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Potential for Treatment of Household Wastewater by Using Waste Seashells as a Biofilter Media

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Master of Science in Environment and Natural Resources - Specialization
Sustainable Water and Sanitation, Health and Development

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

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April 2018

DECLERATION

I, Yasir Nadeem hereby declare that this thesis titled;

Potential for Treatment of Household Wastewater by using Waste Seashells as a Biofilter Media

is my own research findings and investigations. This work has not been previously submitted, printed and published in any university or research institute.

Signature..............................

Date......................................

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ABSTRACT

In Norway, approximately 17% of the population is served by decentralized wastewater treatment systems. In these systems, a septic tank only is used, especially in those areas where sea is the final recipient of the treated water. In a septic tank, primary treatment takes place, which is not sufficient for removing pollutants as nutrients, organic matter and pathogens. To improve the quality of the effluent before its discharge, further treatment is required. To remove phosphorus, different kind of phosphorus sorbing materials such as Leca, Filtralite P, limestone, seashells, shell-sand *etc.* are available in the market. In Frøya Island, most single houses use a decentralized (on-site) wastewater treatment system consisting of a septic tank. Therefore, Frøya municipality is planning to update the existed wastewater treatment system on the entire island by using locally available filter materials. To reduce the investment cost, locally available material is considered used as a filter material. For this purpose three different kinds of sea-shells were investigated through a batch experiment in order to evaluate the phosphorus sorption capacity of each shell type.

Blue-shell, oyster and clam shell samples were collected in the first week of October 2017. Samples were prepared in three sizes (0-2, 2-4 and 4-8 mm) by the crushing and sieving. The batch experiment was performed in the laboratory of the soil section at NMBU. Two experimental set-ups were designed, one for blank analysis in which distilled water was used as a reactant and second for adsorption reactions in which 330 ppm phosphorous solution was used. Phosphorous contents were measured by spectrophotometer and sorbed phosphorus expressed as PO_4-P.

The results of blank analysis showed very low values. Therefore, these values were not considered while calculating the final results of adsorption reactions. The batch experiment results represented that oyster shells had maximum sorption capacity and blue shells had minimum sorption capacity such as 7100 mg/kg and 520 mg/kg respectively. Comparatively, clam shells represented more or less similar sorption capacity like oyster shells, *i.e.* 6650 mg/kg. In addition, smaller sizes (0-2 mm) of all sea-shells showed maximum whereas, larger sizes (4-8 mm) showed minimum sorption capacity. Therefore, on the base of these results, it was

concluded that oyster and blue shells have much higher potential for phosphorous removal from domestic wastewater than blue shells.

Based on the batch experiments, it was also calculated that 7.8 m^3 of filter material is required for sorbing the phosphorus for 15 years from the wastewater produced by an individual Norwegian house with 5 people. It was also calculated, based on the batch experiments, that if all the septic tank effluents in Frøya filtered by crushed oyster shells, 221 m^3 of crushed shells (2-4mm) would be needed per year to remove approximately 81% of the phosphorus. This is less than 15 truck-loads of 18m^3/truck. Although, batch experiment results are reliable but they do not mimic the situation in a full scale filter receiving wastewater and, thus, are not sufficient to predict the real sorption and service life of seashells when applied as a filter material in systems receiving domestic wastewater. Batch experiment can only be feasible when comparing the filter materials and ranking them on the base of their phosphorus sorption capacity. Therefore, to more accurately predict the sorption capacity and service life of seashell based filter materials, large scale experiments with real wastewater are required.

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LIST OF ABBREVIATIONS

Al	Aluminum
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
Fe	Iron
LECA	Light Expended Clay Aggregates
LWA	Light Weight Aggregates
m^3	Cubic meter
mg/l	Milligram per Liter
ml	Milliliter
NMBU	Norwegian University of Life Sciences
P/Kg	Phosphorous per kilogram
ppm	Parts Per Million
RPM	Round per Minute
Si	Silicon
Tot- N	Total Nitrogen
Tot- P	Total Phosphorous
TS	Total Solids
WWTS	Wastewater treatment system

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INTRODUCTION

In Norway, the mainland is covered by 44.4% of mountains, 7% of freshwater and glaciers, 38.2% of forests, 5.8% of marshes and wetlands and only 3.2% of land is used for agricultural activities and 1.4% for urbanization (Statistics Norway, 2009). In 2016, 19.27% of total Norwegian population was reported as rural and mountainous population (World Bank, 2016). In rural settlements, mostly centralized sewer network connections are neither sustainable nor cost efficient. However, in these settlements, to construct decentralized (on-site) treatment facilities is often the most efficient and sustainable method to treat domestic wastewater. Currently, around 17% inhabitants in Norway are served by decentralized wastewater treatment systems and a septic tank, only, is the most common solution, especially where the sea is the final recipient of the treated water. In septic tanks primary treatment steps take place. Septic tanks are not much efficient in purification and removing biological compounds (Paruch et al., 2011, Jenssen et al., 2006). Approximately removal efficiencies in septic tank, are; total phosphorus (Tot-P) 5-10 %, total nitrogen (Tot-N) 5-10%, organic matter (BOD_5) 20-30%, suspended solids (SS) 30-60%, floatable/settleable materials 95% and low removal of pathogens (viruses, bacteria and parasites) (Hensel et al., 2008, Jenssen et al., 2006).

In Norway, Frøya is an outermost island on the coast of Trøndelag County. It is located at the entrance of ocean west to the Trondheim Fjord. The total area of Frøya municipality is 152 km^2 (Frøya Kommune, 2017). In Frøya Island, mostly houses use decentralized wastewater treatment system (On-site). For this purpose, a septic tank is used which is made by cement or fiber glass and having varying capacity and chambers. Few houses have installed sandfilters after the septic tank, but these are very old and mostly non-functional. Houses effluent from the septic tanks is discharge directly into the sea, while some discharge into terrain. Some houses have systems that follow the wastewater discharge guidelines but mostly do not. As a result, along the bank of the sea, algal bloom and noxious smell can be seen. Besides the permanent residential houses, the island also has recreational houses (cabins). People use these houses only for short time (1-2 Months) in a year. Many of these houses have biological outdoor toilets, which are environment friendly. Very few houses rely on burning toilets. Few houses have installed holding tanks for wastewater collection. Frøya municipality is planning to update the existed wastewater treatment system on the entire island. Therefore, municipality has already started to collect information regarding the current wastewater treatment systems (WWTS) and its related issues. The municipality emphasizes; to update the existing decentralized systems *e.g.* by replacing non-functional cement based septic tanks with new fiberglass tanks. The overall purpose is to protect terrestrial and aquatic environments from pathogens and disease causing agents by improving the effluent quality. The largest fish farming industry of Norway is in Frøya. The fish farmers are concerned about having clean pathogen free water and therefore, the fish farmers are take high interest in the municipality's project. Because by improving the WWTS, fish production as well as industrial profit will be increased.

In decentralized wastewater treatment systems, different filter materials, with higher phosphorus sorption capacity are used; such as LECA (Lightweight Expended Clay Aggregate), Filtralite-P, Seashells, Shell-sand, LWA (Light Weight Aggregate) Limestone and CFH (dried ferric hydroxide granules) *etc*. (Canga et al., 2016, Vohla et al., 2011). These filter materials have varying hydro-physical properties *e.g.* grain-size distribution, bulk density, particle density, pore-size distribution and different surface area (Canga et al., 2016). Although these filter materials have high P-sorbing capacity and are commercially available but some of them are expensive. In decentralized wastewater treatment system, sea-shells might play a vital role in phosphorous removal and purification process because of high calcium content and having high absorbent capacity (Ballantine and Tanner, 2010). Different kind of seashells such as blue shells, clam shells and oyster shells are readily available at the shore of islands and usually considered as a waste. According to Frøya database, approximately 2200 tons of seashells produced annually. In Frøya, the industries also produce and process seashells. As a result huge amounts of sea-shell waste is produced by these industries. Ultimately, these sea-shell are directly dumped into the sea.

The present study is based upon different sea-shells which are abundantly available in Frøya. The phosphorus sorption capacity of the shells is estimated through a batch experiment.

1.1 Objectives

The main objectives of this research are listed below;

- To investigate the phosphorus adsorption capacity of different seashells for use in wastewater treatment system.
- To evaluate the overall potential of sea-shells as a treatment medium for domestic wastewater.
- To compare the relationship of grain size of the crushed shells to the sorption capacity for phosphorous.

1.2 Thesis Outline

This research work begins with introduction followed by research objectives and literature review with the brief introduction to wastewater, its compositions, characteristics of seashells, applications of seashells as a filter material in different countries and on-site wastewater treatment through filter material *etc*. Chapter 3 gives an overview of the study area (Frøya) and planning of up-grading of wastewater treatment in the municipality. Chapter 4 explains the sampling methods and treatment techniques used in the soil laboratory of NMBU Ås. Chapters 5 and 6 provide the detailed results and analysis with the discussions respectively. Chapter 7 gives the conclusion of this research project. Chapter 8 presents some future recommendations on base of this research work. All the quoted references are compiled in Chapter 9.

2.0 REVIEW OF LITERATURE

This chapter describes previous studies and research which have been conducted on the use sea-shells for the treatment of wastewater. Sea-shells are frequently present on the shores of sea; which are mostly considered as waste. However, many studies have been utilized these sea-shells as a bio-filter for wastewater treatment.

Literature review defines the research topic as well as provides useful information and appropriate guidelines to the researcher and reader through previous studies on same research topic (Mertens, 2010).

2.1 Definition of Wastewater

Wastewater can be defined as; A liquid waste which is discharged by domestic, commercial, agricultural and industrial sources. Wastewater often contains hazardous contaminants which may cause diseases or ultimately deaths of living organisms. On the base of its origin, wastewater can be classified as sanitary, commercial, agricultural, industrial or surface runoff. Term wastewater and sewage need to be separated from each other because many people use the term sewage referring to wastewater. Actually, sewage is a subset of wastewater which is contaminated by human urine and feces. Municipal wastewater is also refers as a sewage. Generally, wastewater consists of 95% clean water and only around 5% of contaminants (impurities) which must be removed before its discharge or re-use (Salgot et al., 2006).

2.2 Composition of Municipal Wastewater

Generally, municipal wastewater consists of a large proportion of water with a small percentage of solid wastes. These solid wastes are in the form of suspended and dissolved organic and inorganic substances (Pescod, 1992). In domestic sewage even a small amount of impurity may cause water pollution and wastewater needs to be treated before its discharge (Von Sperling and Series, 2007). Sewage contains, together with organic substances; carbohydrates, fats, lignin, synthetic detergents, soaps, proteins and their decomposed products as well as different natural and synthetic chemicals. Table 1 is showing the concentration levels (strong, medium and weak) of main constituents in domestic sewage (Pescod, 1992).

Table 1: ***The concentration of main constituents in typical domestic sewage Pescod (1992).***

Constituents	**Concentration mg/l**		
	Strong	**Medium**	**Weak**
Total Solids (TS)	1200	700	350
Suspended Solids	350	200	100
Total Dissolved Solids	850	500	250
Phosphorous (P)	20	10	6
Nitrogen (N)	85	40	20
Alkalinity ($CaCO_3$)	200	100	50
Chlorides	100	50	30
*BOD_5	300	200	100
Grease	150	100	50
COD	615	500	470

*BOD_5 is the Biochemical Oxygen Demand at 20°C over 5 days. It is a measure of the biodegradable organic matter which is present in wastewater (Pescod, 1992).

During onsite treatment systems, usually influent measurement is performed at the point of outlet of septic tank, where almost 5-10% of total nitrogen and phosphorous is removed (Skjønsberg, 2010). Table 2 is showing the typical inlet concentration of Tot-N, Tot- P, BOD, COD and Total Coliform Bacteria (TCB) for onsite wastewater treatments systems (<50 Pe) in Norway. Whereas table 3 is illustrating general view of overall amount of nitrogen, phosphorous and organic matter, produced per person per day in Norway (Yri et al., 2007).

Table 2: *The typical inlet concentrations for onsite wastewater treatment systems (<50 Pe) in Norway, measured at the point of outlet of septic tank. Table is taken from Yri et al. (2007).*

Parameters	Concentration of Effluent
Tot-N	60-78 mg/l
Tot-P	8-11 mg/l
BOD_5	200-260 mg/l
COD	470-615 mg/l
Total Coliform Bacteria (TCB)	1-20 millions/100ml

Table 3: *The average amount of Tot-N, Tot-P and organic matter produced per person per day in Norway. Sourced by Yri et al. (2007).*

Parameters	Pollution Production in g/ person/day
Tot-N	12
Tot- P	1.6
BOD_5	40
*BOD_7	46
COD	94

Conversion factor for BOD_5 / BOD_7 is equal to 1.15.

*BOD_7 is the Biochemical Oxygen Demand according to Norwegian concept (Source: Ganesh and Nabelsi, (2013)).

2.3 Filter Materials for P-Removal in Wastewater Treatment System

Filter materials which are also known as substrates, are used to remove the P from household wastewater treatment system. They can be described by the high attraction for P and appropriate hydrological characteristics (Westholm, 2006). In on-site wastewater treatment systems, different types of filter materials have been suggested as appropriate media for P-removal. The phosphorous removal capacity of filter material can be evaluated in batch experiments. Frequently, batch experiments are used as a standard for material selection (Cucarella and Renman, 2009). Filter materials can be categorized into three groups: Natural materials, manufactured materials and industrial by-products (Westholm, 2006).

Natural material includes calcium- rich compounds such as sedimentary deposits and sea-shells with high concentration of calcium carbonate. They have been illustrated the highly satisfactory results in wastewater treatment system (Brogowski and Renman, 2004).

Manufactured filter material primly consists of the LWA group which has been broadly studied by many researchers. In this group, most famous and broadly used are LECA (Light Expended Clay Aggregates) and Filtralite (Zhu et al., 1997, Johansson, 1999, Adam et al., 2007).

Industrial by-product material consists of slag materials and fly ash. It has been noticed that since the last decade, in the industrial by-product materials the greatest attention has been devoted (Mann and Bavor, 1993, Jenssen et al., 1996, Suteu et al., 2012, Xu et al., 2006). Usually, slag is a porous and non-metallic by-product which is produced in iron and steel industry (Vohla et al., 2011), whereas, fly ash is a by-product of coal combustion. Fly ash is rich in Al, Si, and Fe compounds. Therefore, it is considered the good candidate filter material for P-removal from wastewater (Ballantine and Tanner, 2010).

For P-removal from household wastewater, inert or non-reactive filter materials such as gravel and sand are considered the most appropriate filter media (Mann and Bavor, 1993, Zhu et al., 1997, Arias et al., 2001). According to (Stumm and Morgan, 1996), reactive materials are indicated as sorbents or adsorbents. Particularly, reactive materials interact with specific chemical species *e.g.* phosphate ions. Adsorption is a surface phenomenon; it can be defined as the total accumulation of molecular species (or matter) at the solid-water interface. The term sorption was explained as a constant process that ranges from adsorption to precipitation reactions (Sparks, 1995). To remove the P from wastewater, the capability of filter material depends on its chemical and physical characteristics. Usually, the shape, particle size and porosity of aggregates or grains explain the specific surface area of the filter material (Mann, 1996, Zhu et al., 1997).

2.4 On-site Wastewater Treatment through Filter Media

Zhu et al. (1997), conducted a study on the use of light-weight aggregates (LWA) as a filter media in wastewater treatment system (WWTS). In this study it was reported that, factory made light-weight aggregates can be used for significant removal of phosphorus (P) and to achieve the high hydraulic conductivity in household WWTS. Mainly, LWA are used in construction material *e.g.* building blocks; but recently they have been used in WWTS as a filter media. In 1996, Jenssen et al. stated that Norwegian-manufactured LWA such as FILTRALITE (Leca) has 95% or more P-removal efficiency in wastewater treatment wetlands for up to five years operational life. Jenssen et al. (1991), reported that P-sorption capacity of FILTRALITE (0-4 mm diameter) is up to 4.5 kg P/m^3. Zhu et al. (1997), investigated that US manufactured light-weight aggregates "UTELITE" has the highest P-sorption capacity *i.e.* 3465 mg P/kg, while the Norwegian-manufactured LWA such as FILTRALITE has the second highest P-sorption capacity *i.e.* 2210 mg P/Kg. It was concluded that the variations in P-sorption capacity is mainly dependent on the chemical properties of LWA.

The lifespan of filter media is very important. It mainly depends on hydraulic loading, adsorption characteristics of the filter material and flow pattern because these parameters directly affect the contact time. Secondly, P concentration also affects the lifespan of the substrate (Cucarella and Renman, 2009).

2.5 Use of Seashells for P-removal in Wastewater Treatment System

Seashells can be used for P-removal in wastewater treatment system due to high concentration of calcium contents. P-removal capacity has been evaluated by using green-lipped mussels, rock oyster and tuatua shells as a bio-sorbent. Results of the study illustrated that initially oyster shells had maximum P-removal capacity at lower solution strength (at 50 ppm) than other shell materials. Investigations depicted that 15% P-removal efficiency declined as the solution strength increased up to 1000 ppm. Finally, it was suggested that oyster shells might be suited for P-removal at low concentration of P (Ballantine and Tanner, 2010).

P-adsorption capacity of Oyster shells with the size ranges from 0.3-0.6 mm and greater than 0.6mm is 26 and 24.5 g P/kg likewise. This capacity was considered as twice that of alum sludge

(Park and Polprasert, 2008a)**.** This shows that oyster shells has a high potential for sorbing phosphorous. Something that also shown by (Park and Polprasert, 2008b), where they found 95% P- removal from secondary wastewater treatment system with the life span of more than one year.

P-sorption capacity in wetlands can be improved by using oyster shells as a filter media. It was suggested that if the filter material consists of only 2% oyster shells, then P-adsorption rate could be increased up to 56%. Similarly, the high percentage rate of oyster shells would yield for higher P-adsorption capacity (Seo et al., 2005).

According to Arias and Brix (2005) different types of seashells demonstrated variable results of P-adsorption rates. It was reported in 2008, that use of seashells in WWTS has no known toxicity issues and as they become saturated, they could be utilized on farm races as a fertilizer or P-rich soil amendment (Drizo et al., 2008).

2.6 Seashells and their Characteristics

Waste recycling is increasing very rapidly in the entire world. Seashells which are a renewable resource and abundantly present, are mostly considered as a waste material. From the recycling viewpoint, seashells can be used as a raw material in many applications. Normally, edible part of seashell is very small. Therefore, waste in large quantities are produced after its usage (Smith, 2012).

Seashells are mainly comprised of calcium carbonate. However, seashells that have little and light pigments such as scallop can be easily used as a calcium resource as compared to those seashells having dark and large pigments. It was reported that calcium phosphate is an important material that can be used in different applications such as adsorbent, ion exchange *etc.* This calcium phosphate can be obtained by the chemical reaction of calcium carbonate (seashells) and phosphoric acid in the availability of water (Onoda et al., 2013).

Seashells have high buffering capacity due to their natural calcium carbonate ($CaCO_3$) configuration. Besides structure, these shells have high porosity, can assist biological activities, high capacity to sustain large amount of water, high attractions for sulfur compounds *etc*. Seashell media technology can be considered as a group of biofilter and biotrickling filter technologies. To control pH in conventional trickling filters, seashells can play a vital role because they release calcareous compounds which neutralize the acidic concentration. Seashell media has been significantly used to remove the odor of H_2S from the onsite treatment systems (Smith, 2012).

2.7 Use of Seashells as a Filter Media in Different Countries

Usually, in rural areas, due to lack of proper wastewater treatment facilities, surface as well as groundwater resources are highly polluted. In many countries on-site wastewater treatment facilities are considered as the best wastewater treatment option. For this purpose, different filtering media are used for phosphorous and nitrogen removal.

Ballantine and Tanner (2010) reported that, in New Zealand for on-site wastewater treatment systems, along with other filtering media; seashells are considered as one of the most efficient filter media. Because seashells have high calcium contents therefore, they are very useful for P-removal. Based on the results, it was concluded that different seashells demonstrated different P-removal capacity and P-retention time. Moreover, it was also narrated that toxicity issue related with seashells are completely negligible.

Recently, In California a study was carried out by Abraham et al. (2015). It was reported that seashells can be used as a biofilter in wastewater treatment plants to mitigate the odors (Sulfide and fecal) and other volatiles. In this study it was concluded that predominantly odorous compounds such as dimethyl sulfide and hydrogen sulfide can effectively be removed (with greater than 99% removal efficiency) by using biofilter in wastewater treatment plants (Abraham et al., 2015).

2.8 Use of Shell-sand as a Filter Material

Shell-sand is mainly manufactured from crushed sea-shells, coral reef and snails. It is a natural calcareous material that can be used as a filter media in household wastewater treatment system (WWTS) (Ballantine and Tanner, 2010).

In 2005, a laboratory batch experiment was performed. In the experiment shell-sand was used as a filter to treat the municipal wastewater. It was investigated that the maximum P sorption capacity of shell-sand was 9.6 g/kg (Søvik and Kløve, 2005).

It was also concluded that shell-sand has P sorption capacity slightly lower than Filtralite-P, due to having high concentration of calcium in shell-sand (Adam et al., 2007). It has been estimated that approximately, one million tons of shell-sand is annually harvested on Norwegian coastline (Roseth, 2000).

3.0 SITE DESCRIPTION

In this chapter, description about study area (Frøya) is given in detail;

3.1 Frøya Island

Frøya is an outermost island on the coast of Trøndelag county, Norway. It is located at the entrance of ocean west to the Trondheim Fjord. The total area of Frøya municipality is 152 km^2. The Frøya Island itself is surrounded by more than 5400 smaller islands, islets and skerries. Currently, around 5000 people live on this island (Frøya Kommune, 2017).

On Frøya Island, the largest towns are named as Sistranda and Titran, which are located towards east and west respectively. Sistranda is the administrative centre of this island, while the other villages include Titran, Hammarvika, Sula and Mausand. Frøya is connected to neighboring municipality Hitra by Frøya Tunnel, which is under the Frøyafjorden. This tunnel is one of the world deepest tunnel (Gonorway, 2017). Frøya map image is shown in the figure 1.

3.1.1 Settlement

The settlement in Frøya is very old. After the World War II, variations in population have been noticed. In 1946 and 1990, approximately 7100 and 4245 people have been registered respectively. Whereas, due to aquaculture development, population have been steadily increasing. The flux of immigrants towards Frøya is rapidly increasing due to their connection with aquaculture. In addition to Frøya with Sistranda municipality, mostly people live in northern and southern Dyrøy, Auka, Uttian and Kvaløy. All of these regions have a bridge connection with Frøya. On the main island, the settlement has been extended along the coast with the settlement Hammarvika (425 inhabitants in 2016) and Sistranda (871 inhabitants in 2016) towards Southeast and East likewise (Great Norwegian Laxicon, 2017). On Frøya, the area between Svellingen and Flatvalsundet is densely populated as compare to the rest of the island (Gonorway, 2017).

Figure 1: *Map of Frøya municipality (Source: www.kommunekart.co)*

3.1.2 Landscape

Naturally, landscape of Frøya is open and low, treeless and mostly flat. The terrain of Frøya characteristically can be described as marshland, low lying hills and many lakes (Gonorway, 2017). Mostly bedrocks consist of granite and gneiss. There are many naked hills and small waterfalls. (Great Norwegian Laxicon, 2017). The highest point of elevation is Bremnestua, which is approximately 74 meters above the sea level. Bremnestua is located at the northwestern part of Frøya (Gonorway, 2017).

3.1.3 Industry

Fish farming is the main industry in Frøya (Gonorway, 2017).The largest fish farming community of Norway is in Frøya, where all big breeders with small actors are present. A huge number of fish farms for salmon and rainbow trout are present on this municipality (Great Norwegian Laxicon, 2017). On the island, the main sources of income for fishermen and active farmers are; fishing and livestock. Approximately 163 fresh water lakes and ponds are present in Frøya; many of them having trout (Gonorway, 2017). Frøya has one of the two largest fishery receipts in the county, and fish processing accounts for 71 percent of the industrial sites (2015).

3.2 Planning Up-gradation of Wastewater Treatment in Frøya Municipality

Frøya municipality is planning to update the existing wastewater treatment systems on the entire island. Therefore, the municipality has started to collect information regarding the current status of the WWTS. The main task for the municipality will be; to improve the centralized wastewater treatment systems in the major villages. The overall purpose of up-gradation is to protect terrestrial and aquatic reservoirs from pathogens and disease causing agents by improving the effluent quality. As mentioned above, the largest fish farming industry of Norway is in Frøya. Therefore, fish farmers are also taking high interest in the municipality's project. Because by improving the WWTS, fish production as well as industrial profit will be increased.

In this research paper, to improve the wastewater quality of Frøya, three types of sea-shell (Blue, Oyster and Clam shells) were used as a filtering media (Biofilter) and investigated their phosphorous removal efficiency.

4.0 MATERIALS AND METHODS

In this chapter, decentralized wastewater treatment system in Frøya will be introduced. Moreover, sea-shells sampling and the methods used to analyze the sea-shells as a filter material in wastewater treatment system will also be described.

4.1 Wastewater Treatment System in Frøya

Frøya rely on a wide selection of onsite wastewater treatment systems and there is no central wastewater treatment plant on the island. Frøya has both permanent residential as well as recreational houses (cabins). Some of the systems used in these houses are malfunctioning and out of date. Major proportion of houses are using septic tanks (both cement and fiberglass, as shown in figures 2 & 3) for holding the wastewater and the release it directly into the fjord or to the terrain. And some houses are even discharging the wastewater directly (as shown in fig 4). This water is rich in pathogens which is risk for the health and also the pollutants have the potential to trigger eutrophication in the shallow fjords as well as the freshwater bodies. Therefore, along the bank of the ocean; algal bloom in bulk quantity could easily be seen as shown in fig 5 and noxious smell can be noticed.

Figure 2: *Fiber glass septic tank, having 4 m^3 volume and 3 chambers*

Figure 3: *Cement based septic tank with the volume of $2m^3$ and 1 chamber*

Figure 4: *Direct discharge of effluent through Pipe from septic tank into the ocean*

Figure 5: *Illustrating the algal bloom resulted from the direct discharge of the effluent.*

Sand-filters have been also installed but these are quite old and mostly non-functional[1]. Only few numbers of houses followed the wastewater discharge guidelines but mostly do not. On the Island, recreational houses are commonly present. People used them only for short time (1-2 months) in a year. Quite few houses have installed package treatment plants. Some houses have outdoor toilets, most of them are biological/pit latrine and a few are incinerating toilets. These toilets, when installed right, have a low environmental impacts. Very few houses have holding tank for blackwater and a few also have collection of all wastewater. The latter is a very expensive solution because it requires a lot of transport.

[1] Above mentioned Information about wastewater treatment system in Frøya was collected during field survey conducted by Frøya Municipality in August 2017.

4.2 Sea-shells Sampling

Three types of sea-shells (blue, oyster and clam Shells) were collected. The collection was done in the first week of October, 2017. After collection, shells were preserved in air-tight plastic bags separately and transported to NMBU soil laboratory for analysis. In the laboratory, the collected samples were washed with distilled water and dried at room-temperature for 24 hours as shown in the figure 6.

Figure 6: *Shells from Frøya. The top left are blue shells, the top right ones are oyster shells whereas the lower picture is from the clam shells.*

4.3 Preparation of Seashells Fractions

4.3.1 Apparatus

To prepare the seashells the following items were used: mortar & pestle, sieve set, cleaning brushes, permanent marker, plastic bags, safety goggles, gloves, distilled water, beaker set, funnel set, 50ml plastic test tubes, physical balance, 100ml glass bottles, pipette, burette, flasks, measuring cylinder, suspension shaker, centrifuge, spectrophotometer, potassium dihydrogen phosphate, molybdate, ascorbic acid and blue ribbon filter paper.

Note that the apparatus for all the experiments is stated here for the purpose of repetition.

4.3.2 Procedure

- The seashells have been crushed by the application of mortar and pestle.
- The crushed shells are segregated in three desired sizes of 0-2mm, 2-4mm and 4-8mm by using the sieve set and are packed in the plastic bags marked with name of shell and the size of particle grains enclosed.
- The procedure was repeated for all three types of shells investigated.
- The samples prepared are ready for the further experiments.

4.3.3 Precautions

Safety goggles and cleaning the sieve set to avoid contamination of samples.

Figure 7: *Demonstrating the adjustment of Sieves with respect to their pore sizes. The largest (4-8mm) is at top, medium (2-4mm) is in second number, the smallest (0-2mm) is in third number. On the bottom it is for the collection of smallest size shells material.*

Figure 8: *Showing 3 fractions of sieved and preserved shells with labeling (names and sizes). On the left side there are blue shells, in the middle, Oyster shells and on the right side there are clam shells. At the top there are largest sizes and bottom smallest size material.*

4.4 Experimental Setup for Phosphorous Adsorption

4.4.1 Procedure

- To analyze the phosphorous adsorption, a sample of 3 grams for 0-2 and 2-4 mm sizes whereas 5 gram for 4-8 mm size was taken in 100 ml glass bottles.
- Added 75ml and 100 ml P-solution in 3 grams and 5 grams sample bottles, respectively. The concentration of solution was 330 ppm.
- Suspension shaker was used for 24 hours.
- Filtered the solution and phosphorus content was measured by spectrophotometer as PO_4-P. Adsorbed P was measured by calculating the difference between added P and P in solution after filtration.
- The experiment comprised of two batch experimental setups. One setup was organized for blank analysis; in which each shell-sample was treated with distilled water. While, second for adsorption reactions, in which shell-samples were treated with 330 ppm Phosphorous solution of Potassium dihydrogen phosphate (KH_2PO_4). To get more reliable results, second set-up was made into 3 replications.

4.4.1 Preparation of 4 Liters Phosphorous Solution (330 ppm) for Analysis

According to Norwegian standard (NS-4725, 1984) Slide 3, Clause no. 4.8; 4 liter Phosphorous solution of 330 ppm was prepared by dissolving 5.8008 g KH_2PO_4 into 4 liter distilled water. Calculations for preparation of 330 ppm P-solution are given below;

4.4.1.1 Calculation for 330ppm P- solution in 4 Liters

First of all, for 50 ppm solution, 0.2197 g KH_2PO_4 is required (NS-4725, 1984). However, for 1 ppm solution, 0.2197 g KH_2PO_4 can be divided with 50ppm. The calculations are given below;

$$0.2197 \div 50 = 0.004394 \text{ g}$$

Therefore, to make 1 ppm P-solution; 0.004394 g KH_2PO_4 dissolved into 1 Liter distilled water.

For making 330 ppm P- Solution;

$$0.004394 \times 330 = 1.45002 \text{ g}$$

Therefore, to make 330 ppm P-solution; 1.45002 g KH_2PO_4 dissolved into 1 Liter distilled water.

For making 330 ppm P-solution in 4 Liters;

$$1.45002 \times 4 = 5.8008\text{g}$$

Therefore, to make 330 ppm P-solution in 4 L; 5.8008g KH_2PO_4 is required to dissolve into 4 liters distilled water.

4.4.2 Preparation of Experimental Setup for Blank Analysis

To evaluate the amount of phosphorous already present in the shell samples, 3:00 grams of each shell sample having sizes of 0-2mm and 2-4 mm were taken in 100 ml glass bottles separately. Whereas, 5 gram of each sample with size 4-8 mm was taken in separate 100ml glass bottles (as shown in fig. 09). The reason of taking high amount of shells of this fraction was due to its largest size. Added 75 ml distilled water with the help of measuring cylinder in each bottle that contains the shell grains with sizes of 0-2mm and 2-4mm. While 100 ml distilled water was added in the ones containing grain sizes of 4-8mm. After adding distilled-water tightened up with blue screw caps and labeled them with numerical number from 1 to 9. Number 1-3 represented blue shell, 4-6 oyster shells and 7-9 for clam shells (As given in table 4).

4.4.3 Preparation of Experimental Setup for P-adsorption Reaction

To analyze the P-adsorption of sea-shells, same procedure was applied as mentioned above for making blank analysis. The only difference was used 330 ppm P-solution instead of distilled water and made three replications for each shell sample (as shown in fig. 10).

The samples were assigned the numbers from 10 to 36. Number 10-12 represented blue shells, 13-15 oyster shells and 16-19 for clam shells. Then number 19- 27 & 28-36 are the replications of 10-18. More clear information regarding experimental set-ups, number, shell-sample name, size, weight and volume used are presented in the following table no. 4.

After assigning numbers to all bottles, fixed them in suspension shaker for 24 hours (as shown in fig. 13). The purpose for using suspension shaker was to get mixed solution (Distilled water or 330ppm P-solution and shell samples with each other properly).

Figure 9: *Glass bottles with blue screw caps having 100 ml volume. Bottles were marked from 1-9. This set-up was used as a blank analysis.*

Figure 10: *27 glass bottles with blue screw caps having 100 ml volume. Bottles were marked from 10-36. This set-up was used to analyze P-adsorption of shell-samples*

Figure 11: *Showing labeled glass-bottles, filled with shell-samples and specific amount of solution (Distilled water or 330 ppm P- solution). To get mixed them properly, bottles were fixed on suspension shaker for 24 hours.*

Table 4: *Showing detailed information regarding Blank and Phosphorous Adsorption Experimental Set-ups. Sample no.* ***1-9*** *representing Blank in which shells were treated with distilled water. Whereas from sample* ***10-36*** *representing the phosphorous adsorption experimental set-up with 3 replications. Here sample* ***10-18*** *representing one replication,* ***19-27*** *is second replication and* ***28-36*** *is third replication.*

Sample no.	Sample Name	Weight in gram	Volume of Solution in ml	Size in mm	Set-Up
1		3	75	0-2	Blank (Treated with distilled water)
2	Blue Shells	3	75	2-4	
3		5	100	4-8	
4		3	75	0-2	
5	Oyster Shells	3	75	2-4	
6		5	100	4-8	
7		3	75	0-2	
8	Clam Shells	3	75	2-4	
9		5	100	4-8	
10		3	75	0-2	Phosphorous Adsorption Experiment (Shell samples Treated with 330 ppm solution
11	Blue Shells	3	75	2-4	
12		5	100	4-8	
13		3	75	0-2	
14	Oyster Shells	3	75	2-4	
15		5	100	4-8	
16		3	75	0-2	
17	Clam Shells	3	75	2-4	
18		5	100	4-8	
19		3	75	0-2	
20	Blue Shells	3	75	2-4	
21		5	100	4-8	
22		3	75	0-2	
23	Oyster Shells	3	75	2-4	
24		5	100	4-8	
25		3	75	0-2	
26	Clam Shells	3	75	2-4	
27		5	100	4-8	
28		3	75	0-2	
29	Blue Shells	3	75	2-4	
30		5	100	4-8	
31		3	75	0-2	
32	Oyster Shells	3	75	2-4	
33		5	100	4-8	
34		3	75	0-2	
35	Clam Shells	3	75	2-4	
36		5	100	4-8	

4.5 Filtration Setup

After 24 hours suspension shaker of solution (Distilled water & 330 ppm Phosphorous), filtration was carried out. Filtration was done by using blue ribbon whatman filter paper. To carry-out this procedure; two filtration set-ups were fixed. One for blank samples while, other for P-solution samples as shown in fig. 12 & 13. To collect the filtrate, 50ml plastic test tubes were used. After collecting filtrate into tubes, tightened them up with blue cap and labeled with permanent marker. To make the filtrate more visible and free of tiny particles, all filtrate tubes were centrifuged at 4000 RPM (Round per Minute) for 30 minutes. After centrifuged, all tubes carefully placed into an iron tube-rack as shown in fig 14.

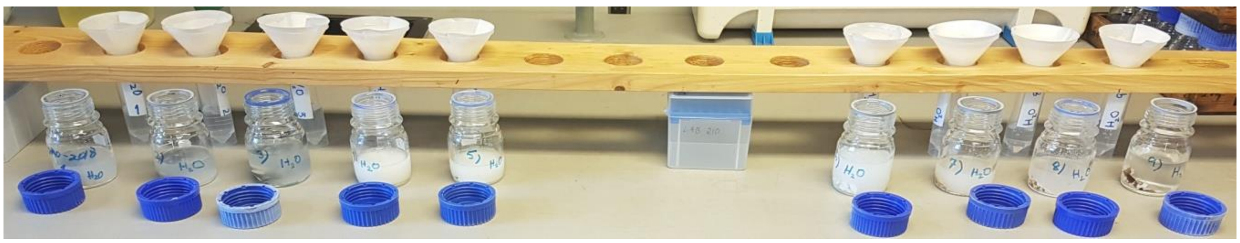


Figure 12: *Filtration procedure used in NMBU soil lab. to collect filtrate that was treated with distilled water (Blank Samples).*

Figure 13: *Filtration of 330 ppm P-solution samples.*

4.5.1 Preparation of 1000 times Dilution of Filtrate

As, P-solution concentration (330 ppm) was quite high. Therefore to get the P-adsorption results from spectrophotometer, filtrate was diluted up-to 1000 time by using distilled water. Dilution procedure is listed below;

For 10 times dilution:

1ml filtrate sample was taken one by one from sample no. 10 to 36 with the help of pipette into separate glass test tubes. Then 9 ml distilled water added in each test tubes. Tubes were labeled and shaken carefully. The solution prepared is 10 times diluted.

For 100 times dilution

1 ml solution was taken one by one from 10 times diluted sample into another glass tubes. Added 9 ml distilled water in each tube. Labeled and shaken carefully. The prepared solution is 100 times diluted.

For 1000 Times dilution

1 ml solution from 100 times diluted sample was taken one by one into another glass tubes. Added 9 ml distilled water in each tube. Labeled them and carefully shaken. The prepared solution in each tube is 1000 times diluted.

Figure 14: *Showing filtrate in test-tubes after centrifuged. Tubes are placed in iron-tube stand, labeled with marker and tightened with blue cap.*

4.5.2 Use of Catalytic Solutions

For P-adsorption analysis, two catalytic solutions were used in filtrate solutions. For this purpose ascorbic acid and molybdate solution were used. These solutions were prepared by following the Norwegian standard NS- 4725, slide 3 and clauses 4.5 and 4.6 respectively (NS-4725, 1984). The amount of catalytic solutions used in the filtrates was 0.4 ml each. After adding catalytic solutions, shaken the tubes properly and kept them undisturbed for 20 minutes. Blue color started to appear which confirmed the amount of Phosphorous in the filtrate solution.

4.6 Phosphorous adsorption Analysis through Spectrophotometer

Phosphorous adsorption was measured by using spectrophotometer at 885 nm absorption. The absorption was measured one by one and noted down. Adsorbed P was taken in mg P/kg (PO4-P). Final calculations were done by applying factor values and results were represented in pie charts and graphs. The spectrophotometer that was used to analyze the p-adsorption is shown in fig 15.

Figure 15: *Gilford Stasar II spectrophotometer used to determine the P-adsorption from filtrate solution at 885 nm absorption.*

5.0 RESULTS

This chapter presents the overall results of this research project.

5.1 Batch Experiment

The batch experiment was performed in February, 2018 at NMBU soil laboratory. After conducting the results through spectrophotometer, compiled them and presented by plotted pie-charts and graphs as given in following Figures.

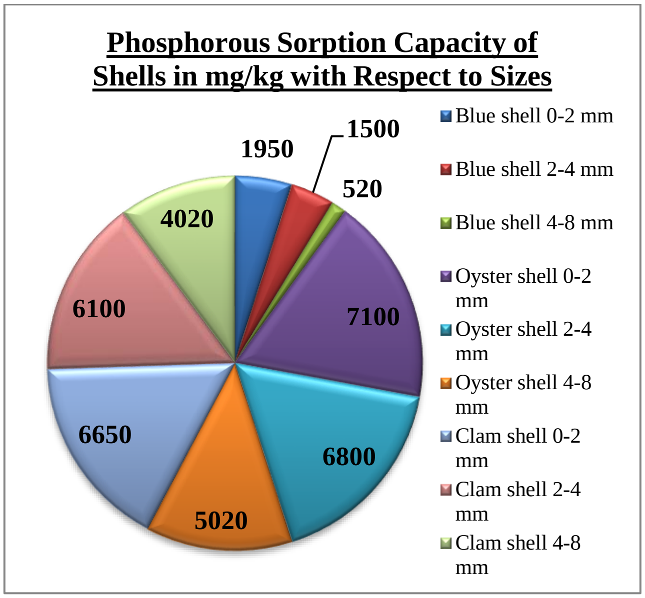


Figure 16: *Showing the entire results of P-sorption capacity of sea-shells in mg/kg. The results illustrated that Oyster shells have maximum, while Blue shells have minimum sorption capacity. Clam Shells showing medium sorption capacity but higher than blue and slightly lower than oyster shells. Moreover, smaller sizes (0-2 mm) of all sea-shells are showing maximum and larger size (4-8 mm) showing minimum sorption capacity.*

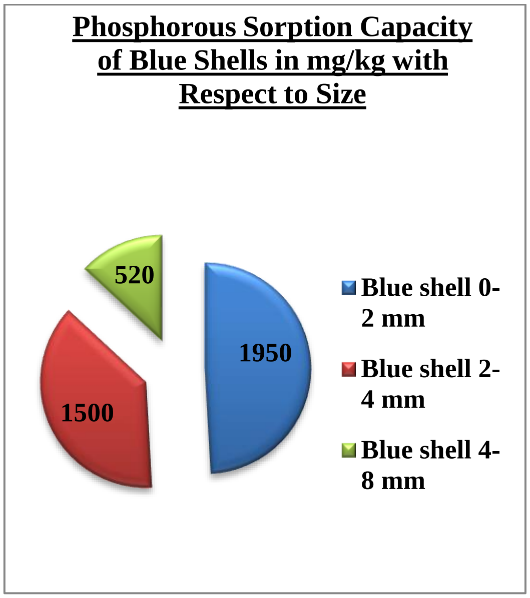
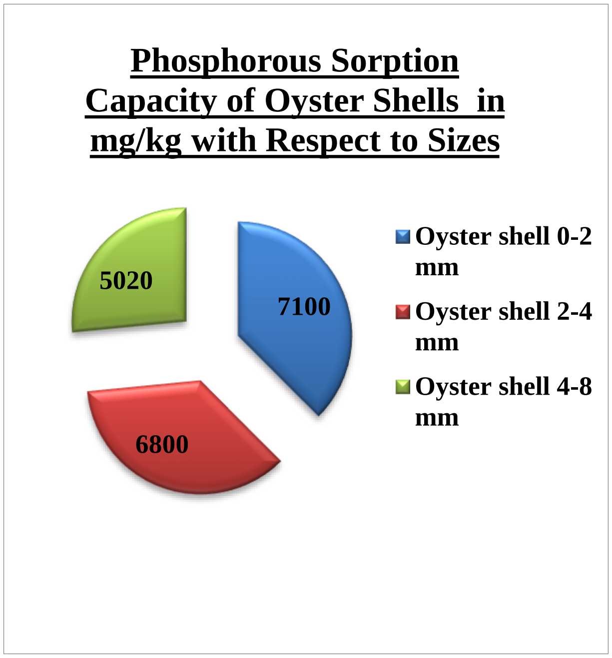


Figure 17: *Showing the P-sorption of Blue-shells in mg/kg with respect to sizes. Smallest size (0-2 mm) shells showing maximum (1959 mg/kg) while largest size (4-8 mm) showing minimum (520 mg/kg) sorption capacity. The medium size (2-4 mm) shells are in between; showing 1500 mg/kg sorption capacity.*



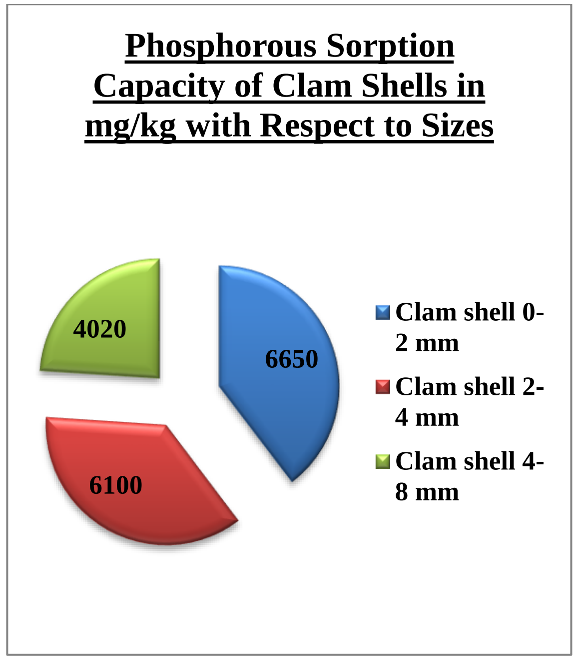


Figure 18: *Showing the P-sorption of Oyster shells in mg/kg with respect to sizes. Smallest size (0-2 mm) shells are showing maximum (7100 mg/kg) while, largest size (4-8 mm) showing minimum (5020 mg/kg) sorption capacity. Medium size (2-4 mm) shells are showing in between sorption capacity (6800 mg/kg).*

Figure 19: *Showing the P-sorption of Clam shells in mg/kg with respect to sizes. Smallest size (0-2 mm) shells are showing maximum (6650 mg/kg) and largest size (4-8 mm) showing minimum (4020 mg/kg) sorption capacity. Whereas, medium size (2-4 mm) shells are also showing medium sorption capacity.*

Note: The values from sample no. 1 to 9 were very low because they were from blank setup. Therefore, only the results from sample no. 10 to 36 were included in the calculations. The results of blank setup are presented in annex 01.

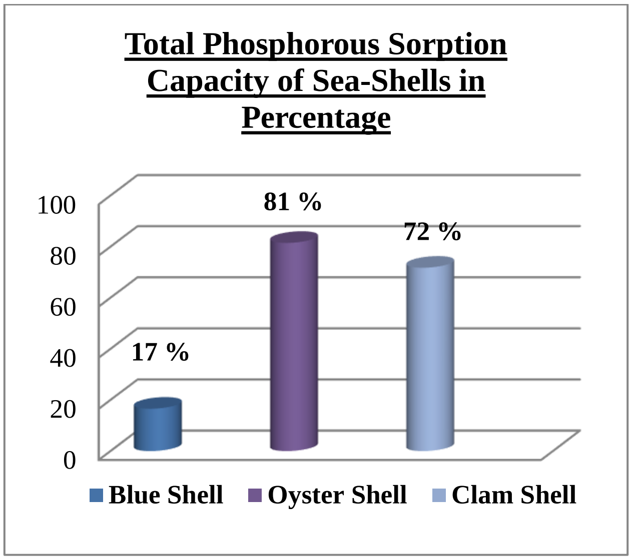


Figure 20: *Graph showing total phosphorous sorption capacity of sea-shells in percentage. Oyster shells are showing highest percentage rate (81%) and blue shells are showing lowest percentage (17%) rate of phosphorous sorption capacity. Clam shells have intermediate value of 72%.*

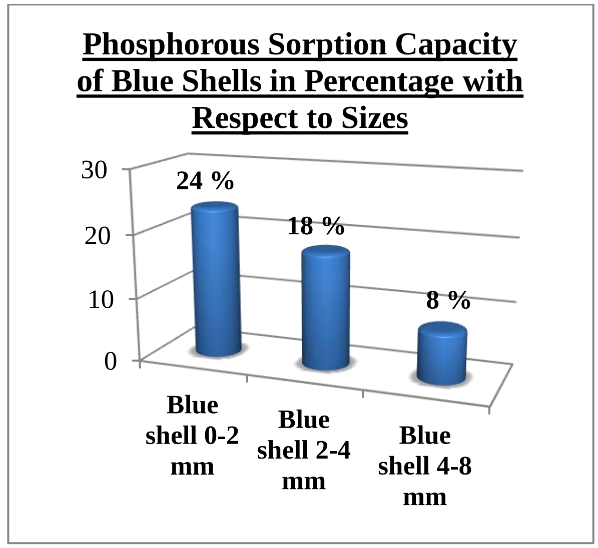


Figure 21: *Graph showing the phosphorous sorption capacity of Blue shells in percentage with respect to sizes. The smallest shell sizes (0-2mm) are showing maximum sorption capacity (24%). While the largest shell sizes (4-8mm) are showing minimum sorption capacity (8%). Medium shell-sizes (2-4 mm) are showing moderate P-sorption rate (18%).*

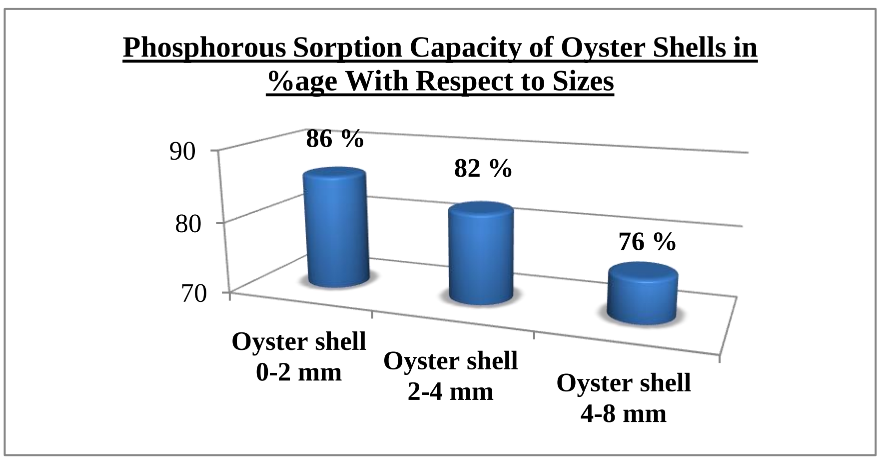


Figure 22: *Graph is illustrating the P-sorption capacity of Oyster shells in % age value with respect to 3 sizes. The small shell sizes are showing highest percentage rate (86 %) of P- sorption capacity. Whereas, the large shell sizes are showing smallest percentage rate (76 %) of P-sorption capacity. Comparatively, medium sizes are showing slightly lower percentage value (82 %) than smallest sizes of shells and quite higher than largest shells sizes.*

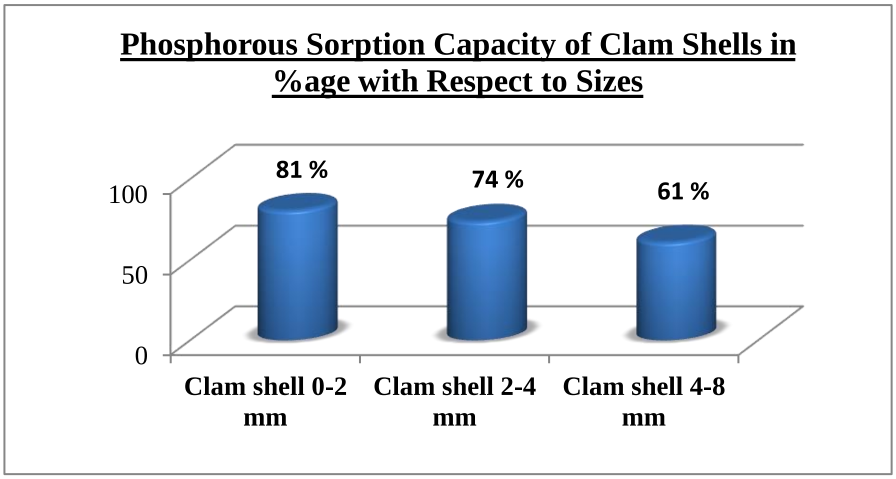


Figure 23: *P-sorption capacity of Clam shells in percentages with respect to three different sizes (0-2mm, 2-4 mm and 4-8 mm). Smaller grain sizes are showing highest percentage value (81%) of P-sorption capacity than larger sizes of shells, which are showing 61% only. Whereas medium sizes of shells are showing in between percentage rate i.e. 74 %.*

6.0 DISCUSSION

In this chapter, on the base of above presented results, significance of sea-shells in wastewater treatment system as a filter media is described.

The entire results of batch experiment are presented in the figures from 16-23 and in annex 02 and 03. The results were formulated on the basis of information in the described annexes. Results are showing the P-sorption capacity of sea-shells as well as their overall potential as a filter media to remove the phosphorous from domestic wastewater. In addition, a comparison of P-sorption capacity between shells with respect to three different sizes is also described in these figures. The results are given in mg/kg and in percentages. Detailed analysis of these figures is as follows;

In Fig. 16, the overall P-sorption capacity of sea-shells (blue, oyster and clam shells) with respect to three different sizes (0-2, 2-4 and 4-8 mm) is given in mg/kg. Generally, this figure is describing different aspects of the shell fractions under observation *e.g.* comparison between the maximum and minimum sorption capacity of these shells, P-sorption capacity of sea-shells with respect to different sizes and fluctuations in medium shells sizes for sorption capacity. The explanation of these aspects is given below;

As shown in fig 16, oyster shells are demonstrating maximum sorption capacity and blue shells are showing minimum sorption capacity such as 7100 mg/kg and 520 mg/kg respectively. Whereas, clam shells are showing more or less similar results like oyster shells, *i.e.* 6650 mg/kg. The values of sorption for oyster shells are very high when compared with the blue shells.

Blue, oyster and clam shells with particle sizes (0-2 mm) have the maximum sorption capacities of 1950 mg/kg, 7100 mg/kg and 6650 mg/kg respectively. The sorption values for the shells with the medium size grains (2-4mm) are 1500 mg/kg, 6800 mg/kg and 6100 mg/kg in that order and similarly the values for the largest shell particles (4-8mm) are 520 mg/kg, 5020 mg/kg and 4020 mg/kg correspondingly. The reason of P-sorption capacity difference between these shells is probably due to the calcium content and their morphology. Oyster and clam shells have high calcium content. Moreover, their structure is very hard and rough. While blue shells have low calcium content and structure is very soft, smooth and easily breakable. In addition, due high calcium contents in oyster and clam shells, their p-sorption capacity is almost similar. Whereas, there is a huge difference in p-sorption capacity between blue shells and oyster/clam shells. In all these shells with decreasing size, new exposure surfaces are formed due to crushing. The surfaces are rougher than the naturally existing faces of the shell. And the sorption capacity of rough surface is comparatively higher than the smooth surfaces.

Fig.17, 18 and 19 are showing P- sorption capacity of blue, oyster and clam shells in mg/kg, with respect to sizes. It can be observed that smaller the sizes of shell grains (0-2 mm), higher the sorption capacity. On the contrary, higher the shells sizes (4-8 mm), lower the sorption capacity. Detail of the sorption capacity of each shell has been written in mg/kg in the above paragraph.

Comparison is made between the sizes and sorption capacity of the shells and it has been found that with increasing grain sizes of shells, the sorption capacity is dropped as shown in the table 5. With 2 fold/times increase in size, the sorption capacity for blue, oyster and clam shells decreases by 1.3, 1.04 and 1.09 folds/times respectively. Similarly, with 4fold increase the values are decreased by 3.75, 1.41 and 1.65 folds respectively. It can be seen in the table that the sorption capacity of blue shells is more sensitive to the increase in the grain sizes as compared to the other two. Especially for 4 times increase in size, the sorption capacity is dropped dramatically by almost 4 folds/times. The difference is probably due to increase in newly formed rough surfaces in the smaller shell grains/chips. But smaller sizes can cause blockage in the filter because the small pores are occupied by the phosphorus sorbed in the system. So to avoid the clogging, the most suited size for the filter media is 2-4 or 4-6 mm.

Table 5: *Relationship between shell grain size and sorption capacity when grain sizes increase.*

Blue Shells (decrease in sorption capacity)	Oyster Shells (decrease in sorption capacity)	Clam Shells (decrease in sorption capacity)	Increase in sizes of Shell grains
1.30	1.044	1.09	**2** folds/ times
3.75	1.414	1.654	**4** folds/times

In Fig 20 total phosphorous sorption capacity of sea-shells is displayed in three bar graphs in percentages. Comparatively, oyster shells have achieved maximum percentage value of P-sorption capacity *i.e.* 81%, while clam shells are indicating slightly lower percentage value than oyster shells *i.e.* 72%. However, blue shells have achieved minimum percentage value (17%) as compared to oysters and clam shells. Therefore, according to results description, it can be concluded that oyster shells and clam shells are highly efficient to remove phosphorous from domestic wastewater as compared to blue shells.

Finally, by analyzing these results, it can be suggested that oyster shells and clam shells have great potential for phosphorous removal from domestic wastewater due to highest sorption capacity. Secondly, the smaller grain sizes (0-2mm) of these shells are more suited as a filter media in domestic wastewater treatment system. The sorption potential of blue shells is comparatively low and therefore, is not suitable candidate for the wastewater treatment units. According to Ballantine and Tanner (2010), oyster shells have good enough P-removal efficiency from wastewater with more than one year life span. Oyster shells are most suited filter media in household wastewater treatment system. Similarly Søvik and Kløve (2005) reported satisfactory results of shell-sand (prepared by sea-shells) for P-removal (9.6 g/kg) in wastewater treatment system and recommended to use shell-sand as a filter material to treat municipal wastewater. Ádám et al. (2007) defined shell sand as the naturally occurring calcium rich sand with chemical composition of 14 g Mg/kg, 300 g Ca/kg, 0.6 g Fe/kg and 0.3 g Al/kg. Filtralite-P perform better than shell sand and has more reliable P-sorption capacity (Adam et al., 2007) and in a comparison experiment in Ås, Filtralite-P seems to perform slightly better than shell-sand (Al Nabelsi and Ganesh, 2013).

Work of different authors have been studied and their experimental findings on various filter media have been presented in the table below and some of them are compared as shown in the bar graph following the table. The experimental setups for all the listed experiments are different from each other. The purpose of presenting them is to get an overview of different media in term of phosphorus removal.

Table 6: *Sorption capacity from different experimental findings.*

Material	P sorption Capacity (%)	P sorption	Authors
Filtralite P®	10, 33 and 50% for different combinations	50 mg P/l – 6 g ,10 mg P/l – 2 g & 2 mg P/l – 1 g	Ádám et al. (2007)
Filtralite P®		12000mg P/kg	Jenssen and Krogstad (2003)
Filtralite P®		476 mg P/kg	Al Nabelsi and Ganesh, 2013)
Filtralite		2210 mg P/kg	Zhu et al. (1997)
Shellsand		149 mg P/kg	(Al Nabelsi and Ganesh, 2013)
Shellsand	92%		Abraham et al., (2015)
Shellsand		9600 mg/kg	Søvik and Kløve (2005)
Oyster Shell		26000 mg P /kg	Park and Polprasert (2008a)
Oyster Shell	95%		Park and Polprasert (2008b)
Oyster Shell	81%	7100mg P/kg	This report

The results from experiments performed by different researchers using various filter materials, listed in the table, show that the oyster shell perform as better as filtralite-P. The results from the experiment performed in the current project have been also pointed towards the better sorption capacity of oyster shells as much as 81%.

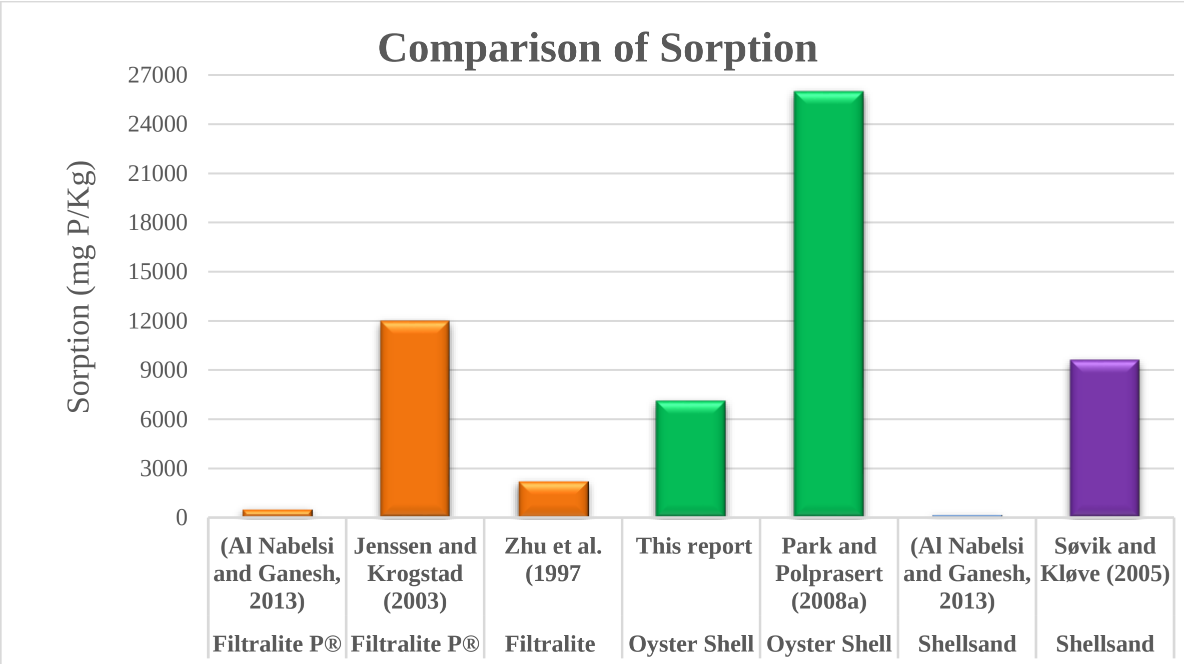


Figure 24 *Comparison of sorption capacity of three different filter materials tested by different authors. Orange color represents Filtralite P®, green is for oyster shells and purple is for shellsand. Oyster shells have comparatively better performance.*

The possible reaction of the process can be the following.

$$3CaCO_3 + 2KH_2PO_4 \longrightarrow Ca_3(PO_4)_2 + 2H_2O + 3CO_2 + K_2O$$

The products of the reaction are water in liquid form, carbon dioxide and di-potassium oxide in gaseous form and the calcium phosphate precipitates during the reaction. This precipitate produced can result in reducing the porosity of filter material by occupying the interstitial spaces between the filter material and thus ultimately clogging the filter. Considering that the P-precipitate might clog pores and, thus, reduce the hydraulic capacity of the filter, the 2-4mm fraction is probably better suited for practical use than the 0-2 mm. The 2-4 mm media also have larger pores. This is beneficial from an aeration point of view and indicates that the 2-4 mm media also would perform better in terms of reduction of organic material (often measured as BOD). In the pretreatment biofilters used in constructed wetlands normally 2-4 or 4-6 mm fractions of filter media is used and the finest fraction below 2mm is avoided (Jenssen PD personal communication).

6.1 Annual Phosphorous Discharge in Frøya from Septic Tank Effluent and after using Seashells as Filter Media

According to the database of Frøya municipality, the total phosphorus produced by wastewater discharge is approximately 2514 Kg annually (Frøya Kommune, 2017). Septic tank is the most widely applied treatment on the island. Assuming that only 5% of phosphorus is removed in a septic tank and the net phosphorus discharge is 2388 Kg, which is almost similar to the total produced phosphorus per year in the island.

By applying the experimentally proven capacity of the phosphorus removal for the oyster shells (81%), the results will look more or less like the right bar, color-coded green, on the bar chart. This is enormous removal, when compared with the septic tank effluent. The removal in case of applying the results from the clam shells (72%), is high but not as much as the oyster shells. Whereas the blue shells have poor performance (17%) as shown by the yellow bar (middle bar) on the bar graph.

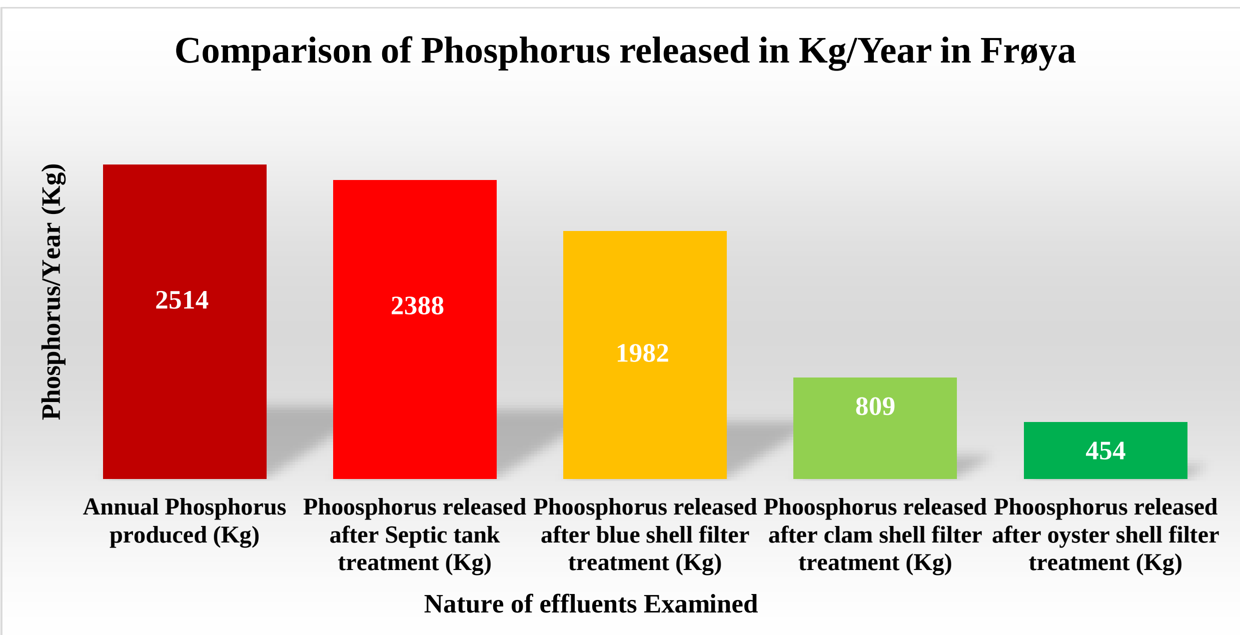


Figure 25: *Comparison between the total annual phosphorus production and the phosphorus contained in the effluents from the septic tank and applied shell filters. The difference between annual P- production and the removal from septic tank is very minor. In the case of shell filters the results are highly satisfactory in terms of phosphorous removal.*

As presented early in the result section, the performances of phosphorus removal for these shells are dependent on their morphology and composition. Blue shells are comparatively smother and have low calcite contents. So their phosphorus removal efficiency is very low as compared to the oyster/clam shells.

6.1.1 Need and Production of Filter Material in Frøya Municipality

Assume that one kilogram of oyster shell can remove 07 grams of phosphorus from wastewater, as shown in above the figure the difference of septic tank effluent and oyster shell filtered effluent is 1934 kilograms (almost 2 tons). To achieve this result the amount of filter material needed in Frøya will be 276 tons annually. Note that the production of shells in Frøya is 2200 tons per year which is far more than the required amount. It must be noticed that the shells were not applied on the wastewater. Therefore, it is necessary to perform more experiments with real wastewater generated from a household. Furthermore, the ability of filter media use as a fertilizer must be tested because it is one of major aims of wastewater treatment to recover nutrients more particularly phosphorus as it is depleting in its mineral form. Based on the proven strength of Filtralite P as a fertilizer, oyster shells are also assumed to be a good fertilizer as it contain high amount of calcium besides the sorbed phosphorus.

As described in the Norwegian guidelines for individual household that the filter should last at least 15 years (Jenssen and Krogstad, 2003). So, based on the batch experiment results, 7.8 m^3 of filter material is required for filtering the phosphorus efficiently for 15 years from the wastewater produced by an individual Norwegian house with 5 people. The calculations are presented in annex 05. Moreover, based on results, it has been calculated that if all septic tank effluents in Frøya are filtered through crushed oyster shells, 221 m^3 crushed shells would be needed per year to remove 81% of the total phosphorus produced in the entire Island. This is less than 15 truck-loads of 18m^3/truck. The calculations are presented in annex 06.

7.0 CONCLUSION

- From batch experiment results, it was found that oyster shells have maximum and blue shells have minimum sorption capacity. Whereas, clam shells showed more or less similar results like oyster shells but huge difference was noticed among clam and blue shells.
- Smaller sizes of seashells presented higher sorption capacity whereas, larger sizes showed its vice versa
- Based on the proven results, 7.8 m^3 of filter material is required for sorbing the phosphorus for 15 years from the wastewater produced by an individual Norwegian house with 5 people
- If 1 kg of oyster shells remove 7g of phosphorous, then 276 tons (15 truck-loads of $18m^3$/truck) of oyster shells are required annually to remove the phosphorous from the entire Frøya Island
- 221 m^3 crushed shells are required annually to remove 81% of total phosphorous produced in the Island

8.0 RECOMMENDATIONS

- In batch experiment 330 ppm phosphorous concentration was used which is very high. Whereas in real wastewater systems, phosphorous concentration is much lower. Therefore, relying only on batch experiment results is not sufficient.
- Application of filter material on large scale experiment with real wastewater is required
- Testing of P fertilizer properties of saturated shall material is needed.
- In Frøya municipality due to local availability of sea-shells, low transportation and investment cost is involved. Therefore a shell filter system can be cost efficient provided that the sorption capacity with real wastewater is also high.
- To increase the longevity of the system and to avoid the clogging, most suited size of filter media is 2-4 mm

9.0 REFERENCES

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ANNEXES

Annex 01

P-sorption efficiency of shells in the blank set-up.

Sample No.	Size in mm	Name of shells	ABS	Concentration (mg/L)	Dilution factor	**Results (PO4-P mg/L)**
1	0-2	**Blue Shell**	0,027	0,040	1	**0,040**
2	2-4		0,0075	0,011	1	**0,011**
3	4-8		0,014	0,020	1	**0,020**
4	0-2	**Oyster Shell**	0,015	0,021	1	**0,021**
5	2-4		0,0015	0,0024	1	**0,0024**
6	4-8		0,010	0,014	1	**0,014**
7	0-2	**Clam Shell**	0,0043	0,0064	1	**0,0064**
8	2-4		0,0010	0,0016	1	**0,0016**
9	4-8		0,0063	0,0094	1	**0,0094**

The blank set-up has very low phosphorous adsorption values. However, to avoid the confusion, these values were not considered while calculating the final results of phosphorous adsorption experimental setup.

Annex 02

Batch Experiment results of three replications in mg/l

Sample Numbers (R1,R2, R3)	Size in mm	Name of shells	Results (PO4-P mg/l) R1	Results (PO4-P mg/l) R2	Results (PO4-P mg/l) R3	Mean of R1,R2 & R3 (PO4-P mg/l)
10,19,28	0-2	Blue Shell	252	260	243	**252**
11,20,29	2-4		300	244	267	**270**
12,21,30	4-8		305	297	311	**304**
13,22,31	0-2	Oyster Shell	40	48	50	**46**
14,23,32	2-4		55	55	64	**58**
15,24,33	4-8		77	82	80	**79**
16,25,34	0-2	Clam Shell	61	65	68	**64**
17,26,35	2-4		80	94	85	**86**
18,27,36	4-8		119	145	122	**129**

The overall information about the results of phosphorous adsorption experimental setup is presented in this annexure. Here, R is representing the replication of shell samples. As three replications of each shell sample were used. So, as presented in table, sample number 10, 19 and 28 are the replication of blue shell and so on. Sample number 13, 22 and 31 are the replication of oyster shell and so on. Similarly, sample number 16, 25 and 34 are the replication of clam shells and goes on. Moreover, in this table; information is presented in mg/l which was converted into mg/kg (as presented in annex 03) by applying the factor value F.

Annex 03

Batch experiment results in mg/kg and percentage values

Sample Numbers	Weight of samples in gram	Volume of Solution Used	Size in mm	Name of shells	Mean value of P. in Filterate (PO4-P mg/L)	Mean value of P. sorbed by shells (PO4-P mg/L)	P-sorption conversion in mg/kg through multiplying with F	Mean value of P sorbed by shells (PO4-P mg/kg)	P. Sorption of shells in %age with respect to size	Total P-sorption of shells in % age
10,19,28	**3**	75	0-2	**Blue Shell**	252	78	For **3** g, F= 25	1950	24	**17**
11,20,29	**3**	75	2-4		270	60	For **3** g, F= 25	1500	18	
12,21,30	**5**	100	4-8		304	26	For **5** g, F= 20	520	8	
13,22,31	**3**	75	0-2	**Oyster Shell**	46	284	For **3** g, F= 25	7100	86	**81**
14,23,32	**3**	75	2-4		58	272	For **3** g, F= 25	6800	82	
15,24,33	**5**	100	4-8		79	251	For **5** g, F= 20	5020	76	
16,25,34	**3**	75	0-2	**Clam Shell**	64	266	For **3** g, F= 25	6650	81	**72**
17,26,35	**3**	75	2-4		86	244	For **3** g, F= 25	6100	74	
18,27,36	**5**	100	4-8		129	201	For **5** g, F= 20	4020	61	

This annexure is displaying the entire results of batch experiment. The results are showing in mg/kg and in % age values as well. To convert mg/l into mg/kg, factor F value was applied. For 3 gram shell sample F= 25 and for 5 gram F= 20 was applied. Calculations of factor F are presented in annex 04.

Annex 04

Calculations of Factor F

In this batch experiment, to convert values from mg/L into mg/kg, factor F value was required. For 3g shell sample F= 25,
And for 5 g shell-samples F= 20 was applied.

Calculations

As, Mg/kg = 1000 ÷1000

If shell sample weight is 3g and solution volume is 75 ml. Then F can be calculated by using following formula;

F for 3 g shell-sample = $1000 \div 1000 \times 75\ ml \div 3g = 25$

Similarly, if shell sample weight is 5g and solution volume is 100 ml. Then F can be calculated by following formula;

F for 5g shell-sample = $1000/1000 \times 100\ ml \div 5g = 20$

Therefore, to convert the phosphorous sorption value from PO_4-P mg/L into PO_4-P mg/Kg, for 3 and 5 gram shell samples F= 25 and F= 20 was used respectively.

Annex 05

Calculations of filter material required

Assume 1 kilogram of oyster shell can remove 07 grams of phosphorus

P- Production per person per day	= 1.6 g (Yri et al., 2007)
No. of person	= 5 (In one Norwegian family)
P- Production per year	= 2920 g/family
P- Production per 15 years	= 43800 g
Oyster shells in kg	= 43800 ÷ 7
	= 6257 kg
1 m^3	= 800 kg
Oyster shells in m^3	= 7.8

Therefore, **7.8 m^3** of filter material is required for sorbing the phosphorus for 15 years from the wastewater produced by a single Norwegian house with 5 people.

Annex 06

Calculations for the size of the filter media required

Density of Shells = 0.8 m^3

Total weight of shell required = 276 tons/year

Size of the Filter Media = 276 × 0.8 ≈ 221 m^3/year

Assume, one truck can load 18 m^3 shell weight,

Number of truck-load per year required = 221÷18 ≈ **13**

However, approximately 13 truck-load of 18m^3/truck of oyster shells are required annually to remove the phosphorous from the entire Frøya Island

Annex 07

PRODUKTSPESIFIKASJON FOR FILTRAMAR® KG
Filtermedia

Kvalitet KG Grov

Handelsnavn	FILTRAMAR® Kvalitet KG Grov
Densitet (volumvekt)	Produktdensitet: 800 kg/m3 Partikkeldensitet: 1400 kg/m3
Type material	Skjellsand
Utseende	Kantede og halvkantede partikler, med høy porøsitet
Produsent	Boston AS, Norge

Størrelser & densitet	Verdi	Avvik	Kommentarer
Effektiv part.størrelse	0,7 mm		d10, tilnærmet verdi
Kornfordelingsområde	0-7 mm	>7 mm max. 2 %	
Sorteringsgrad (sorteringstall)	< 4		d60 / d10
Produktdensitet, tørr	800 kg/m3	± 100 kg/m3	NS-EN ISO 7837
Partikkeldensitet, tørr (PDD)	1400 kg/m3	± 200 kg/m3	

Andre egenskaper	Verdi	Kommentarer
Partikkelporøsitet	50 %	Tilnærmet verdi. Porøsitet indre partikkel: (1-PDD/2800 kg/m^3)*100 %
Hulrom	38-44 %	Tilnærmet verdi. EN 1097-3
Total overflate (BET-verdi)	3000 m^2/kg	BET-målinger, ER-metode 93/19 (Euroc Research)
pH	8,0-8,5	NS 4720, målt ved atmosfærisk CO_2-balanse
P-adsorpsjon (isotermisk)	4,0 g/kg	Adsorpsjon ved blande- og ristemetode
Hydraulisk ledningsevne, kalkulert (Hasens ligning)		
K	800 m/d	Rent vann
K-dim	300 m/d	Filtermedia med våtmarksplanter, førstetrinnsbehandling i septiktank og aerobt biofilter el. tilsvarende system

Avløpsvannet må behandles i ett første trinn i septiktank og aerobt biofilter (eller tilsvarende system) før Filtramar ® KG filterseng. Anbefalt tilførsel av forfiltrert kommunalt avløpsvann: 3-4 m^3 Filtramar ® KG / p.e. (p.e. = 0,6 kg P /år)
Alle verdier er basert på forutsetningen om bruk av filtermateriale i mettet rørlagt seng / konstruert våtmark med lang oppholdstid og bruk av typisk offentlig avløpsvann. Vi anbefaler sterk bruk av rådgivere eller systemleverandører for dimensjonering og utforming av våtmarkssystem.

***MERKNAD OM DRIFTSANSVAR:** Gitte nøkkeltall er dimensjonerende data. Drift av filteranlegg og utenforliggende faktorer med innverkning på massen sin levetid er anleggseier sitt ansvar.*

Boston AS	*Vidare informasjon:*	*Telefon:*
Postboks 537	www.filtramar.com	+47-93217465 / 47775490
N-4291 KOPERVIK, Noreg	E-post: post@filtramar.com	

Annex 08

Produktdatablad
AGRI SKJELLSAND

Miljøkalk AS
Postboks 53
NO-1309 Rud
Telefon : +47 05255
E-post, Web: miljokalk@kalk.no www.kalk.no

MILJØKALK

Materiale: Skjellsand
$CaCO_3$
Reg.nr.: Deklarasjon -
Produktregistret -
REACH nr -

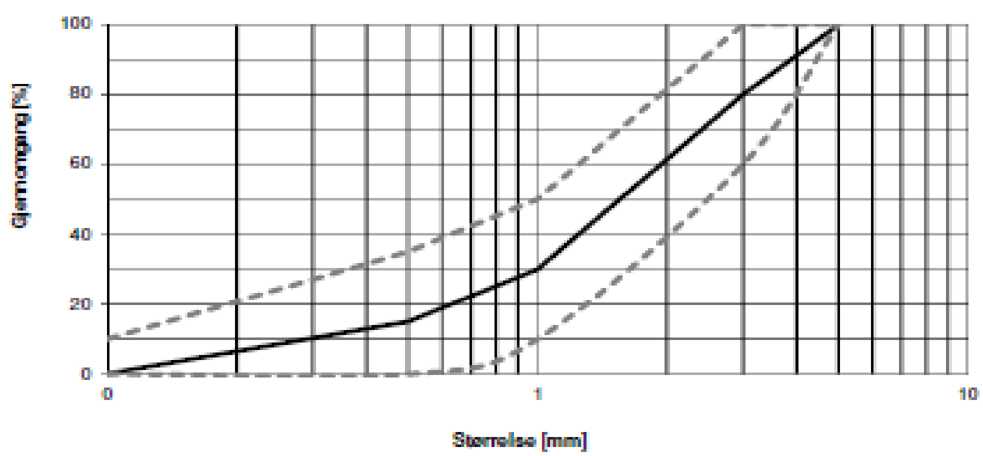
Produsent: Miljøkalk AS, avd Hamar
Råmaterial: Skjellfragmenter fra muslinger og skalldyr
Fremstilt: Knusing av skjellfragmenter
Versjon: 1/18

Anvendelse: Agri Skjell er egnet til alle kalkingsformål. Ved bruk av skjellsand til jordforbedring er det viktig å legge vekt på vannprosenten og event. forurensninger av stein og jord. Kalkverdi og magnesiuminnhold kan variere betydelig avhengig av uttakssted.

Krav: Forskrift om handel med gjødsel og kalkingsmidler

Parameter		Metode	Enhet	Statistikk		Krav		
				Snitt	s	L	H	Toleranse +/-
CaO	Kalsiumoksid	WD-XRF	[%]	47,5	-	-	-	
MgO	Magnesiumoksid	WD-XRF	[%]	2,6	-	-	-	
Ca	Kalsium	Beregnet fra WD-XRF	[%]	34,0	-	-	-	
Mg	Magnesium	Beregnet fra WD-XRF	[%]	1,5	-	-	-	0,5 %-enheter
NV (CaO)		NS-EN 12945	[-]		-		-	2,5-enheter
Fukt		NS-EN 12048	[%]	20	-	-	-	2 %-enheter
Kalkverdi	1. år	Beregnet fra NV	[-]	19	-	-	-	3-enheter
Kalkverdi	5. år	Beregnet fra NV	[-]	28	-	-	-	3-enheter
Massetetthet			[kg/dm^3]	2,2	-	-	-	
0,5 mm		NS-EN 12948	[%]	15	-	-	-	
1,0 mm		NS-EN 12948	[%]	30	-	-	-	
3,0 mm		NS-EN 12948	[%]	80	-	-	-	
5,0 mm		NS-EN 12948	[%]	100	-	-	-	

Kornfordeling



Råmateriale: Råmaterialet er et naturprodukt med variasjoner innenfor visse grenser
Levering: Bulk
Volumvekt: ~0,80 [kg/dm^3]
Lagring: Produktet må lagres tørt
SDS: Se produktets sikkerhetsdatablad for informasjon angående helse, miljø og sikkerhet. Les denne informasjonen og iverksett eventuelle sikkerhetstiltak før produktet tas i bruk.

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
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