-filter medium is heated at high temperatures for a certain period to regenerate P-sorption sites. For example in a batch experiment by Khan (2007) revealed that regenerating Polonite® by heating it at 900^0C for two hours resulted in remarkable increase in P removal. However, the P-filters with Filtra-P and YXP-LWA do not tolerate high temperatures so they were regenerated by heating at 30^0C.The author postulates that regeneration mechanism in Polonite® is due to heating $CaCO_3$ in Polonite® to CaO which facilitates this P-filter to behave as fresh sorbent. To adopt this P regeneration method to Høyås system needs transportation of the used P-filter media to a place with an oven that can heat the media at either 30^0C or 900^0C and then transport them back to the Høyås system. The heating alone is very expensive (Khan, 2007) and the handling is also costly. The cost of handling and heating easily may exceed the cost of replacing the existing filter media with new media. to transport the P-filter tanks with media. The new media costs NOK 600/m^3 for Filtramar® and NOK 1500/m^3 for Filtralite® P (P.D. Jenssen, personal communication, 10th May 2014)

Treating medium with chemicals; this method has been studied in the lab using active slag filter medium used for P removal (Pratt et al, 2011). The P medium was treated independently with hydrochloric acid (HCL), sodium hydroxide (NaOH) and sodium dithionite ($Na_2S_2O_4$). The reagents manipulate pH and oxidizing Eh on adsorbent surfaces hence potentially activates the medium for further P removal. During the process, adsorbed and extractable P is stripped from the P-filter using the reagents and new P-sorption sites are then activated. The solution containing stripped P and chemicals used for treating the medium is collected. The stripped P can then be recovered from the solution by chemical precipitation and reused in agriculture (Pratt et al., 2011).

The laboratory results showed that regenerating the filter medium independently with $Na_2S_2O_4$ and HCL led to increased total P retention by factor of six and thirteen respectively. Regeneration using NaOH was ineffective at increasing P removal in slag filters (Pratt et al., 2011). The main disadvantage of adopting this method to Høyås system is that it needs collection of the solution containing stripped P mixed with chemicals used for P regeneration, and then to use other chemicals to recover the P from the mixture to enable P reuse. Besides, P recovery using chemical precipitation is expensive (LENNTECH, 1998). Another chemical option that can be used to treat and regenerate P-sorption sites in P-filters at Høyås is lime (CaO). The CaO can be applied on top of the existing P-filter media to increase pH and Ca content in PFFM and PFFP media. Consequently, precipitation of $Ca_3(PO4)_2$ should occur in presence of reactive P in the medium. This creates more space for P-sorption (T. Krogstad and P. D. Jenssen, personal communication, 7th April 2014). The CaO is a constituent of PFFM and PFFP, especially, and adding lime is positive because plants easily extract P from P-filters rich in Ca-phosphates (Krogstad et al., 2005).

Resting period: P-filter medium is regenerated by leaving the medium without loading for some time. In most cases a resting period allows the medium to become drier at low temperature for a period of time. For instance, after P-sorption in column experiment using electric arc furnace steel slag filter, the medium was rested for 124 days and regenerated 74% of P-sorption sites. It was, however, not clear what was the regeneration mechanism (Drizo et al., 2002). Another experiment with PFFP by Adam et al. (2005) showed that regenerating the medium by resting resulted in 22-53% decrease in P concentration in the effluent. Resting period method can be easily adopted in Høyås system, but in order for the media to become drier the water in the saturated part of the filters has to be pumped out. Since there are two P-filters in Høyås one filter can be rested while the other is in operation. Another option in Høyås is to bypass the P-filters for a time and rely on the sand filters to sorb P while the P-filters are resting.

Flow enhancement: It has been shown by Suliman et al. (2005) that preferential flow may occur in saturated wetland filters. In Høyås, the upper 20cm of the P-filters are unsaturated and the lower 80cm saturated. The BFE are applied to the P-filters through spray nozzles. It has been observed that the current nozzles distribute the water only in a small zone directly below the nozzle. It is therefore a risk that preferential flow occurs and that there some 'dead zones' in the P-filters that has more capacity to sorb P. Changing to nozzles with a wider spray angle so that the effluent is distributed onto the whole surface of the P-filters should eliminate or at least reduce the possibilities for dead zones.

Based on the above discussion, using heat or chemical treatment is not recommended in Høyås. Changing the nozzles should be tried first as this is very easy to do. If this does not have the desired effect or after the potential effect of flow enhancement ceases, a resting period should be tried. Liming would be the last option to be tried before replacement of the filter media.

4.4 Nitrogen Removal

The parameters TN, NH_4^+, and NO_3^- were analysed to monitor treatment system capacity to remove N. As mentioned earlier, TN influent measured as STE is majorly in form of NH_4^+ (see Section 2.21). The NH_4^+ is oxidized to NO_3^- or adsorbed on negatively charged surfaces. NH_4^+ effluent concentrations are reduced while NO_3^- concentrations increase in consecutive treatment components. TN is reduced in consecutive treatment components (Fig. 16a). The change of concentrations of the N-compounds in the different treatment components depends on rates of the N removal mechanisms i.e nitrification, denitrification, adsorption, biological assimilation, volatization, filtration etc. (Albuquerque et al, 2009; USEPA, 1993).

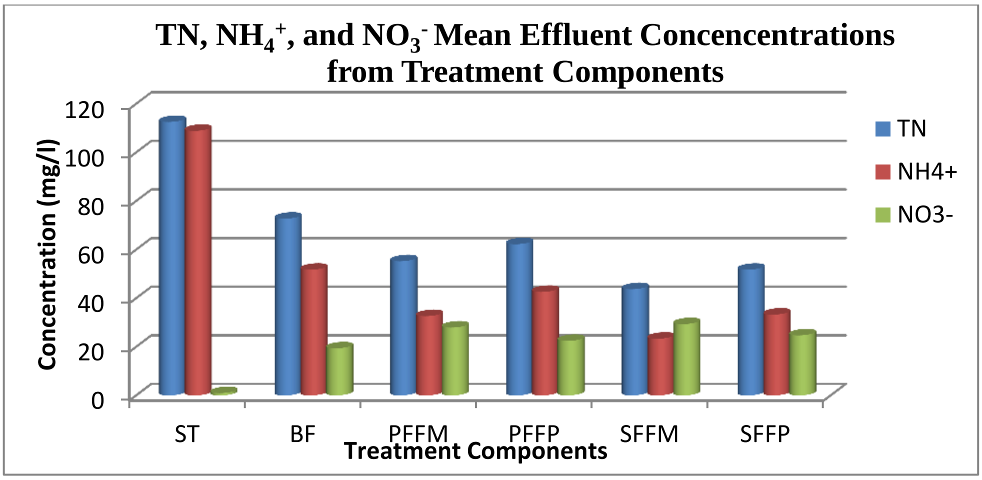


Fig. 16a: *Mean effluent concentrations (mg/l) of total nitrogen (TN), ammonium ions (NH_4^+), and nitrates (NO_3^-) from treatment units septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) during 2013-2014 study period.*

Fig. 16b shows TN concentrations during sampling dates. The mean inlet TN concentration is 112mg/l while mean final TN effluent concentrations are 43mg/l from SFFM and 51mg/l from SFFP (Table 1). The inlet TN concentrations are reduced as WW flows through the consecutive treatment components.

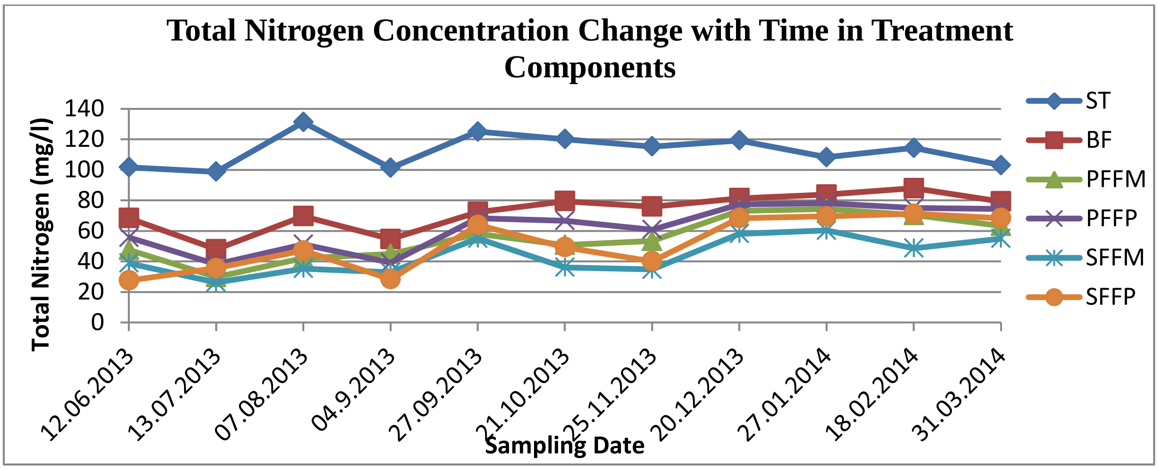


Fig. 16b: *Total nitrogen (TN) effluent concentrations (mg/l) versus time for the treatment components treatment septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) during 2013-2014 study period.*

There is tendency that PFFM has higher capacity to remove N than PFFP as seen in Fig.16b and when comparing the mean TN effluent concentrations of 55mg/l from PFFM and 62mg/l from PFFP (Table 1). However, a t-test suggests that the mean TN concentration from PFFP and PFFM are not significantly different hence both P-filters at Høyås system had the same TN removal capacities at 95% confidence level (Annex 17). The slightly lower N removal capacity in PFFP than PFFM can be due to higher WW pH in PFFP which may hinder microbial activity of nitrification and denitrification (Adam et al., 2007b). The nitrifying bacteria function best at pH range 7.5-8 and pH increase or decrease beyond this pH range slows down nitrification process (Henze et al., 2008). The high pH in PFFP may enhance volatization of NH_3 because at pH>9.6 N is in form of NH_3 (USEPA, 2010; Weiner, 2000).

Regarding NH_4^+, the mean inlet concentration is 109mg/l (Table 1) that is approximately 97% of mean inlet TN concentration. The final effluent has NH_4^+ concentration of 23mg/l and 33mg/l from SFFM and SFFP respectively (Table 1). The inlet NH_4^+ concentrations are reduced as WW flows through consecutive treatment components (Fig. 16c). This is majorly in BF as seen in the curve shift from ST to BF curve. Due to aerobic conditions, nitrification mainly occurs in BF. Ion exchange may occur in filter media such that filter medium may retain NH_4^+ in ion exchange sites and release for instance Mg^{2+} to WW (Schwartz and Zhang, 2003).

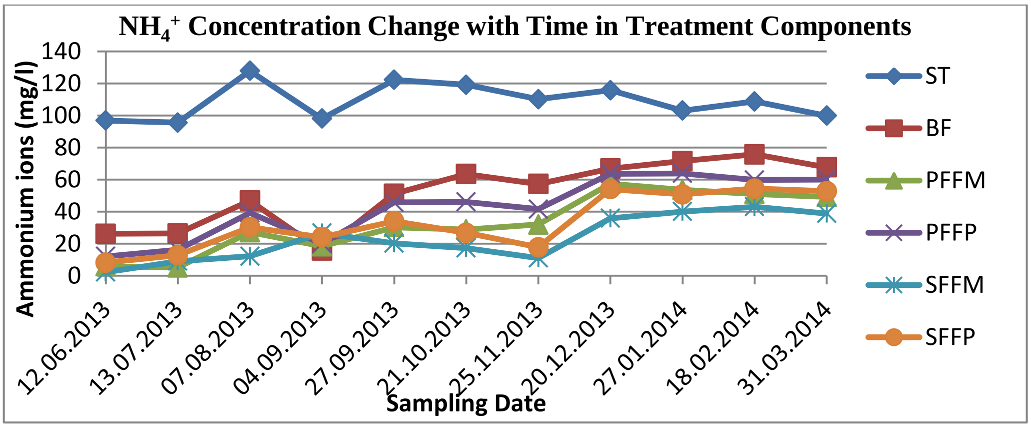


Fig. 16c: *Ammonium ions (NH_4^+) effluent concentrations (mg/l) versus time for the treatment components septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) during 2013-2014 study period.*

According to Fig. 16c, NH_4^+ effluent curves have a tendency of increasing gradually from November 2013 suggesting increasing NH_4^+ effluent concentrations from treatment units. This may indicate reduced nitrification and adsorption rates probably due to decreasing temperatures as from November 2013 throughout until March 2014 (Annex 10). This decreasing temperature effect may also be seen in NO_3^- effluent concentrations (Fig. 16d).

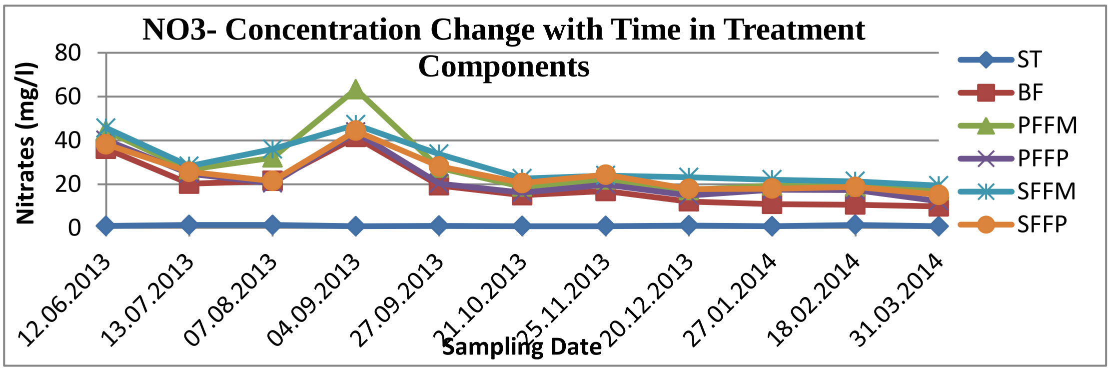


Fig. 16d: *Nitrates (NO_3^-) effluent concentrations (mg/l) versus time for the treatment components septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) during 2013-2014 study period.*

Mean inlet NO_3^- concentration measured as STE is 0.99mg/l and final discharge is 29mg/l in SFFM and 25mg/l in SFFP (Table 1). Inlet NO_3^- concentrations varied with sampling dates with concentration range of 0.7mg/l – 1.4mg/l (Annex 01). The inlet concentrations increase in the consecutive treatment components because of nitrification process (equation 9) especially in BF which is the component responsible for most of the nitrification (Jenssen et al., 2006). NO_3^- effluent concentration curves in Fig. 16d have a decreasing trend as from November. This may be due to decreasing temperature from autumn throughout winter season (Annex 09 and Annex 10) hence low activity of microorganisms.

4.5 BOD Removal

BOD is reduced in the treatment system through biodegradation of OM (Hach et al., 1997).With an average inlet BOD concentration of 254mg/l, final effluent concentration is 3.8mg/l in SFFM and 3mg/l in SFFP (Table 1), shows that the Høyås treatment system has a high BOD removal capacity. Final effluent concentrations are lower than the discharge limit of 20mg/l (NKF and NORVAR, 2001). The main BOD reduction occurs through the BF because the BF has suitable conditions for microorganisms to decompose OM (Jenssen et al., 2006). BF concentrations are further reduced to lower concencentrations in the consecutive treatment components as shown in Fig. 17a.

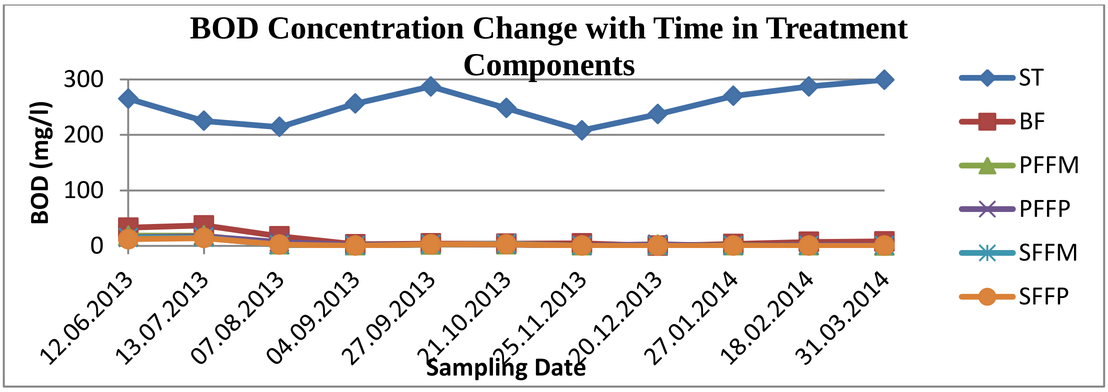


Fig. 17a: *Biochemical oxygen demand* **(***BOD) effluent concentrations (mg/l) versus time for the treatment components septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) during 2013-2014 study period.*

Replacing the insulating tree bark in treatment components BF, SFFM, and SFFP influences the BOD concentrations. Effluent concentrations were higher in BF and in the consecutive treatment components in period before replacing tree bark. This is because tree bark is organic and its decay leach of organic substances and increase BOD concentration (Dalahmeh, 2013).The BOD effluent concentrations have a decreasing trend from September onwards after replacing tree bark in August (Fig. 17b).

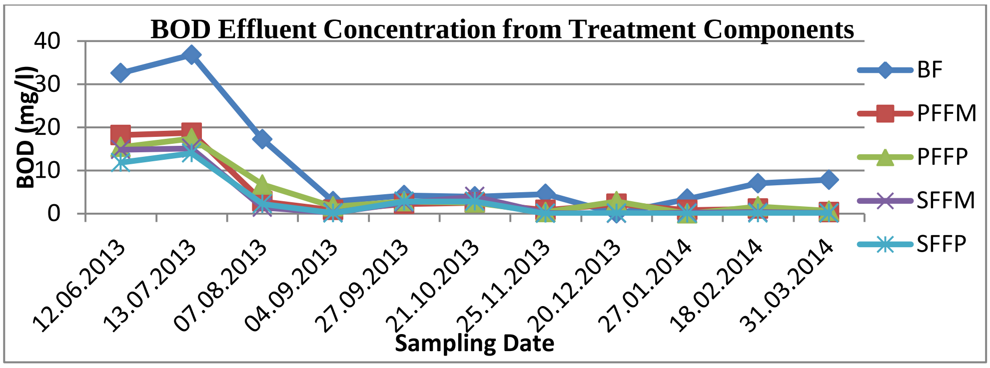


Fig. 17b: *Biochemical oxygen demand (BOD) effluent concentration(mg/l) trends for biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP)treatment components during 2013-2014 study period.*

BFE concentration has a tendency of increasing gradually from December. The increase can be due to decreasing temperatures that cause low microbial activity in degrading OM (Jenssen et al., 2006). The temperatures started to reduce from November 2013 (Annex 10). To improve BOD removal during cold seasons, WW in the BF can be treated twice within the BF. The WW effluent from the last dome in the BF can be recycled back to the first dome and retreated before discharged to the pumping chamber (P.D. Jenssen, personal communication, 23rd April 2014).

The BOD inlet concentrations were relatively high in the previous study than in this study (Fig.17c).

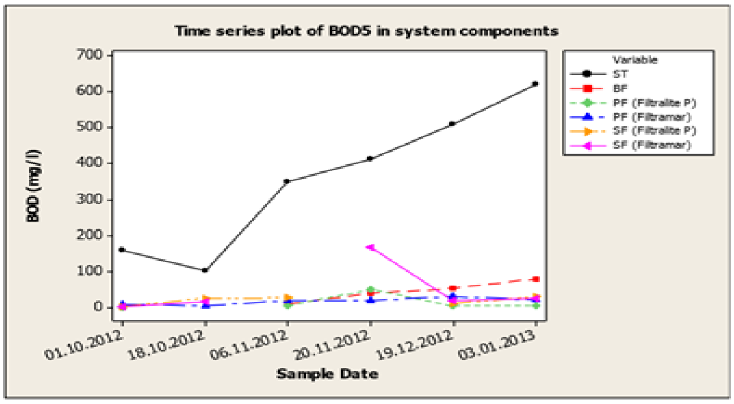


Fig. 17c: *Biochemical oxygen demand (BOD) effluent concentrations (mg/l) versus time from treatment components septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PF(Filtramar)), phosphorus filter Filtralite® P (PF(Filtralite P)), sand filter Filtramar® (SF(Filtramar)), and sand filter Filtralite® P (SF(Filtralite P)) during 2012-2013 study period* (Ganesh and Nabelsi, 2012).

The mean inlet BOD in the previous study was 357.7mg/l and the mean concentration in the final discharge was 45mg/l from SFFM and 24mg/l from SFFP. The mean BOD concentrations were lower in the P-filters than in the sand filters. The mean BOD effluent concentration from PFFM was 19mg/l and 13mg/l from PFFP (Table 2) (Ganesh and Nabelsi, 2012). The increase in BOD concentrations in the previous study can be due to leaching of organic substances from insulating tree bark.

Using tree bark for WW treatment and as insulating medium in onsite filter bed systems is common practice (Dalahmeh, 2013). However, there are needs to study the effect of organic substances that leach from tree bark into filterbed systems. Understanding the effects may help explain reduced BOD and P removal capacities with time in SSWWTSs.

4.6 Conductivity Change

The mean inlet conductivity level measured as STE is 1470µS/cm and final effluent from SFFM is 975µS/cm while from SFFP is 1113µS/cm (Table 1). The inlet conductivity levels decrease as WW flows from ST through the consecutive treatment components except in PFFP effluent that has higher conductivity than preceding effluent from BF (Fig. 18a).

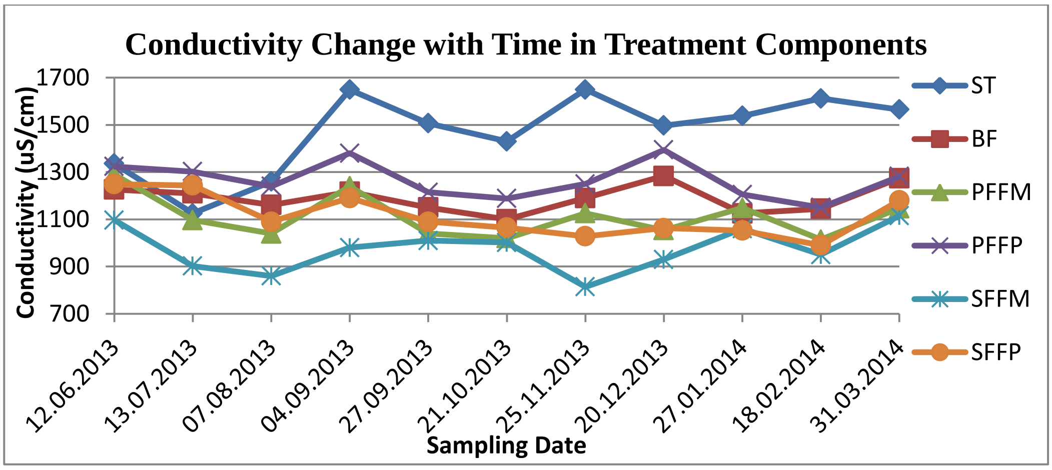


Fig. 18a: *Conductivity effluent levels (µS/cm) versus time for the treatment components septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P (SFFP) during 2013-2014 study period.*

Similar conductivity trends were observed in previous study where inlet conductivity levels reduced in consecutive treatment components except for PFFP (Fig. 18b) (Ganesh and Nabelsi, 2012).

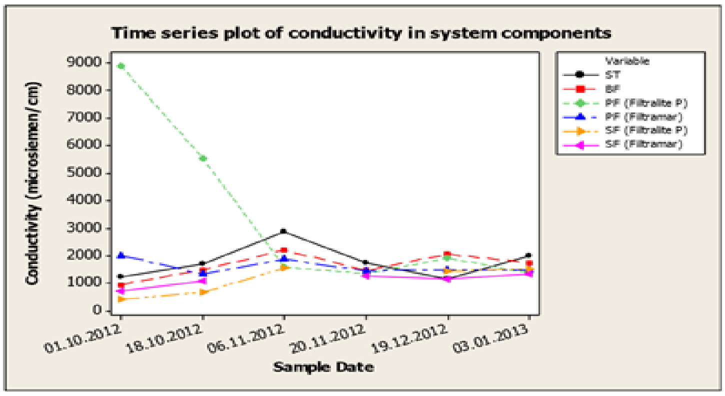


Fig. 18b: *Conductivity effluent levels (µS/cm) versus time for the treatment components septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PF(Filtramar)), phosphorus filter Filtralite® P (PF(Filtralite P)), sand filter Filtramar® (SF(Filtramar)), and sand filter Filtralite® P (SF(Filtralite P)) as per 2012-2013 study period* (Ganesh and Nabelsi, 2012).

The conductivity increase in PFFP effluent is due to increase in Ca leached from PFFP medium. The Ca leaching was also indicated by gradual increase in white deposits witnessed in PFFP outlet pipe throughout this current study period. The deposits indicate $CaCO_3$ precipitates forming after Ca leached from PFFP reacts with CO_2 in WW (Equation 13).

$$Ca(OH)_2 + CO_2 \xrightarrow{\qquad} CaCO_3 + H_2O \qquad \textit{Equation 13.}$$

A study by Adam et al. (2005) discovered that PFFP medium has high P-sorption capacity even after large amount of Ca leakage. The Ca leakage from PFFP increases WW pH in this treatment component as included in the next results.

4.7 pH Change

The mean inlet pH measured at STE is 8.1 and the final effluent has mean pH8.2 from SFFM and pH8.5 from SFFP effluent (Table 1). The mean pH levels from both sand filters are within accepted pH range 6.5-8.5 suitable for organisms in the environment (USEPA, 1997). Fig. 19a shows pH changes in treatment components with sampling dates. The inlet WW pH from STE drops as WW flows through the BF then increases as WW flows through the P-filters and in turn reduces as WW flows through the sand filters (Fig. 19a). The drop in pH in the BF is because of nitrification process in the BF which produces acidic conditions that reduces pH (Kemira, 2003). The pH increases as WW flows from BF to P-filters because the filter medium pH influences WW pH as WW flows through the P-filter media.

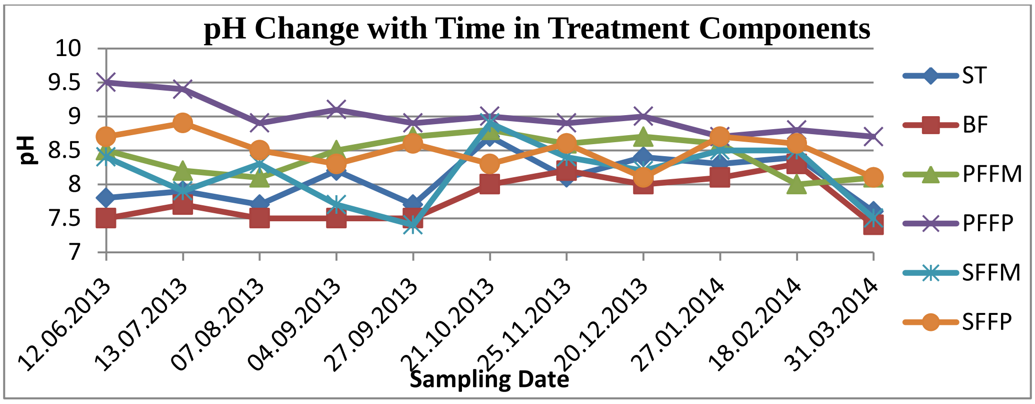


Fig. 19a: *pH effluent levels versus time for the treatment components septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP), sand filter Filtramar® (SFFM), and sand filter Filtralite® P as per 2013-2014 study period.*

The PFFP effluent curve shows higher pH than the PFFM effluent curve (Fig. 19a). This is because of Ca leaching in PFFP which increases pH (Adam et al., 2007a). The WW pH from PFFP was higher in the previous study than in the present study (Fig.19b). This implies that PFFP leached more Ca in previous study than in current study. The high pH in P-filters is reduced to suitable discharge pH range as WW flows through the sand filters. SFFP and SFFM reduce high pH level from PFFP and PFFM respectively (Fig. 19a).

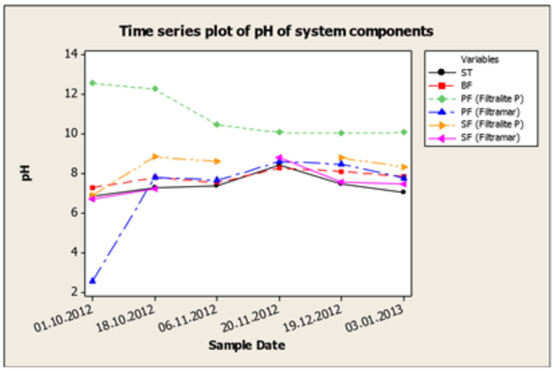


Fig. 19b: *pH effluent levels versus time for the treatment components septic tank (ST), biofilter (BF), phosphorus filter Filtramar® (PF(Filtramar)), phosphorus filter Filtralite® P (PF(Filtralite P)), sand filter Filtramar® (SF(Filtramar)), and sand filter Filtralite® P (SF(Filtralite P))during 2012-2013 study period* (Ganesh and Nabelsi, 2012).

The higher pH in PFFP medium causes precipitation of $Mg(OH)_2$ (equation 5) hence more P-sorption in PFFP than in PFFM treatment component (Adam et al., 2007a). The high pH in PFFP also influences *E. coli* removal as provided next.

4.2.6 Hygiene

Table 3 shows results from the one-time sampling and analysis for hygiene parameters TCB and *E. coli*.

Table 3: Total Coliform bacteria and *E. coli* Effluent Concentrations from Treatment Components at Høyås SSWWTS

Sampling and Analysis Date: 10.03.2014		
	Hygiene Parameters	
Treatment Components	*E. coli* (MPN/100ml)	Total Coliform Bacteria (MPN/100ml)
BF	>24196	>24196
PFFM	137.6	>24196
PFFP	59.4	>24196
SFFM	31.3	1119.9
SFFP	13	727

Table 3 shows that all treatment components at Høyås contained both *E. coli* and TCB. TCB concentration remains above >24196MPN/100ml until the sandfilter. Presence of TCB in the Høyås system is not significantly important because it is difficult to tell what proportion comes from human excreta. This is because TCB concentration represents a collection of different kinds of bacteria with no specificity of origin. The TCB concentration can include bacteria from human excreta, animal manure, soils, vegetation, etc. (USEPA, 1997). In the Høyås system the presence of *E. coli* indicate contamination specifically from human faeces since the WW at Høyås originates from black water.

The *E. coli* concentration was >24196MPN/100ml in BFE. This concentration in the BFE is reduced to 138MPN/100ml after the PFFM, 59MPN/100ml after the PFFP, 31MPN/100ml after the SFFM, and 13MPN/100ml after the SFFP. This represents 2.2log, 2.6log, 2.9log, and 3.3log reductions in PFFM, PFFP, SFFM, and SFFP respectively (annex 08). The *E. coli* concentration in the final effluent from the sand filters meets the discharge limit of <500 *E. coli*/100ml which is swimming water quality (COUNCIL DIRECTIVE, 2006). Major *E. coli* reduction occurs in the P-filter treatment components (Table 3) due to high pH in the P-filters. At high pH the surface charge of the *E. coli* becomes negative. Consequently, the *E. coli* adsorb on the positively charged surfaces of the P-filter media (Pierre, 2013; Heistad et al, 2006). PFFP removes more *E. coli* than PFFM. This can be due to higher pH in PFFP medium than in PFFM medium. Another reason might be due to smaller grains in PFFP with 0.5-4mm (annex 14) than PFFM with 0-7mm (annex 15) hence higher rate of *E. coli* entrapment in the smaller spaces between grains in the PFFP than in the PFFM grains.

5. CONCLUSION

The treatment system at Høyås is after 18 months of operation performing well and meets all treatment requirements. For BOD the discharge limit is 20mg/l and the effluent is below 4mg/l. This means a BOD removal of more than 98%. The BOD removal has improved substantially after replacing the insulating tree bark with lightweight aggregate (Leca). The bark leached organic substances to the biofilter. This resulted in the biofilter effluent having a dark yellow and/or brown colour and also affected the BOD removal negatively. After replacing the bark the effluent gradually became clearer and the BOD removal for the overall system improved.

The phosphorus sorption in the two phosphorus filters, one with Filtramar® (Shellsand) PFFM and one with Filtralite® P (PFFP) also improved after replacing the bark but the improvement was temporary and the effluent concentrations are now gradually increasing indicating that the filters are approaching saturation. Both filters now produce an effluent exceeding the discharge limit of 1mg/l. However, the sand filters succeeding the phosphorus filters reduce the concentration of total Phosphorus to below 1 mg/l and the overall removal efficiency is more than 95%. It is therefore not urgent to replace the phosphorus filter media, but regeneration (see recommendations below) or replacement should be planned. The comparison of P sorption was described by t-test that showed that PFFP has higher P sorption capacity than PFFM at 95% confidence level.

The Høyås system also removes 50-60% of the total nitrogen. The major removal is occurring in the biofilter with a slight reduction in the following treatment steps (phosphorus filters and sand filters). The number of indicator bacteria in the final effluent is 31 *E. coli/*100ml from sandfilter following the PFFM line and 13*E. Coli/100ml* from sandfilter following the PFFP line. The effluent meets the European standard for swimming water quality (500 *E. coli*/100ml) by a good margin. However, this is based on only one sample and therefore only indicates that the system has a high removal potential for bacteria.

6. RECOMMENDATIONS

To improve the performance of the phosphorus filters the following approaches can be tried before replacing the filter media:

- New spraying nozzles in the P filter units with better distribution of the effluent over the filters. This may eliminate preferential flow and utilize sorption material that potentially has been in zones of little flow, “dead zones”.
- Regeneration of P-sorption sites in the phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP) media by applying resting periods where the filters are not dosed and preferably drained.
- Improvement of P-sorption in the phosphorus filter Filtramar® (PFFM), phosphorus filter Filtralite® P (PFFP) media by applying a layer of lime on the filters. The lime itself adds reactive Ca the can sorb P additionally the lime will rise the pH of the filters and this may also affect the sorption positively.

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8. ANNEXES

ANNEX 01

SEPTIC TANK (ST)EFFLUENT CONCENTRATIONS AND LEVELS

	PARAMETERS							
SAMPLING DATE	TP (mg/l)	ORTHO-P (mg/l)	TN (mg/l)	NH4+ (mg/l)	NO3- (mg/l)	BOD (mg/l)	Cond. (µS/cm)	pH
12.06.2013	19.3	14.6	101.7	96.9	0.89	265	1336	7.8
13.07.2013	13.7	13.4	98.7	95.6	1.3	225	1125	7.9
07.08.2013	15.3	14.2	131.2	127.9	1.34	214	1260	7.7
04.09.2013	17.62	14.14	101.2	98.1	0.78	256	1649	8.2
27.09.2013	13.66	10.5	125	122.3	0.94	287	1507	7.7
21.10.2013	18.4	11.5	120.1	119.2	0.82	248	1430	8.7
25.11.2013	13.2	12.7	115.3	110.2	0.84	208	1650	8.1
20.12.2013	17.7	17.5	119.2	115.8	1.1	237	1497	8.4
27.01.2014	17.3	17.1	108.3	103.1	0.72	270	1538	8.3
18.02.2014	17.3	14.8	114.3	108.8	1.4	287	1612	8.4
31.03.2014	18.7	17.4	103	99.9	0.76	299	1565	7.6
Mean	**16.56**	**14.35**	**112.55**	**108.89**	**0.99**	**254.18**	**1470**	**8.07**
Median	**17.30**	**14.20**	**114.30**	**108.80**	**0.89**	**256.00**	**1507.00**	**8.10**
Std.Dev.	**2.20**	**2.32**	**10.78**	**11.17**	**0.25**	**30.77**	**168.24**	**0.36**
Max.	**19.30**	**17.50**	**131.20**	**127.90**	**1.40**	**299.00**	**1650.00**	**8.70**
Min.	**13.20**	**10.50**	**98.70**	**95.60**	**0.72**	**208.00**	**1125.00**	**7.60**
Range	**6.10**	**7.00**	**32.50**	**32.30**	**0.68**	**91.00**	**525.00**	**1.10**

ANNEX 02

BIOFILTER (BF) EFFLUENT CONCENTRATIONS AND LEVELS

	PARAMETERS							
SAMPLING DATE	TP (mg/l)	ORTHO-P (mg/l)	TN (mg/l)	NH4+ (mg/l)	NO3- (mg/l)	BOD (mg/l)	Cond. (µS/cm)	pH
12.06.2013	16.4	13.6	68.4	26.2	36.1	32.6	1226	7.5
13.07.2013	11.04	9.13	47.9	26.4	20.2	36.8	1210	7.7
07.08.2013	13.45	10.25	69.6	46.9	21.47	17.2	1161	7.5
04.09.2013	15.52	13.15	54.6	15.7	41.5	2.8	1217	7.5
27.09.2013	7.82	5.84	72.3	51.2	19.4	4.2	1150	7.5
21.10.2013	10	8.21	79.4	63.5	14.9	3.9	1100	8
25.11.2013	6.22	6.28	75.9	57.3	16.81	4.5	1190	8.2
20.12.2013	7.8	6.9	81.3	66.9	12.1	0	1284	8
27.01.2014	8.2	7.75	83.7	71.6	10.9	3.4	1125	8.1
18.02.2014	7.9	8.1	87.9	75.8	10.6	7	1145	8.3
31.03.2014	10.1	9.8	79.2	67.7	9.2	7.8	1274	7.4
Mean	**10.40**	**9.00**	**72.75**	**51.75**	**19.38**	**10.93**	**1189.27**	**7.79**
Median	**10.00**	**8.21**	**75.90**	**57.30**	**16.81**	**4.50**	**1190**	**7.70**
Std.Dev.	**3.38**	**2.56**	**12.22**	**20.60**	**10.52**	**12.58**	**59.25**	**0.33**
Max.	**16.40**	**13.60**	**87.90**	**75.80**	**41.50**	**36.80**	**1284**	**8.30**
Min.	**6.22**	**5.84**	**47.90**	**15.70**	**9.20**	**0.00**	**1100**	**7.40**
Range	**10.18**	**7.76**	**40.00**	**60.10**	**32.30**	**36.80**	**184**	**0.90**

ANNEX 03

PHOSPHORUS FILTER FILTERMAR® (PFFM) CONCENTRATIONS AND LEVELS

	PARAMETERS							
SAMPLING DATE	**TP**	**ORTHO-P**	**TN**	**NH4+**	**NO3-**	**BOD**	**Cond.**	**pH**
	(mg/l)	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(µS/cm)**	
12.06.2013	2.16	1.93	47.5	5.9	44.4	18.2	1290	8.5
13.07.2013	1.91	1.82	29.7	5.2	26.7	18.7	1097	8.2
07.08.2013	2.05	2.08	42.1	27.2	32.1	2.8	1040	8.1
04.09.2013	2.32	1.99	44.9	18.4	63.3	0.8	1240	8.5
27.09.2013	1.77	1.79	58.1	30.3	27.4	2.2	1040	8.7
21.10.2013	1.21	1.18	50.8	28.9	18.8	2.5	1020	8.8
25.11.2013	0.82	0.91	53.4	32	22.1	0.8	1126	8.6
20.12.2013	1.23	1.09	73.2	57.4	17.3	2.2	1054	8.7
27.01.2014	1.57	1.46	74.3	53.7	19.3	0.8	1148	8.6
18.02.2014	1.68	1.59	70.3	51.1	18.8	1.1	1014	8
31.03.2014	1.81	1.76	63.2	49.2	17.1	0.3	1147	8.1
Mean	**1.68**	**1.60**	**55.23**	**32.66**	**27.94**	**4.58**	**1111**	**8.44**
Median	**1.77**	**1.76**	**53.40**	**30.30**	**22.10**	**2.20**	**1097.00**	**8.50**
Std.Dev.	**0.45**	**0.39**	**14.14**	**18.42**	**14.31**	**6.91**	**90.99**	**0.28**
Max.	**2.32**	**2.08**	**74.30**	**57.40**	**63.30**	**18.70**	**1290.00**	**8.80**
Min.	**0.82**	**0.91**	**29.70**	**5.20**	**17.10**	**0.30**	**1014.00**	**8.00**
Range	**1.50**	**1.17**	**44.60**	**52.20**	**46.20**	**18.40**	**276.00**	**0.80**

ANNEX 04

PHOSPHORUS FILTER FILTRALITE® P (PFFP) EFFLUENT CONCENTRATIONS AND LEVELS

	PARAMETERS							
SAMPLING DATE	**TP**	**ORTHO-P**	**TN**	**NH4+**	**NO3-**	**BOD**	**Cond.**	**pH**
	(mg/l)	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(µS/cm)**	
12.06.2013	1.43	1.37	55.7	12.1	40.1	15.4	1324	9.5
13.07.2013	1.12	0.93	38.2	16.3	24.8	17.4	1302	9.4
07.08.2013	1.07	1.12	51.2	39.2	20.4	6.7	1240	8.9
04.09.2013	1.62	1.48	39.1	20.1	43.8	1.6	1380	9.1
27.09.2013	0.68	0.53	68.3	45.8	20.3	2.8	1215	8.9
21.10.2013	1.12	1.17	66.7	46.1	16.1	2.5	1188	9
25.11.2013	0.59	0.46	60.8	41.6	19.8	0.3	1250	8.9
20.12.2013	1.48	1.39	77.4	63.7	14.8	2.8	1394	9
27.01.2014	1.21	1.14	78.1	63.9	17.5	<5	1205	8.7
18.02.2014	1.39	1.42	75.1	59.8	17.3	1.6	1150	8.8
31.03.2014	1.38	1.33	74.3	60.1	12.2	0.6	1282	8.7
Mean	**1.19**	**1.12**	**62.26**	**42.61**	**22.46**	**5.17**	**1266**	**8.99**
Median	**1.21**	**1.17**	**66.70**	**45.80**	**19.80**	**2.65**	**1250.00**	**8.90**
Std.Dev.	**0.32**	**0.35**	**14.59**	**19.14**	**10.22**	**6.19**	**78.16**	**0.26**
Max.	**1.62**	**1.48**	**78.10**	**63.90**	**43.80**	**17.40**	**1394.00**	**9.50**
Min.	**0.59**	**0.46**	**38.20**	**12.10**	**12.20**	**0.30**	**1150.00**	**8.70**
Range	**1.03**	**1.02**	**39.90**	**51.80**	**31.60**	**17.10**	**244.00**	**0.80**

ANNEX 05

SANDFILTER FILTRAMAR (SFFM) EFFLUENT CONCENTRATIONS AND LEVELS

	PARAMETERS							
SAMPLING DATE	**TP**	**ORTHO-P**	**TN**	**NH4+**	**NO3-**	**BOD**	**Cond.**	**pH**
	(mg/l)	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(µS/cm)**	
12.06.2013	1.63	1.23	38.8	2.3	45.6	14.8	1097	8.4
13.07.2013	1.19	0.91	26.3	9.1	28.2	15.1	902	7.9
07.08.2013	1.4	0.93	35.3	12.2	36	1.4	860	8.3
04.09.2013	1.61	1.48	32.9	26.7	47.2	0.2	980	7.7
27.09.2013	0.52	0.54	55.1	20.3	33.7	2.5	1010	7.4
21.10.2013	0.68	0.57	36.1	17.3	22.5	3.9	1002	8.9
25.11.2013	0.43	0.41	34.7	11.1	23.9	0.1	814	8.4
20.12.2013	0.72	0.69	58.1	35.9	23.1	<5	930	8.2
27.01.2014	0.74	0.75	60.3	40.1	22	0.2	1060	8.5
18.02.2014	0.79	0.77	48.7	43.1	21.3	0	950	8.5
31.03.2014	0.74	0.71	54.9	38.9	19.3	0.1	1115	7.5
Mean	**0.95**	**0.82**	**43.75**	**23.36**	**29.35**	**3.83**	**975**	**8.15**
Median	**0.74**	**0.75**	**38.80**	**20.30**	**23.90**	**0.80**	**980.00**	**8.30**
Std.Dev.	**0.43**	**0.31**	**11.90**	**14.31**	**9.91**	**6.00**	**95.29**	**0.47**
Max.	**1.63**	**1.48**	**60.30**	**43.10**	**47.20**	**15.10**	**1115.00**	**8.90**
Min.	**0.43**	**0.41**	**26.30**	**2.30**	**19.30**	**0.00**	**814.00**	**7.40**
Range	**1.20**	**1.07**	**34.00**	**40.80**	**27.90**	**15.10**	**301.00**	**1.50**

ANNEX 06

SAND FILTER FILTRALITE P (SFFP) EFFLUENT CONCENTRATIONS AND LEVELS

	PARAMETERS							
SAMPLING DATE	**TP**	**ORTHO-P**	**TN**	**NH4+**	**NO3-**	**BOD**	**Cond.**	**pH**
	(mg/l)	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(µS/cm)**	
12.06.2013	1.05	0.97	27.5	8.2	38.2	11.8	1249	8.7
13.07.2013	0.68	0.7	35.6	12.8	25.6	14	1244	8.9
07.08.2013	0.75	0.68	47.1	30.3	21.4	2.2	1090	8.5
04.09.2013	1.18	1.02	28.3	24.1	44.4	0.1	1190	8.3
27.09.2013	0.19	0.152	63.8	34.1	28.1	2.8	1090	8.6
21.10.2013	0.49	0.51	49.3	26.8	20.5	2.8	1065	8.3
25.11.2013	0.192	0.194	40.1	17.8	24.3	0	1028	8.6
20.12.2013	0.44	0.36	68.3	54.1	17.8	0.1	1063	8.1
27.01.2014	0.58	0.59	69.5	50.8	17.9	0.2	1053	8.7
18.02.2014	0.57	0.54	71.2	54.4	18.7	0.1	990	8.6
31.03.2014	0.55	0.52	68.3	52.8	15.1	0.1	1180	8.1
Mean	**0.61**	**0.57**	**51.73**	**33.29**	**24.73**	**3.11**	**1113**	**8.49**
Median	**0.57**	**0.54**	**49.30**	**30.30**	**21.40**	**0.20**	**1090.00**	**8.60**
Std.Dev.	**0.31**	**0.28**	**17.17**	**17.30**	**9.13**	**5.00**	**88.26**	**0.26**
Max.	**1.18**	**1.02**	**71.20**	**54.40**	**44.40**	**14.00**	**1249.00**	**8.90**
Min.	**0.19**	**0.15**	**27.50**	**8.20**	**15.10**	**0.00**	**990.00**	**8.10**
Range	**0.99**	**0.87**	**43.70**	**46.20**	**29.30**	**14.00**	**259.00**	**0.80**

ANNEX 07

Contaminant Removal Efficiencies in Treatment Components (%)

	Parameters				
Treatment Components	**TP**	**Ortho-P**	**TN**	**NH4+**	**BOD**
S.T mean effluent concentration (mg/l)	16.56	14.35	112.6	108.89	254.18
BF mean effluent concentration (mg/l)	10.4	9	72.75	51.75	10.93
Removal Efficiency (%)	**37**	**37**	**35**	**52**	**96**
PFFM mean effluent concentration (mg/l)	1.68	1.6	55.23	32.66	4.58
Removal Efficiency (%)	**90**	**89**	**51**	**70**	**98**
PFFP mean effluent concentration (mg/l)	1.19	1.12	62.26	42.61	5.17
Removal Efficiency (%)	**93**	**92**	**45**	**61**	**98**
SFFM mean effluent concentration (mg/l)	0.95	0.82	43.75	23.36	3.83
Removal Efficiency (%)	**94**	**94**	**61**	**79**	**98**
SFFP mean effluent concentration (mg/l)	0.61	0.57	51.73	33.29	3.11
Removal Efficiency (%)	**96**	**96**	**54**	**69**	**99**

ANNEX 08

Hygiene Parameter Percentage and Log Reductions

Sampling and Analysis Date: 10.03.2014

	Hygiene Parameters	
	***E. coli* (MPN/100ml)**	**Total Coliform Bacteria(MPN/100ml)**
BF effluent concentration	24196	>24196
PFFM effluent concentration	137.6	>24196
Percentage and Log Reduction	**99.43 (2.24log)**	**0**
PFFP effluent concentration	59.4	>24196
Percentage and Log Reduction	**99.75 (2.6log)**	**0**
SFFM effluent concentration	31.3	1119.9
Percentage and Log Reduction	**99.87 (2.9log)**	**95.37 (1.3log)**
SFFP effluent concentration	13	727
Percentage and Log Reduction	**99.95 (3.3log)**	**97 (1.5log)**

ANNEX 09

Weather Conditions During Sampling Dates

Sampling Date	**Precipitation (mm)**	**Temperature (^{0}C)**		
		Minimum	**Maximum**	**Average**
12.06.2013	0	11.4	15.7	12.4
13.07.2013	0.3	11.6	16.9	21.6
07.08.2013	3.6	14.8	24.2	18.6
04.09.2013	0	13.6	20.8	15.9
27.09.2013	0.6	-3.4	13.6	4.4
21.10.2013	0	2	4.5	3
25.11.2013	0	-7.1	0	-4.9
20.12.2013	5.5	0.8	5.1	2.5
27.01.2014	1.7	-6.4	-2.2	-3.3
18.02.2014	0	-4.3	3.3	-1
31.03.2014	0	0.2	9.8	4.7

(Source; yr.no, 2014)

ANNEX 10

Tabular view for temperature and precipitation per month							
Months	**Temperature**				**Precipitation**		
	Average	**Normal**	**Warmest**	**Coldest**	**Total**	**Normal**	**Highest daily value**
Mar 2014	3.9°C	-0.7°C	16.3°C Mar 29	-4.0°C Mar 13	44.5 mm	48.0 mm	10.3 mm Mar 8
Feb 2014	1.7°C	-4.8°C	7.8°C Feb 17	-4.9°C Feb 1	132.3 mm	35.0 mm	28.4 mm Feb 16
Jan 2014	-2.6°C	-4.8°C	7.4°C Jan 7	-14.7°C Jan 13	84.2 mm	49.0 mm	17.5 mm Jan 3
Dec 2013	2.4°C	-3.4°C	8.9°C Dec 16	-10.9°C Dec 8	150.6 mm	53.0 mm	27.9 mm Dec 25
Nov 2013	1.8°C	0.4°C	12.8°C Nov 16	-9.3°C Nov 26	54.2 mm	79.0 mm	15.9 mm Nov 4
Oct 2013	7.0°C	6.2°C	16.8°C Oct 8	-3.9°C Oct 19	93.3 mm	100.0 mm	24.5 mm Oct 23
Sep 2013	11.1°C	10.6°C	21.9°C Sep 7	-3.4°C Sep 27	56.5 mm	90.0 mm	14.5 mm Sep 17
Aug 2013	15.5°C	14.9°C	24.2°C Aug 7	5.0°C Aug 20	57.1 mm	83.0 mm	15.5 mm Aug 17
Jul 2013	17.4°C	16.1°C	27.6°C Jul 21	7.2°C Jul 23	20.2 mm	81.0 mm	5.8 mm Jul 4
Jun 2013	14.2°C	14.8°C	22.2°C Jun 21	6.2°C Jun 7	114.4 mm	68.0 mm	33.9 mm Jun 27
May 2013	12.7°C	10.3°C	25.6°C May 18	-1.9°C May 1	116.0 mm	60.0 mm	33.9 mm May 22
Apr 2013	3.5°C	4.1°C	13.8°C Apr 30	-7.4°C Apr 1	57.9 mm	39.0 mm	11.4 mm Apr 29

(*Source; yr.no, 2014*).

ANNEX 11

Estimating Q for Høyås WW Treatment System

Daily WW Discharge (Q = L/day)

Registration Date	kWh Used Per Day	Cycles per day	Q (L/day)
17.12.2013	0.548	78.29	2348.57
08.01.2014	0.535	76.43	2292.86
14.01.2014	0.518	74.00	2220.00
21.01.2014	0.454	64.86	1945.71
06.02.2014	0.345	49.29	1478.57
11.02.2014	0.322	46.00	1380.00
04.03.2014	0.246	35.14	1054.29
18.03.2014	0.215	30.71	921.43
	Average Q		1705.18

Notes:

Pump uses 0.007kWh per run cycle (dosing)

The pump discharges 30L per cycle (dose)

Q (L/day) = # of cycles/day * 30L/cycle

# of cycles/day = Total kWh per day/0.007kWh

Weekly WW Discharge (Q = L/week)

Registration Date	kWh Used Per Week	Cycles per Week	Q (L/week)
17.12.2013	0	0	0
08.01.2014	0.218	31.1	934.29
14.01.2014	0.15	21.4	642.86
21.01.2014	3.149	449.9	13495.71
06.02.2014	2.449	349.9	10495.71
11.02.2014	2.205	315.0	9450.00
04.03.2014	1.696	242.3	7268.57
18.03.2014	1.47	210.0	6300.00
	Average Q		6941.02

Q (L/week) = # of cycles/week * 30L/cycle

# of cycles/week = Total kWh per week/0.007kWh

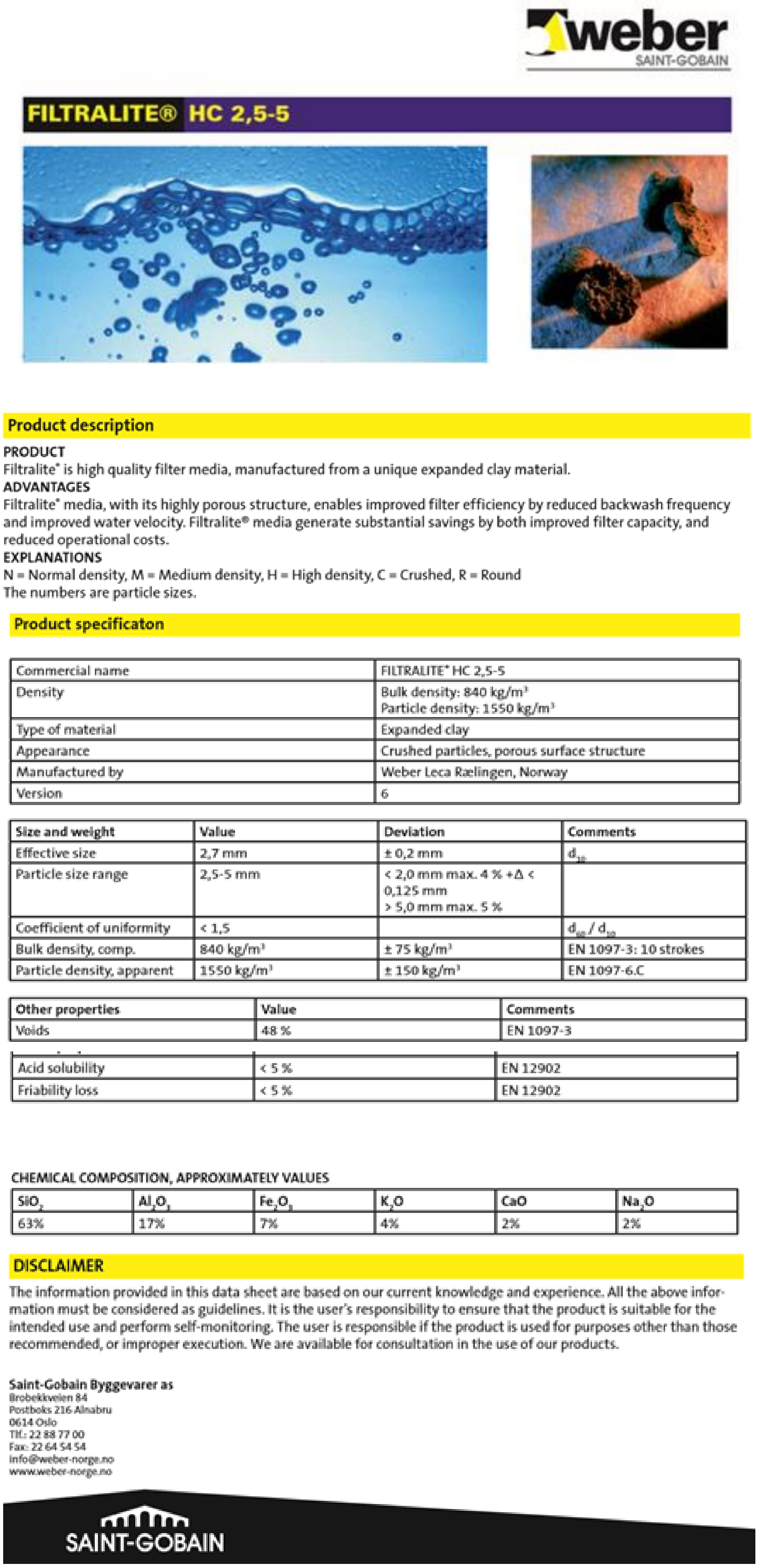
Monthly WW Discharge (Q = L/Month)

Registration Date	kWh Used per Month	Cycles per Month	Q (L/month)
17.12.2013	0	0	0
08.01.2014	0.6	85.71	2571.428571
14.01.2014	0.621	88.71	2661.428571
21.01.2014	16.26	2322.86	69685.71429
06.02.2014	11.62	1660.00	49800
11.02.2014	11.62	1660.00	49800
04.03.2014	7.754	1107.71	33231.42857
18.03.2014	7.754	1107.71	33231.42857
	Average Q		34425.91837

Q (L/month) = # of cycles/month * 30L/cycle

# of cycles/month = Total kWh per month/0.007kWh

ANNEX 12



weber
SAINT-GOBAIN

FILTRALITE® HC 2,5-5

Product description

PRODUCT
Filtralite® is high quality filter media, manufactured from a unique expanded clay material.
ADVANTAGES
Filtralite® media, with its highly porous structure, enables improved filter efficiency by reduced backwash frequency and improved water velocity. Filtralite® media generate substantial savings by both improved filter capacity, and reduced operational costs.
EXPLANATIONS
N = Normal density, M = Medium density, H = High density, C = Crushed, R = Round
The numbers are particle sizes.

Product specificaton

Commercial name	FILTRALITE® HC 2,5-5
Density	Bulk density: 840 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
Version	6

Size and weight	Value	Deviation	Comments
Effective size	2,7 mm	± 0,2 mm	d_{10}
Particle size range	2,5-5 mm	< 2,0 mm max. 4 % +Δ < 0,125 mm > 5,0 mm max. 5 %	
Coefficient of uniformity	< 1,5		d_{60} / d_{10}
Bulk density, comp.	840 kg/m^3	± 75 kg/m^3	EN 1097-3: 10 strokes
Particle density, apparent	1550 kg/m^3	± 150 kg/m^3	EN 1097-6.C

Other properties	Value	Comments
Voids	48 %	EN 1097-3
Acid solubility	< 5 %	EN 12902
Friability loss	< 5 %	EN 12902

CHEMICAL COMPOSITION, APPROXIMATELY VALUES

SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	Na_2O
63%	17%	7%	4%	2%	2%

DISCLAIMER

The information provided in this data sheet are based on our current knowledge and experience. All the above information must be considered as guidelines. It is the user's responsibility to ensure that the product is suitable for the intended use and perform self-monitoring. The user is responsible if the product is used for purposes other than those recommended, or improper execution. We are available for consultation in the use of our products.

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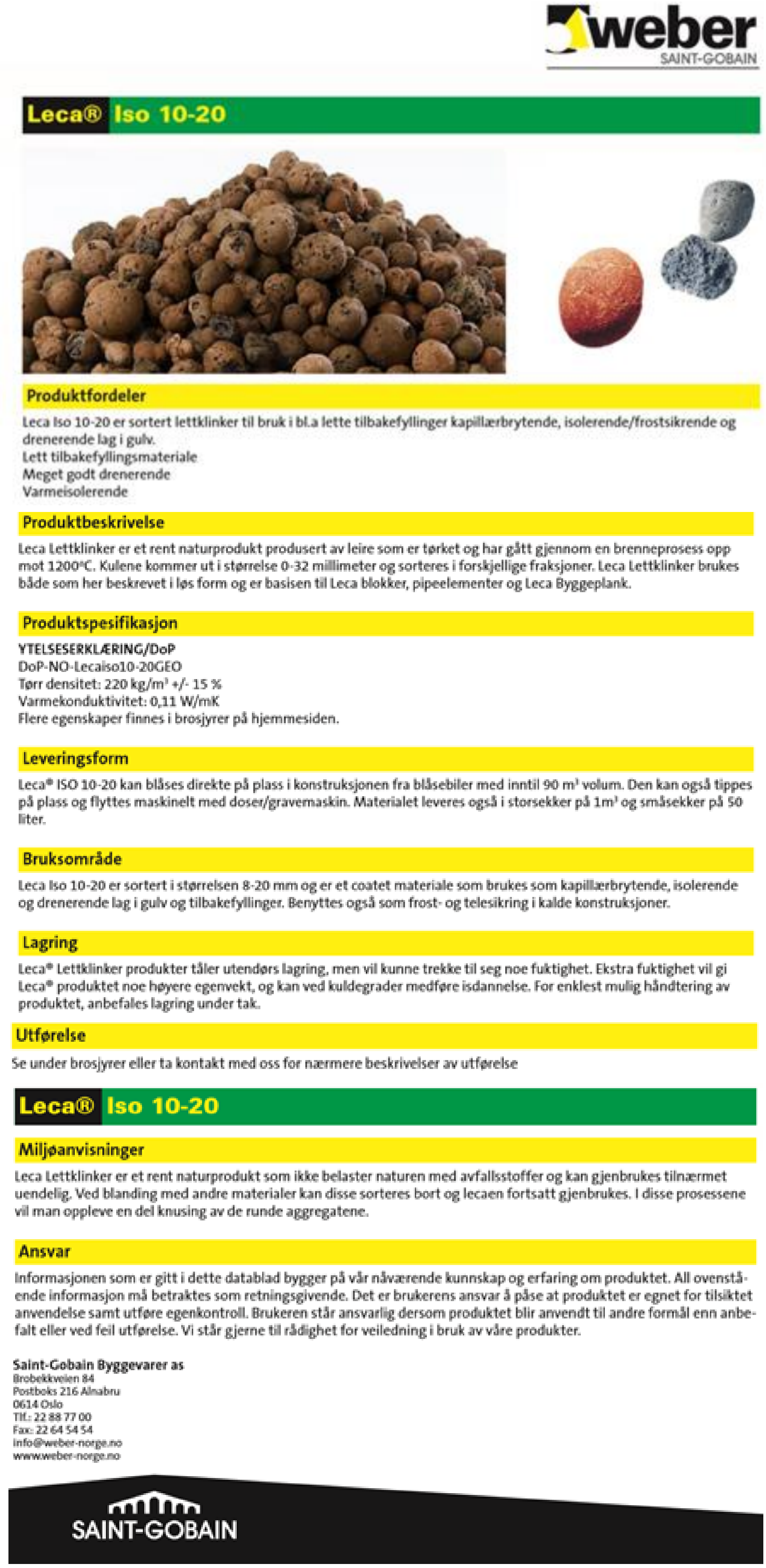
SAINT-GOBAIN

ANNEX 13



weber SAINT-GOBAIN

Leca® Iso 10-20

Produktfordeler

Leca Iso 10-20 er sortert lettklinker til bruk i bl.a lette tilbakefyllinger kapillærbrytende, isolerende/frostsikrende og drenerende lag i gulv.
Lett tilbakefyllingsmateriale
Meget godt drenerende
Varmeisolerende

Produktbeskrivelse

Leca Lettklinker er et rent naturprodukt produsert av leire som er tørket og har gått gjennom en brenneprosess opp mot 1200°C. Kulene kommer ut i størrelse 0-32 millimeter og sorteres i forskjellige fraksjoner. Leca Lettklinker brukes både som her beskrevet i løs form og er basisen til Leca blokker, pipeelementer og Leca Byggeplank.

Produktspesifikasjon

YTELSESERKLÆRING/DoP
DoP-NO-Lecaiso10-20GEO
Tørr densitet: 220 kg/m³ +/- 15 %
Varmekonduktivitet: 0,11 W/mK
Flere egenskaper finnes i brosjyrer på hjemmesiden.

Leveringsform

Leca® ISO 10-20 kan blåses direkte på plass i konstruksjonen fra blåsebiler med inntil 90 m³ volum. Den kan også tippes på plass og flyttes maskinelt med doser/gravemaskin. Materialet leveres også i storsekker på 1m³ og småsekker på 50 liter.

Bruksområde

Leca Iso 10-20 er sortert i størrelsen 8-20 mm og er et coatet materiale som brukes som kapillærbrytende, isolerende og drenerende lag i gulv og tilbakefyllinger. Benyttes også som frost- og telesikring i kalde konstruksjoner.

Lagring

Leca® Lettklinker produkter tåler utendørs lagring, men vil kunne trekke til seg noe fuktighet. Ekstra fuktighet vil gi Leca® produktet noe høyere egenvekt, og kan ved kuldegrader medføre isdannelse. For enklest mulig håndtering av produktet, anbefales lagring under tak.

Utførelse

Se under brosjyrer eller ta kontakt med oss for nærmere beskrivelser av utførelse

Leca® Iso 10-20

Miljøanvisninger

Leca Lettklinker er et rent naturprodukt som ikke belaster naturen med avfallsstoffer og kan gjenbrukes tilnærmet uendelig. Ved blanding med andre materialer kan disse sorteres bort og lecaen fortsatt gjenbrukes. I disse prosessene vil man oppleve en del knusing av de runde aggregatene.

Ansvar

Informasjonen som er gitt i dette datablad bygger på vår nåværende kunnskap og erfaring om produktet. All ovenstående informasjon må betraktes som retningsgivende. Det er brukerens ansvar å påse at produktet er egnet for tilsiktet anvendelse samt utføre egenkontroll. Brukeren står ansvarlig dersom produktet blir anvendt til andre formål enn anbefalt eller ved feil utførelse. Vi står gjerne til rådighet for veiledning i bruk av våre produkter.

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SAINT-GOBAIN

ANNEX 14

weber
SAINT-GOBAIN

FILTRALITE® P 0,5-4

Product description

PRODUCT
Filtralite® is high quality filter media, manufactured from a unique expanded clay material.
ADVANTAGES
Filtralite® media, with its highly porous structure, enables improved filter efficiency by reduced backwash frequency and improved water velocity. Filtralite® media generate substantial savings by both improved filter capacity, and reduced operational costs.
EXPLANATIONS
N = Normal density, M = Medium density, H = High density, C = Crushed, R = Round
The numbers are particle sizes.

Product specificaton

Commercial name	**FILTRALITE® P 0,5-4**
Density	Loose bulk density: 370 kg/m³
Type of material	Expanded clay
Appearance	Porous surface with white particles
Manufactured by	Weber Leca Rælingen, Norway
Version	6

Size and weight	**Value**	**Deviation**	**Comments**
Particle size range	0,5-4 mm	> 4 mm max. 10 % < 0,5 mm max. 10 %	
Bulk density, dry	370 kg/m³	± 75 kg/m³	EN 1097-3
Particle density, apparent	910 kg/m³	± 200 kg/m³	EN 1097-6.C

Other properties	**Value**	**Comments**
Voids	~ 60 %	Approximately value. EN 1097-3
pH	12	Weber Norm
Alkalinity	35 mekv/l	NS 4754

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 prefiltrated 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.

Side 1/2
2014-03-31

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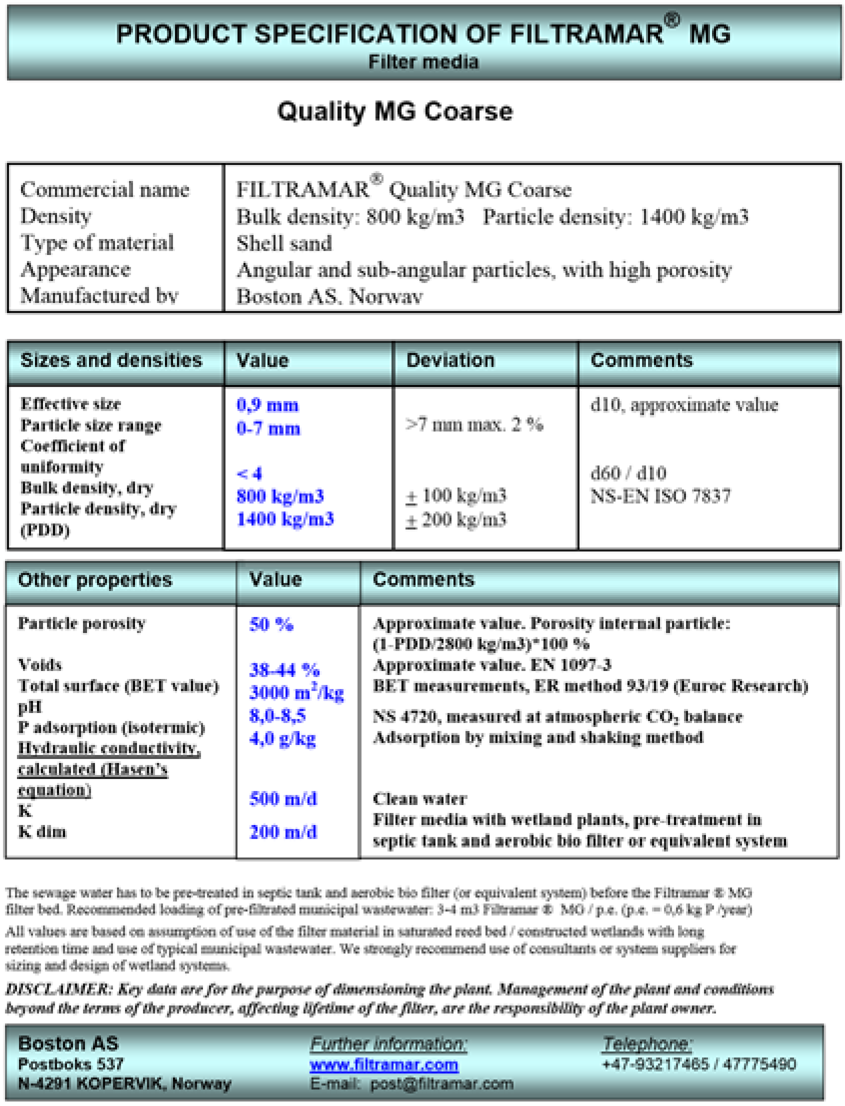
SAINT-GOBAIN

ANNEX 15



PRODUCT SPECIFICATION OF FILTRAMAR® MG
Filter media

Quality MG Coarse

Commercial name	FILTRAMAR® Quality MG Coarse
Density	Bulk density: 800 kg/m3 Particle density: 1400 kg/m3
Type of material	Shell sand
Appearance	Angular and sub-angular particles, with high porosity
Manufactured by	Boston AS, Norway

Sizes and densities	Value	Deviation	Comments
Effective size	**0,9 mm**		d10, approximate value
Particle size range	**0-7 mm**	>7 mm max. 2 %	
Coefficient of uniformity	**< 4**		d60 / d10
Bulk density, dry	**800 kg/m3**	± 100 kg/m3	NS-EN ISO 7837
Particle density, dry (PDD)	**1400 kg/m3**	± 200 kg/m3	

Other properties	Value	Comments
Particle porosity	**50 %**	**Approximate value. Porosity internal particle: (1-PDD/2800 kg/m3)*100 %**
Voids	**38-44 %**	**Approximate value. EN 1097-3**
Total surface (BET value)	**3000 m²/kg**	**BET measurements, ER method 93/19 (Euroc Research)**
pH	**8,0-8,5**	**NS 4720, measured at atmospheric CO_2 balance**
P adsorption (isotermic)	**4,0 g/kg**	**Adsorption by mixing and shaking method**
Hydraulic conductivity, calculated (Hasen's equation)		
K	**500 m/d**	**Clean water**
K dim	**200 m/d**	**Filter media with wetland plants, pre-treatment in septic tank and aerobic bio filter or equivalent system**

The sewage water has to be pre-treated in septic tank and aerobic bio filter (or equivalent system) before the Filtramar ® MG filter bed. Recommended loading of pre-filtrated municipal wastewater: 3-4 m3 Filtramar ® MG / p.e. (p.e. = 0,6 kg P /year)

All values are based on assumption of use of the filter material 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.

DISCLAIMER: Key data are for the purpose of dimensioning the plant. Management of the plant and conditions beyond the terms of the producer, affecting lifetime of the filter, are the responsibility of the plant owner.

Boston AS	*Further information:*	*Telephone:*
Postboks 537	www.filtramar.com	+47-93217465 / 47775490
N-4291 KOPERVIK, Norway	E-mail: post@filtramar.com	

ANNEX 16

Two-Sample T-Test and CI Output Results

Testing whether mean TP effluent concentrations from PFFM and PFFP are significantly different

Sample	**N**	**Mean**	**Std.Dev**	**SE Mean**
PFFM	11	1.680	0.450	0.14
PFFP	11	1.190	0.320	0.096
Difference = mu (1) - mu (2)				
Estimate for difference: 0.490				
95% CI for difference: (0.143, 0.837)				
T-Test of difference = 0 (vs not =): T-Value = 2.94 P-Value = 0.008 DF = 20				
Both use Pooled Std.Dev = 0.3904				

Two-Sample T-Test and CI

Testing whether mean Ortho-P effluent concentrations from PFFM and PFFP are significantly different

Sample	N	Mean	StDev	SE Mean
1	11	1.600	0.390	0.12
2	11	1.120	0.350	0.11
Difference = mu (1) - mu (2)				
Estimate for difference: 0.480				
95% CI for difference: (0.150, 0.810)				
T-Test of difference = 0 (vs not =): T-Value = 3.04 P-Value = 0.006 DF = 20				
Both use Pooled StDev = 0.3705				

ANNEX 17

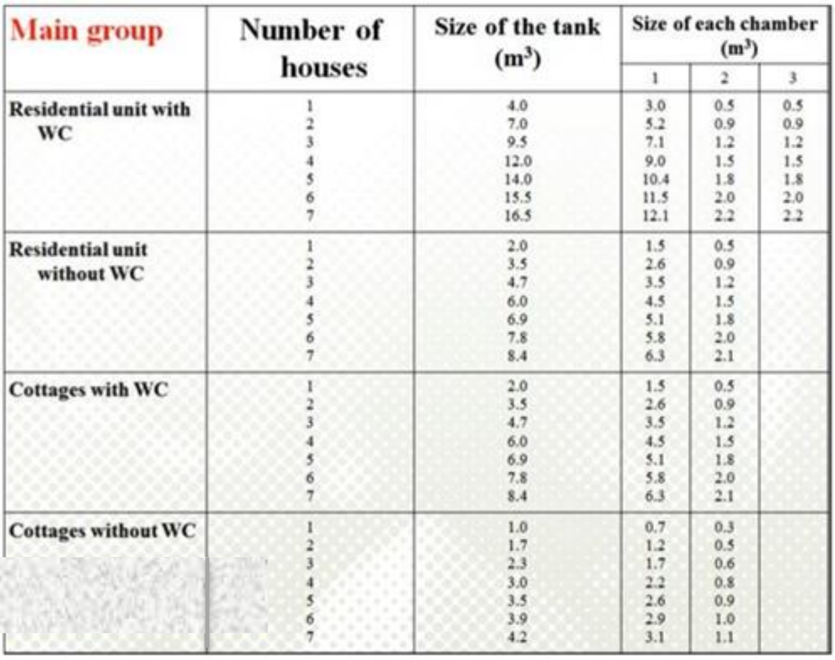
T-Test and CI Output Results for Total Nitrogen Removal from P-filters

Testing whether mean TN effluent concentrations from PFFM and PFFP are significantly different

Sample	N	Mean	StDev	SE Mean
PFFM	11	55.2	14.1	4.3
PFFP	11	62.3	14.6	4.4
Difference = mu (1) - mu (2)				
Estimate for difference: -7.03				
95% CI for difference: (-19.81, 5.75)				
T-Test of difference = 0 (vs not =): T-Value = -1.15 P-Value = 0.265 DF = 20				
Both use Pooled StDev = 14.3668				

ANNEX 18

Septic Tank Sizing in Relation to Number of Houses with/without WC



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; Jenssen et al., 2006)

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