Removal of Phosphorus from anaerobic digested blackwater by precipitation with struvite from Seawater and Magnesium Chloride
Removal of Phosphorus from anaerobic digested blackwater by Precipitation with struvite from Seawater and Magnesium Chloride.

A Thesis submitted in partial satisfaction of the requirements for the degree

Master of Science

in

Environment and Natural Resources - Specialization Sustainable Water and Sanitation, Health and Development.

By

Emanuel Kapela Chaula

Faculty of Environmental Sciences and Natural Resource Management

Norwegian University of Life Sciences (NMBU)

Ås, Norway July 2019
Acknowledgment

This master thesis is done at the faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences NMBU. I would like to thank my supervisors Petter D. Jenssen and Melesse Eshetu Moges for their guides, advice and the time they devoted to this thesis. I am proud and grateful that I had the chance to learn from them through my academic journey at NMBU during the thesis and lectures.

Also am truly grateful for Adreas for his time and helpful during the analysis and preparation of my experiment samples. Thanks to good friends of mine Saksham and Shafqat for their cooperation, positive attitude and encouragement for the entire period of this project.

Eventually, I would like to thank and appreciate my late lovely parents for their they did for me during my entire life. Your kind support made me stronger and illuminate my presence in this World. This thesis is dedicated to both of you.
Abstract

Phosphorus is a finite resource with the largest remaining resources in West Sahara and China. India and Europe have no significant mineral Phosphorus. The increase of awareness about the recovery of Phosphorus as fertilizer is an important issue for the food security and environmental protection. In this thesis the recovery of Phosphorus was carried out by precipitating anaerobic digested blackwater with Magnesium Chloride (MgCl\(_2\).6H\(_2\)O) and Seawater. The main purpose was to determine the effect of mixing ratio and pH on the removal of nutrients from blackwater. Based on the main goal two hypothesis were formulated, firstly addition of Mg source is an important factor on the removal efficiency of P. The use of ratio of struvite Mg : P 1.3:1 and 1:1 led to about 90% and 80 of P removal respectively. And Secondary hypothesis was that an increase of pH from 8.5 to pH 9 increase removal efficiency.

To carry out the experiment digested blackwater was taken from Realtek laboratory and source of seawater was taken from Drøbak. The adjustment of pH was done by adding few drops of Sodium hydroxide. Analysis of nutrients was done by using LCK 350 method and the reading was taken from using Hack Lange 3900DR.

The results showed the highest total P removal of 99.7% with MgCl\(_2\) at pH 9 and Mg:P of 1.3:1 with MgCl\(_2\) and 96.3% with seawater. Also, removal of PO\(_4\)-P removal efficiency was 99% at seawater with mixing ratio of 1:1 at pH 9 and the lowest value was 95.1% with MgCl\(_2\) at pH 8.5 mixing ratio 1:1.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgCl₂</td>
<td>Magnesium Chloride</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>P</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>MAP</td>
<td>Magnesium Ammonium Phosphate</td>
</tr>
<tr>
<td>HCl</td>
<td>Hydrochloric Acid</td>
</tr>
<tr>
<td>Mg/l</td>
<td>Milligram per Liter</td>
</tr>
<tr>
<td>Mt</td>
<td>Million Tones</td>
</tr>
<tr>
<td>PO₄³⁻</td>
<td>Phosphate</td>
</tr>
<tr>
<td>Ppb</td>
<td>part per million</td>
</tr>
<tr>
<td>NMBU</td>
<td>Norwegian University of Life Science</td>
</tr>
</tbody>
</table>
Contents

1. INTRODUCTION ................................................................................................................... 1

2. LITERATURE REVIEW ........................................................................................................... 4

2.1 Urine ................................................................................................................................. 4

2.2 Phosphorous ..................................................................................................................... 5

2.3 Phosphorus transport ........................................................................................................ 6

2.4 Phosphorus cycle into soil ............................................................................................. 6

2.5 Full scale technologies for P recovery for Municipal and industrial wastewater ........... 8

2.5.1 General P recovery in practice .................................................................................. 8

2.5.2 NuRESyS .................................................................................................................. 8

2.5.3 Calcium phosphate .................................................................................................... 9

2.5.4 Recovery of Phosphorus from mixed tanks .............................................................. 9

2.5.5 Anphos .................................................................................................................... 10

2.5.6 Crystalaector ............................................................................................................. 10

2.5.7 Airprex ..................................................................................................................... 10

2.5.8 Seaborne Technology ............................................................................................... 11

2.5.9 Phospaq technology ................................................................................................. 12

2.5.10 Chemical precipitation methods ............................................................................. 12

2.5.11 Electrochemical method ......................................................................................... 13

2.5.12 Advantages of electrochemical precipitation ......................................................... 14

2.5.13 Chemical precipitation method in agitated reactor ................................................. 14

2.5.14 Ion Exchange method ............................................................................................ 15

2.5.15 Biomineralization method ...................................................................................... 16

2.5.16 Phosphorus recovery from sludge ash .................................................................. 16
2.15 Agricultural waste suitable for Anaerobic digestion ...................................................... 31
2.15.1 Pig slurry..................................................................................................................... 31
2.16 Pharmaceuticals, hormones and Struvite........................................................................ 32
2.17 Heavy metals................................................................................................................... 34
2.18 Application of struvite in agriculture............................................................................. 35
3.0 Hypothesis, Goals and objectives .................................................................................. 36

4.0 MATERIALS AND METHODS ................................................................................ 37
4.1 Wastewater sample collection .................................................................................... 37
4.1.1 Digested black water from Kaja ................................................................................... 37
4.2 Magnesium sources........................................................................................................ 37
4.2.1 Seawater........................................................................................................................ 37
4.2.2 Magnesium chloride ..................................................................................................... 37
4.3 Adjustment of pH ....................................................................................................... 37
4.5 Mixing ........................................................................................................................ 38
4.6 Chemical analysis....................................................................................................... 38
4.6.1 Sample treatment .......................................................................................................... 38
4.6.2 Sample preparation for Total Phosphorous ................................................................. 38
4.7 Design of experiment................................................................................................... 40
4.8 Removal efficiency..................................................................................................... 40

5.0 RESULTS AND DISCUSSION................................................................................... 41
5.1 Removal of Phosphorous ............................................................................................ 41
5.2 Influence of pH ............................................................................................................ 42
5.3 Influence of Mg............................................................................................................. 42
5.4 Total Phosphate........................................................................................................... 43
5.5 NH4-N removal ........................................................................................................... 43
List of figures
Figure 1: Nutrients components and volume of domestic water ((Jönsson, 2001) ......................... 4
Figure 2: Global balance of Phosphorus Source (Elser and Bennett, 2011) ............................ 5
Figure 3: Phosphorus transport (Pierzynski et al., 2005) .............................................................. 6
Figure 4: Phosphorus Cycle (Pierzynski et al., 2005) .................................................................... 7
Figure 5: Effects of pH on Phosphorus (Pierzynski et al., 2005) ................................................... 7
Figure 6: Possible locations for phosphorous recovery modified from (Cornel et al., 2009) ....... 8
Figure 7: Schematic process overview of NuRESyS technology modified from ......................... 9
Figure 8: Crystalactor process flow diagram (Desmidt et al., 2015) ............................................ 10
Figure 9: AirPrex schematic overview (Heinzmann, 2009) ......................................................... 11
Figure 10: Process flow sheet of Seaborne Technology (Müller et al., 2005) .................................. 12
Figure 11: Electrochemical precipitation ...................................................................................... 13
Figure 12: Chemical precipitation of struvite .............................................................................. 14
Figure 13: Ion exchange method of struvite precipitation adapted from (Kataki et al., 2016) ...... 15
Figure 14: Schematic diagram of struvite precipitation through biomineralization .................... 16
Figure 15: Schematic overview of the Ash Dec process (Adam et al., 2009) .............................. 17
Figure 16: Mechanism of struvite Crystallization (Le Corre et al., 2009) ................................. 18
Figure 17: Concentration of nitrogen, magnesium and phosphorous versus pH at 25C .......... 20
Figure 18: Phosphorous usage scenarios at 1.5% increase per annum and 1.5% decrease per annum .................................................................................................................................... 24
Figure 19: Sustainable use way of closing loop of animal manures by anaerobic digestion ...... 26
Figure 20: Methane production ..................................................................................................... 27
Figure 21: Feedstocks from diferent sources ................................................................................ 29
Figure 22 Total P procedures according to LCK 350 method .................................................. 39
Figure 23 Phosphate Sample preparation according to LCK 350 method ................................. 39
Figure 24: Removal of total Phosphorous .................................................................................... 41
Figure 25: Phosphate removal ...................................................................................................... 43
Figure 26 Removal of NH\textsubscript{4}-N .................................................................................. 44
List of table

Table 1: Technologies for Recovery and removal of Phosphorous ................................................. 3
Table 2: Source of pollutant in domestic wastewater ........................................................................ 4
Table 3: Parts affected by struvite deposition ................................................................................... 21
Table 4: Nitrogen removal efficiency by struvite precipitation ....................................................... 22
Table 5: Saving on recovery as struvite over disposal ..................................................................... 23
Table 6: Contribution of recovered P from WWTPs worldwide to the reduction of mineral P rock ................................................................................................................................. 24
Table 7: Different substrate for biogas production ........................................................................... 28
Table 8: Composition of manure from different animals in Kg m⁻³ in UK (Lukehurst et al., 2010) ................................................................................................................................................... 29
Table 9: Examples national limit regulating storage time of digested amended from Nordberg 1992 ................................................................................................................................................. 30
Table 10: List of Pharmaceutical and hormones ............................................................................. 33
Table 11: Concentration and recovery efficiency of Pharmaceutical after batch Experiment with Struvite ............................................................................................................................................ 34
Table 12: Comparison of heavy metals concentration in struvite produced from various wastewater with legal limits (Liu et al., 2013b) ................................................................................................. 35
Table 13: Conditions for struvite precipitation .................................................................................. 40
Table 14: Characteristics of pretreated Digested blackwater ............................................................. 40
Table 15: Results removal of Phosphorous by using seawater and MgCl₂ at pH ......................... 41
CHAPTER ONE

1. INTRODUCTION

Rapidly increase of global population result to the high demand of food production which can be met by investment on the agricultural sector. The use of fertilizer for agricultural is inevitable among of three essential nutrients for plants to grow NPK. Phosphorous (P) is the major essential nutrient for the growth of crops (Kemacheevakul et al., 2014). Since P is very reactive when met with other elements in the soil this make P to be essential for the better growth of plants. Phosphorous element found mostly in the form of phosphate with the combination of other elements, the largest quantity of Phosphorous found conserved into terrestrial soil and sediments like oceans, lakes and freshy water.

Currently the amount of commercial P fertilizer used in the World is originated from Morocco, China, Russia and United States (Kelly et al., 2005). About 80% mined Phosphorous is used in agriculture production as a fertilizer, 15% used industrial sector for production of detergents and only 5% used as additives for the manufacturing of animals foods. Development of agriculture sector depend more on the availability of enough fertilizer with affordable price, the application of fertilizer in developing countries is increasing due to severe loss natural soil fertility in most of the South Saharan countries (Cordell et al., 2011).

Demand of Phosphorous fertilizer is related with population growth and expansion of the food requirements. The global population estimated to increase by 50% in on 2050 and reach 11 billion people compared to 7 billion on year 2011. The peak demand of Phosphorous fertilizer is estimated to occur at 2035 the need of recovering of P in order to meet the demand of fertilizer in the future is needed (Cordell and White, 2011).

Conventional wastewater treatment system is common approach used worldwide for the treatment of wastewater but showed highly investment, construction, operations and maintenance costs (Larsen et al., 1996). Also failed to meet the rapid urbanization of many city and it fails to match with Millennium development goal number 6 which to ensure availability and sustainable management of water and sanitation for all (United Nations 2015). In 1990s source separating
system got famous as alternative method of wastewater treatment in per urban area and into the informal settlement in big towns of Africa and Asia. It has couple of benefits like energy saving, water saving, decrease greenhouse gas emission, low risk to pollute environment and easy to recovery the nutrients (Jönsson et al., 1997, Maurer et al., 2006).

Currently various biological and physio-chemical technologies have been invented for the purpose to removal of phosphorous from wastewater, the process physio chemical done by precipitation of wastewater with is insoluble salts most of aluminum and iron. During that process phosphorous particles are attached to metals particles. The challenge of this technology is the cost for chemicals and handling of sludge (Morse et al., 1998).

Recovery of Phosphorous recently has becoming a great discussion to most of decision makers and politicians in Europe. Different technologies are discovered to enhance the campaign of recovering nutrients.

The recovery process is more efficient than the removal since both the treatment and reuse are taking place simultaneously. During the process of Precipitation of Phosphorous useful form of Phosphorus is used as fertilizer and applied to the farms to increase nutrients into soil. Some of recovering and removal technologies are described table1 (Morse et al., 1998).

The recovery of Phosphorous from the wastewater showed the promise substitute for the demand of fertilizer, especially urine from domestic water contain richness values of essential elements for fertility of the soil 80% Nitrogen, 50% phosphorous P and 90% Potassium K (Zamora et al., 2017a).

In Norway NMBU is running the project of sustainable use of wastewater to improve the living and recovering of nutrient at Frederiksted old hospital in Norway. With the idea of source separation whereby nutrients from urine used as struvite to make a phosphorous fertilizer which can be used for urban agriculture at Frederiksted.
Table 1: Technologies for Recovery and removal of Phosphorous (Morse et al., 1998)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Objective</th>
<th>Process summary</th>
<th>Main input</th>
<th>Main output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical precipitation</td>
<td>P removal</td>
<td>Addition of metal salt to precipitate P removed in sludge</td>
<td>Wastewater</td>
<td>Chemical sludge</td>
</tr>
<tr>
<td>Biological precipitation</td>
<td>P removal (may also include N removal)</td>
<td>Uptake of P by bacteria in aerobic stage following anaerobic stage</td>
<td>Wastewater (primary effluent)</td>
<td>Biological sludge</td>
</tr>
<tr>
<td>Crystallization</td>
<td>P removal and recovery</td>
<td>Crystallization of calcium Phosphate using sand as a seed material</td>
<td>Wastewater (secondary effluent)</td>
<td>Calcium Phosphate, sand</td>
</tr>
<tr>
<td>Advanced chemical precipitation (HYPO)</td>
<td>P and N removal</td>
<td>Crystallization of Porganic matter to produce carbon source for N removal</td>
<td>Wastewater (primary effluent)</td>
<td>Chemical sludge</td>
</tr>
<tr>
<td>Ion exchange</td>
<td>Fertilizer (struvite production)</td>
<td>Phosphate and ammonium are removed via precipitation</td>
<td>Wastewater (secondary effluent)</td>
<td>Struvite (MgNH₄PO₄)</td>
</tr>
<tr>
<td>Magnetic</td>
<td>P removal</td>
<td>Precipitation, magnetic attachment, separation and recovery</td>
<td>Wastewater (secondary effluent)</td>
<td>Primarily calcium Phosphate</td>
</tr>
<tr>
<td>P adsorbents</td>
<td>P removal</td>
<td>Adsorption and separation</td>
<td>Wastewater</td>
<td>No information</td>
</tr>
<tr>
<td>Tertiary filtration</td>
<td>Effluent polishing</td>
<td>Filtration</td>
<td>Wastewater (secondary effluent)</td>
<td>Tertiary sludge</td>
</tr>
<tr>
<td>Sludge treatment</td>
<td>Sludge disposal</td>
<td>E.g. sludge drying, reaction with cement dust</td>
<td>Sludge</td>
<td>Soil conditioner</td>
</tr>
<tr>
<td>Recovery from sludge ash</td>
<td>P recovery</td>
<td>Extraction from sludge ash</td>
<td>Sludge ash from biological removal</td>
<td>NA</td>
</tr>
</tbody>
</table>
2. LITERATURE REVIEW

2.1 Urine

(Jönsson, 2001) Define Urine as an urban waste fraction which contain high amount of nutrients. It contains about 70% of nitrogen and 50% of phosphorus in the all household waste water contents fraction. It is estimated that the adult person can produce about 1.4L of urine per day (Rose et al., 2015), the amount of urine in total household wastewater it showed to be only 1% as described in the figure 1.

Figure 1: Nutrients components and volume of domestic water ((Jönsson, 2001)

The application of urine as fertilizer it has less health danger to human compared to the direct application of feces, but some human pathogen microorganisms like salmonella typhi and helminth eggs can be found in urine. The storage of urine with urea for six month it can reduce the possibility of urine to cause the dangerous effects to human health (Pandey and Jenssen, 2017). In the study done by (Larsen et al., 1996) showed that human urine contain about 57% of P when is separated from other domestic wastewater.

Table 2: Source of pollutant in domestic wastewater

<table>
<thead>
<tr>
<th>Source</th>
<th>Total Organic Carbon</th>
<th>Total Kjeldahl Nitrogen</th>
<th>Total Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitchen, Cleaning, Bathroom</td>
<td>15</td>
<td>0.2</td>
<td>*</td>
</tr>
<tr>
<td>Feces</td>
<td>17</td>
<td>1.5</td>
<td>0.6</td>
</tr>
<tr>
<td>ANS / Urine</td>
<td>5                  **</td>
<td>12.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Total</td>
<td>37</td>
<td>13.9</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Source: (Larsen et al., 1996)
However the question about how to deal with microplastic nutrients such as plastics and pharmaceutical from urine and their effects to the quality of soil and crop products after being harvested made the direct application of urine to the industrialized societies to be difficult compared to the developing societies (Maurer et al., 2006).

2.2 Phosphorous
The element Phosphorus was discovered by the German scientist Henning Brandt in the 17th century where he used 50 buckets of urine and distilled it by evaporating and heating in search of the legendary ‘Philosopher’s Stone’ (Emsley and Huxtable, 2000).

Phosphorus is important for the human, plants and animals life. It plays big role in the challenge of World food scarcity and soil fertility (Scholz et al., 2013). However rapidly increase of population it threatens the capacity of currently deposit of mineral P its estimated by 2050 the population of World will be about 9 billion people and the peak accumulation of P to occur in 2035. The needs of alternative source of P is inevitable since the current production capacity from minerals P rock is 20 million tones (Ashley et al., 2011) figure 2. Also the overuse of P fertilizer and other P sources like from detergents has contributed to the pollution of surface water sources due to the eutrophication. Which made depletion of oxygen and growth of algal bloom which result to the disturbance of the aquatic ecosystem and scarcity of fresh water sources (Van Vuuren et al., 2010).

![Figure 2: Global balance of Phosphorus Source (Elser and Bennett, 2011)](image-url)
2.3 Phosphorus transport
Phosphorus transport and fate in terrestrial and aquatic ecosystem is summarized in the figure 3 whereby organic and inorganic P are dissolved and detached by means of moving across and through soil. Dissolved P can be deposited into riverbanks or carried into water reservoirs and lakes. The amount of soluble phosphorus inside lakes is taken by algae while the insoluble P is depleted.

Figure 3: Phosphorus transport (Pierzynski et al., 2005)

2.4 Phosphorus cycle into soil
Total amount concentration of P into soil varies from 50-3000mg-kg. In mineral soils, 50-70% are in forms of inorganic. While at organic soil 20-30% are organic matter and only 60-90% of total P can be organic into soil. The amount of soil organic P such as plants and animals residuals and soil organic matter are converted into inorganic P by mineralization process since the inorganic P is the one that taken by plants. Soluble P is adsorbed to clay, Aluminum and iron oxides which make P unavailable for plants growth.
Dissolved Phosphorus enter the soil in the forms of primary $\text{PO}_4^{3-}$ and secondary in the form of ortho-Phosphate $\text{HPO}_4^{2-}$ and $\text{H}_2\text{PO}_4^-$. Amount of pH is the controlling factor for the availability of primary and secondary Phosphorus into soil. Fig illustrate that at pH 4 to 6.5 Dihydrogen Phosphate is formed $\text{H}_2\text{PO}_4^-$ while at pH above 7.5 Hydrogen Phosphate $\text{HPO}_4^{2-}$ is dominant.
2.5 Full scale technologies for P recovery for Municipal and industrial wastewater
2.5.1 General P recovery in practice

Recovery technologies for Phosphorous can be applied at any points in the treatment scheme of wastewater can be recovered from liquid phase, sludge phase and from mono-incinerated and sludge ash. As showed in the figure below. High amount of P about 90% of incoming phosphorous load from wastewater is inform of sewage sludge (Cornel et al., 2009). Recovery rate of P from sewage sludge and sewage ash can have possibility to reach up to 90% while at liquid phase recovery rate ranges from 40-50%.

Figure 6: Possible locations for phosphorous recovery modified from (Cornel et al., 2009)

2.5.2 NuRESyS

Liquid phase removal of Phosphorous usually is located into WWTPs which contain biological removal process since polyphosphates are stored into cell of bacteria and are released under anaerobic conditions. Amount of P in biological removal ot ranges from 75-300mg-l (Garcia-Belinchón et al., 2013). Substantial difference between traditional P removal and modern P recovery from waste is that P recover technologies aim to have a final product which can be used as fertilizer.
2.5.3 Calcium phosphate
Formation of Calcium phosphate precipitation very complex and it need various parameters ionic strength, pH, temperature, supersaturation and mixing time. Forms of crystallized calcium phosphate it depends mainly on pH and kinetic of chemical reaction.

2.5.4 Recovery of Phosphorus from mixed tanks
This technology of P recovery was developed by Akwadok company in Belgium and it operated into two reactors as shown in Figure. NuRESyS stand for Nutrients Recycle System, operation mode of this technology is continuous compared to ANPHOS technology which operated into batch mode. Also magnesium chloride is the main source of magnesium used into this technology with addition of 29 percent of NaOH. Simple bladder impeller installed for the purpose of optimizing pH between 8-8.5 also impeller help to prevent occurring of scaling (Moerman et al., 2009).

Figure 7: Schematic process overview of NuRESyS technology modified from Source: (Moerman et al., 2009).

Full scale plant was first taken into operation in 2005 in northern Germany at diary processing company with a capacity of 1580kgstruvute-day. The removal attained was 85% of phosphate and used into agriculture.
2.5.5 Anphos
This process was developed by Colsen and operation is divided into two batch reactors, first reactor wastewater is aerated for purpose of raising pH due to Cabo dioxide air stripping, Second reactor MgO added for the recovery of P as struvite(Lodder et al., 2011).The removing capacity of ANPHOS is 80-90% of phosphate.

2.5.6 Crystalactor
This technology was invented by Dutch in 1980s for the purpose of removing hardness from drinking water, also technology was used to removal heavy metals from drinking water and wastewater.(Giensen and van der Moldeh, 1996).Calcium hydroxide is added into a reactor for the purpose of increasing pH 9, recovery rate can reach to 70-80%PO4-P by selecting good operation condition and minimizing impurities(Cornel et al., 2009)

Figure 8: Crystalactor process flow diagram (Desmidt et al., 2015)

2.5.7 Airprex
AirPrex technology is designed to control the incrustations of wastewater pipes due to the deposition of struvite into the sides of pipe. Air Prex technology figure … digested sludge firstly entered to cylindrical reactor with an inner cylindrical zone mixed by air up flow and sedimentation zone at bottom between inner and outer cylinder. Air bubbles help to lift sludge and to increase pH and to increase the grow of struvite crystals until they reach size to escape flow recycle flow and settle.
Struvite is removed at the bottom of two tanks, an equipment for sand washing placed to ensure that recovered struvite be cleaned and purification. The GmbH, Hamburg from Germany are the owner of the AirPrex technology, and they built three treatment plant for recovery of P. Phosphate from those plant was removed at the liquid phase of digested liquid and the removal efficiency was 80-90% Phosphate.

2.5.8 Seaborne Technology
Seaborne technology was innovated by Seaborne Environmental Research Laboratory for the treatment of digested sewage sludge from municipal wastewater. Main purpose of this technology was to separate heavy metals, recovery of nitrogen and phosphorous and incineration of solids for the recovery of energy. Seaborne process recovered fertilizer is free from organic pollutant and heavy metals(Müller et al., 2005).
First Seaborne full-scale treatment plant was built in 2006 in Germany with a capacity to serve 50000 people. The recovery efficiency was 90% for phosphate and nitrogen. Addition of sulphuric acid helps the acidification process to take place and dissolving of solids for purpose of releasing nutrients and heavy metals. Also Sodium hydroxide addition help to adjust the value of pH since struvite formation it depend on the value of pH (Müller et al., 2005).

2.5.9 Phosphaq technology
Phosphaq technology was developed in Netherlands by Paques. This technology is commercialized by agriculture authority in Netherlands to be used as fertilizer. The process recovers up to 80% of phosphate and recovered P used in growing of potatoes. MgO is added to amend phosphate and aeration by air stripping is used to adjust pH which speed up the recovery process and reduce the amount of chemical oxygen demand (Remy et al., 2013).

2.5.10 Chemical precipitation methods
Chemical precipitation is the most widely methods for struvite recovery, however it requires sophisticated equipment.
2.5.11 Electrochemical method

This method precipitation of struvite is induced by chemical reaction. Electrochemical battery is used with anode formed by inert materials such as nickel, platinum and graphite. At cathode is the place where deposition of struvite occurs and analyte solution containing the ions of magnesium, phosphate and ammonia Figure below

![Electrochemical precipitation](image)

Figure 11: Electrochemical precipitation

Reduction of oxygen occur at cathode and forming hydroxide ions \( \text{O}_2 + 2\text{H}_2\text{O} + 4e^- \rightarrow 4\text{OH}^- \) while hydrogen gas is released. This reaction at cathode is very important for creating the alkaline conditions which are favorable for struvite precipitation since hydroxide help to raise the value of pH(Hao et al., 2008).
2.5.12 Advantages of electrochemical precipitation
There is no chemical required for the adjustment of pH, also production of hydrogen during the process can offset other cost if hydrogen gas recovery done. However, drawback of electrochemical precipitation is an electric potential of 1.23V is required for the reduction of water (Wang et al., 2010, Cusick and Logan, 2012, Cusick et al., 2014). For reducing cost of energy, microbial electrochemical cell was innovated this is done by the microbes which produce electricity from organic matter released by microbes and convert into inorganic matter through oxidation at anode. Recovery capacity from microbial fuel cell is higher compared to feedstock since at amicrobial inorganic phosphate is reduced and hence the amount of P available increase to 48% of the total P. Also, this method retain the amount of heavy metals at the sludge matrix in the immobilized form (Fischer et al., 2011, Wang et al., 2010).

2.5.13 Chemical precipitation method in agitated reactor
At this method struvite is precipitate from wastewater by the addition of Mg in a mechanically agitated reactor figure. Efficiency of this method depend on pH and type of magnesium salt used. Common sources of magnesium used are MgCl2, MgO and MgSO4 also for the cost effective the use of seawater and wood ash are in progress as alternative source of Mg (Suzuki et al., 2007, Huang et al., 2011). The alkaline condition is important to be created for the purpose of pH adjustment which is suitable for struvite precipitation by addition of sodium hydroxide.

Figure 12: Chemical precipitation of struvite
2.5.14 Ion Exchange method
At this method nutrients from wastewater are selectively exchanged in ion exchanger and struvite is precipitated after addition of magnesium in the controlled value of pH. In ion exchange column NaCl is added as regeneration solution where by PO$_4^{3-}$ are exchanged for Na$^+$ in cationic ion exchanger and NH$_4^+$ are exchanged for Cl$^-$ at anionic exchanger (Liberti et al., 1986).

![Ion exchange method of struvite precipitation](image)

Figure 13: Ion exchange method of struvite precipitation adapted from (Kataki et al., 2016)

Externally MgCl$_2$ added to react with regenerated NH$_4^+$ and PO$_4^{3-}$ in stoichiometric ratio of Mg$^{2+}$ : NH$_4^+$ : PO$_4^{3-}$ equal to 1 : 1 : 1.figure above. Also, ion exchange isothermal supersaturation has been used to modify the convectonal ion exchange. The main purpose is to facilitate enable spontaneous crystals of struvite formation and widening solubility of struvite precipitating solution beyond a given level of temperature(Mijangos et al., 2013, Ortueta et al., 2015).
2.5.15 Biomineralization method
This is the natural process of deposition of minerals by microbes for hardening their structure tissues and hence production of struvite. (Omar et al., 1998) reported that some bacteria like Myxococcus Xanthus and Staphylococcus aureus could precipitate struvite when they exposed into medium containing Mg and phosphate.

Figure 14: Schematic diagram of struvite precipitation through biomineralization (Kataki et al., 2016)

2.5.16 Phosphorus recovery from sludge ash
This method is used to recover P that is not recovered from liquid phase. Sewage sludge produced from different wastewater treatment plants mostly it ends up in landfills and into incinerators. Ashes from incinerators contains nutrients and organic contents, in case of nutrients from incinerator ashes phosphorus is vital resource to be recovered. Since ashes still contain concertation of heavy metal above the allowable limits used in agriculture. Dry thermal and wet thermal methods are the ones that used for the recovery of P from incinerator ashes(Kaikake et al., 2009). The remaining ashes after recovery of P can be missed with cement or concrete to from bricks and ceramic materials.
Figure 15: Schematic overview of the Ash Dec process (Adam et al., 2009)
2.6 Struvite
Struvite is formed by an equal molar combination of magnesium, phosphate and ammonium with six molecules of water MgNH₄PO₄.6H₂O) and readily soluble in acid and neutral to alkaline also it can occur into different colors such as white, yellowish, and brownish. Presence of struvite into wastewater pipe has a tendency of reducing the durability of waste water due to the formation of scaling the precipitation of struvite lead to best option of controlling scaling of pipes.(Rahman et al., 2014).

2.6.1 Conditions for Struvite Precipitation
Efficiency of struvite it depends on the parameters such as Molar ratio, pH, temperature, aeration rate and presence of Ca²⁺ in the reaction media.

2.6.2 Crystallization
Formation of struvite crystals occur into two phases which are nucleation and crystal growth, the mechanism of these two processes is complex and controlled by different factors such as mass transfer between the liquid and solid phases and thermodynamic equilibrium between the liquid to solid phases and reaction kinetics of the compound(Ohlinger et al., 1999). Stages of both two processes it depends on supersaturation, Nucleation stage it can be homogenous or heterogenous. Crystal growth process combined by both integration and diffusion process. Also crystal growth determine the final size of crystal according to the rate of growth(Jones, 2002). The whole procedures of nucleation are stated on the figure 16.

Figure 16: Mechanism of struvite Crystallization(Le Corre et al., 2009)
2.6.3 Molar ratio
Struvite formation depends on the mixing ratio of Magnesium Mg, Phosphate $\text{PO}_4^{-3}$ and Ammonium $\text{NH}_4^+$ into molar ratio of 1:1:1. Higher ratio of Mg: $\text{PO}_4^{-3}$ showed best removal efficiency of Most of researchers have been using $\text{MgCl}_2$ as the main source of magnesium in precipitation of struvite since is available easily compared to other magnesium sources like MgO and brucite.

<table>
<thead>
<tr>
<th>Mg sources</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{MgCl}_2$</td>
<td>(Ronteltap, 2009, Liu et al., 2013a)</td>
</tr>
<tr>
<td>Brucite MgOH</td>
<td>(Huang et al., 2011, Münch and Barr, 2001)</td>
</tr>
<tr>
<td>MgO</td>
<td>(Ganrot et al., 2007)</td>
</tr>
</tbody>
</table>

2.6.4 pH
The pH play an important role during process of precipitating struvite. Struvite precipitation occurs into wide range of pH from 7-11.5 but the suitable pH is between 7.5-9 with minimum solubility (Hao et al., 2008). Increasing of pH it reduce the solubility of struvite and result to higher removal efficiency of P and N, also raising of pH to 8.3 can recover amount of P up to 90% (Adnan et al., 2003). In order to achieve the adjustment of pH done by using HCl and NaOH or by aeration.

<table>
<thead>
<tr>
<th>Water sources</th>
<th>pH range for struvite precipitation</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm waste</td>
<td>7-9</td>
<td>(Burns et al., 2001)</td>
</tr>
<tr>
<td>Industrial waste</td>
<td>9-11</td>
<td>(Liu et al., 2013a)</td>
</tr>
<tr>
<td></td>
<td>8-11</td>
<td>(Moerman et al., 2009)</td>
</tr>
<tr>
<td>Municipal wastewater</td>
<td>8-9</td>
<td>(Uysal et al., 2010)</td>
</tr>
</tbody>
</table>

Also the amount of pH above 10 has reported by (Shin and Lee, 1998) that have a tendency to reduce the purity of struvite due to formation of amorphous precipitate.
Figure 17: Concentration of nitrogen, magnesium and phosphorous versus pH at 25°C (Shin and Lee, 1998)

Increase of pH it decrease the solubility of struvite which lead to the deposition of struvite into different parts of wastewater treatment especially the distribution pipes, valves, elbow, and pumps to be affected by scaling as it showed by (Le Corre et al., 2009) on the table below.
Table 3: Parts affected by struvite deposition (Le Corre et al., 2009)

<table>
<thead>
<tr>
<th>Authors</th>
<th>Location of deposit</th>
<th>Effects</th>
<th>Type of plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rawn et al. (1937)</td>
<td>Digestion sludge process: pipes carrying supernatants liquors</td>
<td>Accumulation in some places to the thickness of an inch (~2.5 cm)</td>
<td>Wastewater treatment plant (USA)</td>
</tr>
<tr>
<td>Borgerding (1972)</td>
<td>Activated/digested sludge process: suction side of pump onto separating screen</td>
<td>310 mm-diameter of the suction side reduced to 150 mm</td>
<td>Hyperion waste water treatment plant (USA)</td>
</tr>
<tr>
<td>Booram et al. (1975)</td>
<td>Items in contact with anaerobic liquids: pump impellers, pipes, etc.</td>
<td>—</td>
<td>Livestock waste treatment and management plant (USA)</td>
</tr>
<tr>
<td>Mohajit et al. (1989)</td>
<td>In floating aerators, raw waste pumps, pipelines and outfall pipelines.</td>
<td>Accumulation: from 5.88 up to 14.44 mm in aerators; from 8 up to 28 mm in pipes carrying digester effluents</td>
<td>Pig waste treatment plant (Singapore)</td>
</tr>
<tr>
<td>Ohlinger et al. (1998)</td>
<td>Accumulation on pipe walls from sludge basins supernatant system</td>
<td>Accumulation along 5.6 km of pipes.</td>
<td>Wastewater treatment plant (USA)</td>
</tr>
<tr>
<td>Williams (1999)</td>
<td>Accumulation of struvite crystals in pipelines from the sludge holding tank to the centrifuges</td>
<td>Bore of pipes reduced from 100 to 50 mm</td>
<td>Wastewater treatment plant (UK)</td>
</tr>
<tr>
<td>Doyle et al. (2000)</td>
<td>Pipes carrying centrate liquors</td>
<td>Pipe diameter reduction from 150 to 60 mm in 12 weeks</td>
<td>Sludge destruction plant (UK)</td>
</tr>
<tr>
<td>Battistoni et al. (2004)</td>
<td>Pipes carrying anaerobic supernatants</td>
<td>Reduction of pipes diameter</td>
<td>Demonstrative fluidised bed reactor plant, WWTP (Italy) WWTP (USA)</td>
</tr>
<tr>
<td>Neethling and Benisch (2004)</td>
<td>Streaming pipes controlling polymer feed-flowmeters</td>
<td>Two-month build up in a 3” rubber lined 90° elbow</td>
<td></td>
</tr>
</tbody>
</table>

2.6.5 Aeration rate
Air flows has crucial role in the removal of nutrients from wastewater particularly the removal of NH4-N, airflow creates the pathway for the volatilization of NH4-N dissolved in the solutional it raises pH since it promote the process of CO2 stripping (Rahman et al., 2014). Enough aeration time provide high efficiency of NH4-N as indicated by (Yetilmezsoy and Sapci-Zengin, 2009) and about 93.3% of NH4-N recovered at period of 24hr with aeration rate of 0.6Lmin⁻¹. Also increase of aeration rate promote the raise of pH as reported by (Suzuki et al., 2007) whereby pH raised from 7.5 to 8 with aeration rate of 12m3h⁻¹.
2.6.6 Presence of foreign ions
Presence of impurities in solution it affects the growth rate of crystalline compounds due to the reduction of space where crystals can be formed. Especially the presence of calcium and ions in media it affects negatively the growth rate. When Calcium ion concentration is high in solution it interact with phosphate to form calcium phosphate as hydroxyapatite according to equations below as reported by (Le Corre et al., 2009).

\[5\text{Ca}^2+ + 3\text{PO}_4^- + \text{H}_2\text{O} \rightarrow \text{Ca}_5(\text{PO}_4)_3\text{OH} + \text{H}^+\]

2.7 Advantages of controlling and recovering of P as struvite
2.7.1 Sludge reduction
Sludge production and disposal is the major challenges to most of wastewater treatment plants to both of municipal and company’s treatment plants. Most sludge production resulted from an increase application of coagulant to enhance settling of particles from wastewater. It was predicated that the use coagulant would increase production of sludge from 7 to 9.4 million in EU by the year of 2005. Also in UK was predicted that sludge would increase from 1.1 to 1.5 million tones in seasons of 2005/2006. The use of struvite was studied by (Woods et al., 1999) showed that sludge production can be reduced by 8-30% through applying phosphorus recovery as struvite.

2.7.2 Reduction of pollution
Increase of amount of nutrients especially Phosphorous and nitrogen into aquatic environment has led to occurrence of eutrophication to the water bodies which result to growth of algae. Effect of eutrophication has made scarcity of good drinking water sources, also death of fish and aquatic living organism has made un imbalance of ecosystem between different species. Most experimental methods of struvite precipitation showed the promise toward to solve the problem of eutrophication if applied, since struvite has a capacity to recover both nitrogen and phosphorus as described in table 4 below

<table>
<thead>
<tr>
<th>Sources of wastewater</th>
<th>Efficiency</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human urine</td>
<td>Up to 95%</td>
<td>(Kabdağlı et al., 2006)</td>
</tr>
<tr>
<td>Slurry type swine</td>
<td>99% depending on ratio</td>
<td>(Kim et al., 2004)</td>
</tr>
<tr>
<td>Anaerobic digested manure</td>
<td>95%</td>
<td>(Uludag-Demirer et al., 2005)</td>
</tr>
<tr>
<td>Swine wastewater</td>
<td>90%</td>
<td>(Maekawa et al., 1995)</td>
</tr>
</tbody>
</table>
2.7.3 Uses as fertilizer
The agronomic properties of struvite as fertilizer is ongoing discussion nowadays. Struvite contains essential nutrients for plants growth like P, N and Mg (Li and Zhao, 2003). In Japan, struvite has been commercialized as fertilizer for growing rice and vegetables, however, the communication between farmers and producers of struvite fertilizer need to be increased for the purpose of widening the uses of recovered phosphorous (Fang et al., 2015).

2.8 Economic value of struvite
Recovering of struvite from wastewater has numerous advantages: it reduces pollution caused by excessive discharge of nutrients to water bodies, reduces scaling problems to wastewater treatment plants, and also the potential of fertilizer would be a benefit to the companies dealing with recovering of phosphorous (Doyle and Parsons, 2002). The sustainability of phosphorous recovering into the economy view it faced challenge on the cost-effective by taking into account cost of production which include maintenance, chemicals and energy. Proximately amount of phosphorous that can be recovered as struvite from 100m³ of wastewater which increase saving of cost of disposal as described into table 5 below.

Table 5: Saving on recovery as struvite over disposal

<table>
<thead>
<tr>
<th>Cost</th>
<th>100 m³/d</th>
<th>1000 m³/d</th>
<th>55000 m³/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss producing struvite</td>
<td>0.065</td>
<td>0.65</td>
<td>35.75</td>
</tr>
<tr>
<td>Gain producing struvite</td>
<td>0.74</td>
<td>7.4</td>
<td>407</td>
</tr>
<tr>
<td>Reduction in sludge handling</td>
<td>1.10</td>
<td>11.0</td>
<td>605</td>
</tr>
<tr>
<td>Reduction in WW flow (20%)</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Reduction in Al₂(SO₄)₃</td>
<td>0.27</td>
<td>2.7</td>
<td>148.5</td>
</tr>
<tr>
<td>Reduction in sludge disposal</td>
<td>0.033</td>
<td>0.33</td>
<td>18.34</td>
</tr>
<tr>
<td>Reduction in cleaning struvite deposit</td>
<td>5.5–27.4</td>
<td>5.5–27.4</td>
<td>5.5–27.4</td>
</tr>
<tr>
<td>Reduction in landfill area</td>
<td>0.003</td>
<td>0.03</td>
<td>1.73</td>
</tr>
</tbody>
</table>

Concentration of Phosphorus in wastewater typically is range from 4-14mg PO₄³⁻-P/L according to (Metcalf, 2003). The recovery of 1kg of phosphorus from 100m³-d wastewater the efficiency of p recovery rate need to be 96.78% with waste water of 4mg PO₄³⁻-P per recovering process has reduce potential operating costs on chemical, sludge disposal and time to clean polluted water bodies by nutrients.
2.8.1 Recovery of P Worldwide waste stream
Mineral P available is estimated to be exhausted in 90 years, and current world population is around 6-7 billions. Which means that issue of food security for the 90 year coming is questionable by assuming 1.5% annual increase of demand of supplemented of recovery of phosphorus as fertilizer will last longer since the population is increasing as it shown on figure 18 below.

![Figure 18: Phosphorous usage scenarios at 1.5% increase per annum and 1.5% decrease per annum](image)

2.8.2 Population growth on P recovery
At worst case scenarios whereby all amount of mineral P assumed be exhausted, the only hope for phosphorous will remain in recovery of P as struvite from WWTPs. Research done by indicated that an increase of population by 1 billion in earth will increase the load of phosphates into WWTPs by 0.3 millions tons Table 6 below. Also demand of food will increase.

Table 6: Contribution of recovered P from WWTPs worldwide to the reduction of mineral P rock

<table>
<thead>
<tr>
<th>Population billions</th>
<th>Recovered P$_2$O$_5$/yr (million tons)</th>
<th>kg/ha/yr of P$_2$O$_5$ from recovered phosphorus</th>
<th>% reduction in rock mining</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2.31</td>
<td>1.25</td>
<td>5.76</td>
</tr>
<tr>
<td>7</td>
<td>2.69</td>
<td>1.45</td>
<td>6.72</td>
</tr>
<tr>
<td>8</td>
<td>3.07</td>
<td>1.66</td>
<td>7.68</td>
</tr>
<tr>
<td>9</td>
<td>3.46</td>
<td>1.87</td>
<td>8.64</td>
</tr>
<tr>
<td>10</td>
<td>3.84</td>
<td>2.08</td>
<td>9.60</td>
</tr>
</tbody>
</table>

Assume the entire world population is connected to WWTPs and phosphorus recovery is 100%. Assume at present, P$_2$O$_5$ consumption = 40 million tons/yr and 80% of it is used as fertilizer. World arable land 1.48 billion ha.
2.9 Cost of struvite production
Challenge of production cost of struvite depends on the amounts of chemicals to be used in the whole process and the quantities of energy require for the mixing process during the crystallization (Jaffer et al., 2002, Münch and Barr, 2001). Most studies showed high amount of chemicals is used in the adjustment of pH of precipitation by adding NaOH and amount of MgCl2 to reach an appropriate mixing ratio of Mg:N:P molar ratio (Jaffer et al., 2002) estimated that sodium hydroxide addition would took 97% of all expenses in chemicals for daily operation costs of the WWTPs ranging from 0.0014-0.51 €/m3. The use of air stripping method as alternative for pH adjustment of struvite precipitation, could be used as way of minimizing cost of NaOH (Battistoni et al., 2005).

The use of seawater or brine as source of magnesium could reach the removal of Phosphorous up 95% compared to 97% of MgCl2. But an issue of where to get brine can increase the cost of production if wastewater treatment plant located far from the sea (Shin and Lee, 1998).

2.10 Commercialization and application of struvite precipitation
Struvite precipitation is commercially used by different manufacturers to recover fertilizer from wastewater some of these technologies have been mentioned by (Lin et al., 2015) recently technologies are air prex from Germany, PHOSNIX from Japan, Crystalactor® from Netherlands. These technologies have made struvite precipitation to be become famous and efficiency technology compared to adsorption, incineration and hydrolysis.

2.11 Legal and regulation of phosphorous
The use of recovered phosphorous in European Union is increasing daily especially in Germany. In 2017 German government regulated the use and application of fertilizer and other ingredient to agriculture sector according to good professional coding. Struvite is termed as slow release fertilizer (Escher et al., 2006). The full scale technologies for recovery of Phosphorus

2.12 Anaerobic digestion
Anaerobic digestion is a biological process whereby organic carbon is converted into most oxidized state CO2 and its most reduced state methane CH4. Also anaerobic digester is good for the treatment of sludge which contain large volume of solid particles both suspended and volatiles occurs in the limited supply of oxygen with the help of microorganism catalyze. The mixture of
different gas results to the formation of biogas. Main output of anaerobic digestion process are methane and carbon dioxide, also small amount of nitrogen, ammonium and hydrogen sulphide gas (Angelidaki et al., 2003).

2.12.1 Sustainable cycle of anaerobic digestion
Rapidly increase of production in meat industry has made high amount of animals slurries and manures to be produced daily. Also wet organic waste from animals bleeding nowadays have increased threats to the pollution of environment. The needs of closing the loop of pollution as it have shown in the fig 19, it emphasizing the innovations of good sustainable technologies which can be affordable and gave positive results to the environment and improve the soil fertility and energy consumption through using biogas.

Figure 19: Sustainable use way of closing loop of animal manures by anaerobic digestion (Holm-Nielsen et al., 2009)

Poor management of animal manures or when is untreated it results to the main source of aquatic and air pollution. Hence made scarcity of surface drinking water due to concentration of nitrogen, phosphorous, ammonia and pathogen contamination. Also (Steinfeld et al., 2006) reported that the animals sector contribute to the environmental pollution especially increase of greenhouse gas
emission about 37% of anthropogenic N2O and 64% of anthropogenic NH3 gasses are in the World are originated from animal production sector.

Production of biogas from anaerobic process offer multiple benefits compared to other form of energy production. It reduces the greenhouse gas emission compared to fossils fuel. The digestate is an important resource which can be used as fertilizer in the agriculture and be a substitute for the mineral fertilizer (Weiland and biotechnology, 2010).

2.12.2 Biochemical process of Methane production
Process of methane formation is a complex process which is divided into four phases, hydrolysis, acinogenesis, dehydrogenation and methanogenesis. All four phases of digestion process depend on the degradation rates. Equal sizes of degradation rates it prevents the drops down on pH because the drop down can affect the methanogenic bacteria.

![Methane production diagram](image)

Figure 20: Methane production
Digestion process takes place at mesophilic 35-42C and thermophilic 45-60C temperature conditions it is important to keep constant temperature during digestion process, as temperature changes or fluctuations will affect the biogas production negatively. various substrate can be used
for the production of biogas as they have shown by (Weiland and biotechnology, 2010) this substrate have shown on the table below.

Table 7: Different substrate for biogas production

<table>
<thead>
<tr>
<th>Biogas yield [m³/ha FM]</th>
<th>Agricultural Wastes</th>
<th>Agricultural Raw Materials</th>
<th>Non-Agricultural Wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow manure</td>
<td>25</td>
<td>102 Grass</td>
<td>120 Biowaste</td>
</tr>
<tr>
<td>Pig manure</td>
<td>30</td>
<td>110 Fodder beets</td>
<td>24 C Food residues</td>
</tr>
<tr>
<td>Wheat grass</td>
<td>200</td>
<td>125 Sudan grass</td>
<td>400 Fat trap</td>
</tr>
<tr>
<td>Maize</td>
<td>650</td>
<td>200 Maze</td>
<td>800 Used grease</td>
</tr>
</tbody>
</table>

2.12.3 Biomass of biogas
There are three main types of biomass for biogas production which are (substrate from private households and municipal wastewater, substrate from farm such as liquid manure, harvest waste and feed waste, industrial byproducts from food processing of fat separators. The degradation of substrate depends on uniform pH, optimum temperature, nutrients supply and the absence of oxygen gas (Gerardi, 2003)

2.13 Feed stock
Feed stock is any substrate that can be converted to methane by anaerobic bacteria. The increase of environment awareness and good ways of management of waste in 1970s lead for the formation of word biogas feedstock. Various sources of feedstocks as they have been by (Steffen et al., 1998) on the table below were categorized into agriculture, community waste and industry.
Figure 21: Feedstocks from different sources

Feedstock from anaerobic digester contain nutrients which are essential to plant both micro and macro nutrients, also it happen containing heavy metals and organic compound which are resulted from the food of animal and from some medicine. Most of animals they do not use macro nutrient they give out as excreta and this nutrients are important for the life of animals, bacteria and plants composition of animals manure depends on the digestive system of animals, also geographical location and climatic condition of the area. Example composition of manures from different animals in UK has shown on table 8 below.

Table 8: Composition of manure from different animals in Kgm⁻³ in UK (Lukehurst et al., 2010)

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>TS %</th>
<th>Total N</th>
<th>NH₄-N</th>
<th>P</th>
<th>K</th>
<th>S</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy cow slurry</td>
<td>6</td>
<td>3.0</td>
<td>2.0</td>
<td>0.5</td>
<td>2.9</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Pig slurry</td>
<td>4</td>
<td>4.0</td>
<td>2.5</td>
<td>0.9</td>
<td>2.1</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Poultry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layer manure</td>
<td>30</td>
<td>16.0</td>
<td>3.2</td>
<td>5.7</td>
<td>7.5</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Broiler/turkey litter</td>
<td>60</td>
<td>30.0</td>
<td>12.0</td>
<td>10.9</td>
<td>15</td>
<td>3.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Farmyard Manure cattle</td>
<td>25</td>
<td>6.0</td>
<td>0.6</td>
<td>1.5</td>
<td>6.7</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Pig</td>
<td>25</td>
<td>7.0</td>
<td>0.7</td>
<td>3.1</td>
<td>4.2</td>
<td>0.7</td>
<td>0.4</td>
</tr>
</tbody>
</table>

2.13.1 Storage of digested
For the application of digested manure as fertilizer the storage is important since manures is produced every day from animals. Storage time it varies from one country to another due to different in climatic conditions, geographical location, winter seasons, soil type, crop rotations and rules and regulation governing the application of manure. Usually the recommended time for
storage of manure is 6-9 months. Some countries have put the storage time of before applied to the farms as is shown on the table

**Table 9**: Examples national limit regulating storage time of digested amended from Nordberg 1992

<table>
<thead>
<tr>
<th>Country</th>
<th>Maximum nutrient load</th>
<th>Required storage capacity</th>
<th>Compulsory season for spreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>170 kg N/ha/year</td>
<td>6 months</td>
<td>28 Feb – 5 Oct</td>
</tr>
<tr>
<td>Denmark</td>
<td>170 kg N/ha/year (cattle)</td>
<td>9 months</td>
<td>1 Feb – harvest</td>
</tr>
<tr>
<td></td>
<td>140 kg N/ha/year (pig)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>170 – 500 kg N/ha/year</td>
<td>90 – 180 days</td>
<td>1 Feb – 1 Dec</td>
</tr>
<tr>
<td>Sweden</td>
<td>170 kg N/ha/year (calculated from livestock units per ha)</td>
<td>6 – 10 months</td>
<td>1 Feb – 1 Dec</td>
</tr>
<tr>
<td>Northern Ireland</td>
<td>170 kg N/ha/year</td>
<td>4 months</td>
<td>1 Feb – 14 Oct</td>
</tr>
<tr>
<td>Germany</td>
<td>170 kg N/ha/year</td>
<td>6 month</td>
<td>1 Feb – 31 Oct Arable land 1 Feb – 14 Nov Grassland</td>
</tr>
</tbody>
</table>

Source: (Holm-Nielsen et al., 2009)

For the purpose of minimizing emission of methane and ammonia gas, most storage of digestate slurries are covered by a protective layer which can be plastic a floating layer or natural crust of 10-20 cm (Lukehurst et al., 2010)

### 2.13.2 Application of digestate

The machine used for the spreading of farmyard manure it can also be used for the application of raw slurry and digestate. For optimum use of fertilizer, the digestate must be applied to the farm during the growing season.
2.14 Environmental effects of using digestate as fertilizer
2.14.1 Odors
Manures from animals and organic waste contains volatiles organic compound like butanoic acid, iso-butanoic and valeric acid. These organic compounds are the ones that produce unpleasant smell. Proper spreading method and digestion of manures it helps to reduce the concentration of organic compound as reported by (Prapaspongsa et al., 2010).

2.14.2 Plant pathogen reduction
Few studies have tested the effects of Anaerobic digestate on the survival of the rate of pathogen that affects the plants. (Haraldsson, 2008) Showed that the using of mesophilic digestion hydraulic retention time between 25-30days, the chance of inhibiting fungal diseases of plants is higher. Also the combination of factors for operation of digester which are temperature, time, pH level, quantities of volatiles fatty acid and hydrogen sulphide, the combination of these factors create the holistic environment for the growth of fungi spores.

2.15 Agricultural waste suitable for Anaerobic digestion
2.15.1 Pig slurry
Pig meat production global has increased in recent decades, which result to the production of large volume waste that cannot be recycled. The amount of Phosphorus and nitrogen in pig excreta is
Pig farming is the major agricultural industry in the European Union nowadays, due to its increase the EU has made some of regulation and rules to direct the farmers on how to use pig manure as direct fertilizer to the farms since manure from pig contained high amount of odor and organic contents which threatens the health of farmers (Karakashev et al., 2008). Also production of manure claimed to contribute the increase of greenhouse gas emission. The need of suitable and sustainable ways to control and manage pig manure for the purpose of minimizing N2O gas emission and recovering of Phosphorus and nitrogen. The best way to close the loop of N2O gas emission is to practice recycling measures from the production to utilization of different sources of wastewater as described by Anaerobic digestion of pig manure in full scale biogas plant it offers a lot of advantages such as production of renewable energy methane, recycling nutrients back to the soil, odor and pollution reducing. In order to meet the wastewater discharge effluents, treatment of pig manure it advised to be like of treating domestic wastewater. Ways of treatment that are used frequently are upflowed anaerobic sludge blanket, phosphorus removal by struvite precipitation, complet autotroph nitrogen removal over nitrite (Slikers et al., 2002). Also in Europe production of animal manures is about 1500 million tones every year (table 10) this it include manures from pigs, cattle production industry and from poultry, fish and fur all of this can be used for the production of biogas and recovering of nutrients as fertilizers.

2.16 Pharmaceutics, hormones and Struvite

In conventional wastewater treatment, the removal of micro-pollutant such as hormones and pharmaceutical is difficult since they require sophisticated technology for removing it from wastewater. (Winker et al., 2009) Showed that in source separation treatment the concentration of hormones and pharmaceutical based on urine or blackwater are present at higher concentration (µg/L to mg/L range) as shown on table 10. Also for a safe use of urine as fertilizer World Health organization advises a period of more than six month of storing urine before applying as fertilizer. Hormones and pharmaceutical are considered potential danger in both aquatic and human being. Few nanograms per liter of these micro-pollutant can affect the reproductive system and imbalance I hormones for the riverine fish (Baronti et al., 2000).
Also (Clausen et al., 2001) reported that ionic and non-ionic molecules can adsorb to the surface of inorganic minerals, the need of investigating if hormones and pharmaceutical precipitate together with struvite and they can adsorb to the struvite crystals. List of Pharmaceutical and hormones at table 10

<table>
<thead>
<tr>
<th>Drug</th>
<th>specification</th>
<th>study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diclofenac</td>
<td>Anti-inflammatory</td>
<td>(de Boer et al., 2018, Ronteltap et al., 2007)</td>
</tr>
<tr>
<td>Propanol</td>
<td>Betablocker</td>
<td>(de Boer et al., 2018)</td>
</tr>
<tr>
<td>Estradiol E2</td>
<td>Natural hormone</td>
<td>(Ronteltap et al., 2007, de Boer et al., 2018)</td>
</tr>
<tr>
<td>Ethinylestradiol EE2</td>
<td>Synthetic steroid oral contraceptive</td>
<td>(Ronteltap et al., 2007)</td>
</tr>
<tr>
<td>Estrone E1</td>
<td>Natural hormone</td>
<td>(Ronteltap et al., 2007)</td>
</tr>
<tr>
<td>Tramadol</td>
<td>Opioid analgesic</td>
<td>(Schürmann et al., 2012)</td>
</tr>
<tr>
<td>Nebivolol</td>
<td>Betablocker</td>
<td>(Schürmann et al., 2012)</td>
</tr>
<tr>
<td>Metoprolol</td>
<td>Betablocker</td>
<td>(Schürmann et al., 2012)</td>
</tr>
</tbody>
</table>

To see if hormones and pharmaceutical they can adsorb struvite crystal (Escher et al., 2006) stimulated an average population in their study, whereby the urine collected was spiked with pharmaceutical and hormones. From table 11 it shows the results from different studies about the recovery efficiency of pharmaceutical is interpreted as the number of pharmaceuticals which are remaining in the solution after struvite precipitation. High recovery rate it indicates the clean of struvite crystals.
Table 11: Concentration and recovery efficiency of Pharmaceutical after batch Experiment with Struvite

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>PO4-P</th>
<th>Mg</th>
<th>Propranolol</th>
<th>Ibuprofen</th>
<th>Diclofenac</th>
<th>Carbamazepine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Initial</td>
<td>[mg.L⁻¹]</td>
<td>255</td>
<td>-</td>
<td>19.05</td>
<td>37.84</td>
<td>54.12</td>
<td>63.90</td>
</tr>
<tr>
<td>Effluent</td>
<td>[mg.L⁻¹]</td>
<td>2</td>
<td>56</td>
<td>19.09</td>
<td>37.88</td>
<td>52.88</td>
<td>53.35</td>
</tr>
<tr>
<td>Struvite</td>
<td>[mg.L⁻¹]</td>
<td>278</td>
<td>241</td>
<td>0.15</td>
<td>&lt;LOD</td>
<td>&lt;LOD</td>
<td>0.20</td>
</tr>
<tr>
<td>Recovery</td>
<td>[%]</td>
<td></td>
<td></td>
<td>95.3</td>
<td>99.2</td>
<td>97.1</td>
<td>83.0</td>
</tr>
<tr>
<td>2nd Initial</td>
<td>[mg.L⁻¹]</td>
<td>255</td>
<td>-</td>
<td>10.86</td>
<td>38.95</td>
<td>54.15</td>
<td>53.90</td>
</tr>
<tr>
<td>Effluent</td>
<td>[mg.L⁻¹]</td>
<td>2</td>
<td>76</td>
<td>19.53</td>
<td>37.74</td>
<td>53.35</td>
<td>54.75</td>
</tr>
<tr>
<td>Struvite</td>
<td>[mg.L⁻¹]</td>
<td>286</td>
<td>214</td>
<td>0.15</td>
<td>&lt;LOD</td>
<td>&lt;LOD</td>
<td>0.14</td>
</tr>
<tr>
<td>Recovery</td>
<td>[%]</td>
<td></td>
<td></td>
<td>96.6</td>
<td>98.7</td>
<td>98.0</td>
<td>99.8</td>
</tr>
<tr>
<td>3rd Initial</td>
<td>[mg.L⁻¹]</td>
<td>0.014</td>
<td>-</td>
<td>2.7</td>
<td>0.640</td>
<td>0.234</td>
<td></td>
</tr>
<tr>
<td>Effluent</td>
<td>[mg.L⁻¹]</td>
<td>0.006</td>
<td>-</td>
<td>3.2</td>
<td>0.550</td>
<td>0.180</td>
<td></td>
</tr>
<tr>
<td>Struvite</td>
<td>[%]</td>
<td>58%</td>
<td>-7%</td>
<td>14%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovery</td>
<td>[%]</td>
<td>&gt; 99.9</td>
<td>&gt; 99.9</td>
<td>&gt; 99.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(8)(Ronteltap et al. 2007), (9)(Boer et al. 2018), (10)(Escher et al. 2006)

The lowest recovery of Carbamazepine in batch 1 was likely caused by contamination (Ronteltap et al., 2007). Also difference from Escher and Ronteltap recovery rates are significant lower due different in concentration used from table 11 it is easy to recover larger quantity of higher amount than one which contain small quantity of micro-pollutant.

Also the ratio of Mg:P plays an important roles in the uptake of pharmaceutical as showed by (Kemacheevakul et al., 2014). Ronteltap used a ratio of 1.5:1 while De Boer used 1.2:1. Lower ratio have a capacity to uptake hormones and pharmaceutical due to higher potential of amorphous impurity to adsorb in the struvite (de Boer et al., 2018).

2.17 Heavy metals
Heavy metals are natural element and have density of at least five times than of water. Heavy metals are widely used in industries, agricultural, medical and technological application led to their distribution in the environment. Their toxicity affect environment and living organisms depending on the route, degree of exposure and chemical sources (Tchounwou et al., 2012).
Presence of trace element silver, mercury, cadmium, lead, and chromium in struvite can increase the possibility of affecting human being, it was reported that heavy metal can substitute P, Mg and NH4. Also cadmium is important matter for the growth of plant but it has health impacts if consumed by human it results to the kidney failure, skeletal and respiratory systems to perform worse (Zamora et al., 2017b).

Pure urine from healthy person contain less concentration of heavy metals than convectional fertilizers (Ronteltap et al., 2007). Presence of heavy metals in fertilizer is undesirable in the sustainable agriculture, since may accumulate into soil diffuse into aquatic environment and led to adverse impact on both plants and animals. (Liu et al., 2013b) did a study to investigate the concentration of heavy metals from different sources and compared with the legal limit table 12.

Table 12: Comparison of heavy metals concentration in struvite produced from various wastewater with legal limits (Liu et al., 2013b)

<table>
<thead>
<tr>
<th>Heavy metal</th>
<th>Legal limit</th>
<th>Recovered struvite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Germany</td>
<td>Turkey</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>1.5</td>
<td>ND</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>80</td>
<td>120</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>70</td>
<td>ND</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>150</td>
<td>ND</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>2</td>
<td>ND</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>1000</td>
<td>1100</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>References</td>
<td>119</td>
<td>ND</td>
</tr>
</tbody>
</table>

2.18 Application of struvite in agriculture

Struvite is currently considered, recyclable, environmental friendly fertilizer because as good slow release Phosphorus-based on the small content of magnesium and ammonia, have low content of heavymetals, has less loss of N compared to urea (Doyle and Parsons, 2002). Different trials conducted based on the pot evaluation showed that MAP have good quality and efficiency on the improving growth of fruits, grasses, turf, seedling and vegetables (Münch and Barr, 2001).

MAP has been found to good effective slow release fertilizer source of N, P and Mg. The behavior of MAP on slow release made it to be advantageous when highly soluble fertilizer are undesirable to some environmental conditions like grassland, coastal agriculture and forests. Also MAP can be applied frequent into plants since it has no burning effects to the roots of plants (Nelson et al., 2000).
4.0 MATERIALS AND METHODS
Different sources of information were used but most scientific journals were used since they are currently updated compared to books. This chapter give an overview of different reagents and chemicals used for the laboratory experiment.

4.1 Wastewater sample collection
4.1.1 Digested black water from Kaja
500ml of digested blackwater were taken from the anaerobic biogas reactor found at Realtek laboratory NMBU and stored at room of 4C temperature.

4.2 Magnesium sources
4.2.1 Seawater
Seawater was collected into 7lites plastic bottle at 9th April, 2019 in Drøbak Norway the eastern shore of Oslo Fjord. Sample were stored in REALTEK laboratory fridge since there were no any visible turbidity during the sampling. Whatman glass microfibre GF/C filter of pore size 1.2 µm with pressure filtration were used for filtration of sample in order to remove the unwanted suspended particle since unwanted particles can alter the reaction. Sample were taken to REALTEK lab for the analysis of Total P, N and PH of sea water.

4.2.2 Magnesium chloride
Magnesium chloride powdered were used as source of Magnesium because it has the good capacity to precipitate struvite, easy to handle, short reaction rate and availability. MgCl2 solution was prepared dissolving 40grams of MgCl2 into 100ml of deionized water to form 2molar of MgCl2 solution.

4.3 Adjustment of pH
The value of pH is an important factor for struvite precipitation, the adjustment of pH were done by adding few drops sodium hydroxide solution. Struvite precipitation occurs at pH range of 8 to 9 (Le Corre et al., 2009) also wastewater pH is valid due to poor buffer capacity and low concentration of ammonium compared to urine (Zamora et al., 2017a). The pH were measured by using portable pH 20 VWR electrode were pH meter calibrated by measuring the pH on a pH 7 buffer at a room temperature. Also the pH meter were rinsed in tap water and dried by a paper tissue and placed in 3M Potassium chloride solution. The initial pH value of Kaja wastewater was
pH 7.4 the adjustment of pH was done by adding few drops of 2M NaOH and reached to pH 8.5 and 9 which are favorable for struvite precipitation.

4.5 Mixing
Speed of stirring need to be slow because it can limit the crystal growth and lead scaling on the walls of the reactor (Wilsenach et al., 2007). Magnetic stirrer was used to ensure that wastewater and source of magnesium they are mixed well for this experiment stirring was done at 300rpm for three minutes and lowered to 2 minutes. The mixing time of sea water was limited to 10 minutes before the filtration process started. Stirring is vital for struvite precipitation since it enhance the pH caused by carbon dioxide stripping and it increase the removal efficiency from 72.2% without stirring to 97.3% with mixing (Liu et al., 2013a).

4.6 Chemical analysis
4.6.1 Sample treatment
4.6.2 Sample preparation for Total Phosphorous
All samples for Total P was done according to LCK350 method as it shown on the figure. Whereby for total P all the procedures from 1 to 14 were followed. Finally, the sample were placed into a Hach Lange 3900 DR for N and Total P and Phosphate for reading values.
Figure 22 Total P procedures according to LCK 350 method

Phosphate
Sample for Phosphate were prepared by taking procedure from 1-5

Figure 23 Phosphate Sample preparation according to LCK 350 method.
4.7 Design of experiment

According to the theory and hypothesis, maximum P removal should occur under the conditions which are shown on Table 11. For the better removal efficiency the value of PO\textsubscript{4} was kept constant while value of Mg is changed as in ratio 1:1 and 1.3:1 of Mg:PO\textsubscript{4} respectively. The experiment carried out at constant pH 9 and Mixing time.

Table 13: Conditions for struvite precipitation

<table>
<thead>
<tr>
<th>Mixing ratio</th>
<th>Digested black water from Kaja</th>
<th>Seawater</th>
<th>MgCl\textsubscript{2}</th>
<th>pH</th>
<th>Mixing time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 :1</td>
<td>25ml</td>
<td>25ml</td>
<td>25ml</td>
<td>9 and 8.5</td>
<td>10</td>
</tr>
<tr>
<td>1.3 :1</td>
<td>25ml</td>
<td>32.5ml</td>
<td>32.5ml</td>
<td>9 and 8.5</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 14: Characteristics of pretreated Digested blackwater

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Digested anaerobic blackwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.4</td>
</tr>
<tr>
<td>Total Phosphorous mg-l</td>
<td>112.0</td>
</tr>
<tr>
<td>PO\textsubscript{4}-P mg-l</td>
<td>101.0</td>
</tr>
<tr>
<td>NH\textsubscript{4}-N mg-l</td>
<td>1230.0</td>
</tr>
</tbody>
</table>

4.8 Removal efficiency

The removal efficiency for both total P and PO\textsubscript{4}-P was calculated by the following

% Removal efficiency = \([C_i - C_e]/C_i \times 100\)

where:

\(C_i\) = initial concentration in mg/l
\(C_e\) = effluent concentration after treatment with seawater or MgCl\textsubscript{2} in mg/l
5.0 RESULTS AND DISCUSSION

In this chapter, the key findings of the experiment on the removal of phosphorous, influence of pH, the crystallization reaction formula, influence of Mg source, total phosphorous removal and NH4-N removal are presented.

5.1 Removal of Phosphorous

Table 15: Results removal of Phosphorous by using seawater and MgCl\textsubscript{2} at pH

<table>
<thead>
<tr>
<th>Magnesium source</th>
<th>pH</th>
<th>Total P-mg/L</th>
<th>Total P% removal</th>
<th>PO4-P mg/L</th>
<th>PO4-P % removal</th>
<th>NH4-N mg/L</th>
<th>NH4-N% removal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seawater</strong></td>
<td>8.5</td>
<td>8.1</td>
<td>92</td>
<td>1.43</td>
<td>98.6</td>
<td>631</td>
<td>48.7</td>
</tr>
<tr>
<td>9.0</td>
<td>4.9</td>
<td>95.6</td>
<td>1.00</td>
<td>99.0</td>
<td>559</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seawater</td>
<td>8.5</td>
<td>4.7</td>
<td>95.8</td>
<td>1.60</td>
<td>98.4</td>
<td>451</td>
<td>63.3</td>
</tr>
<tr>
<td>9.0</td>
<td>4.1</td>
<td>96.3</td>
<td>1.20</td>
<td>98.8</td>
<td>487</td>
<td>60.4</td>
<td></td>
</tr>
<tr>
<td>MgCl\textsubscript{2}</td>
<td>8.5</td>
<td>4.2</td>
<td>96.3</td>
<td>4.90</td>
<td>95.1</td>
<td>618</td>
<td>49.8</td>
</tr>
<tr>
<td>9.0</td>
<td>0.7</td>
<td>99.4</td>
<td>2.40</td>
<td>97.7</td>
<td>546</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MgCl\textsubscript{2}</td>
<td>8.5</td>
<td>5.0</td>
<td>95.6</td>
<td>4.20</td>
<td>95.9</td>
<td>625</td>
<td>49.2</td>
</tr>
<tr>
<td>9.0</td>
<td>0.3</td>
<td>99.7</td>
<td>3.10</td>
<td>97</td>
<td>455</td>
<td>63.0</td>
<td></td>
</tr>
</tbody>
</table>

Source: Own Data 2019

Figure 24: Removal of total Phosphorous
At high mixing ratio of Mg : P of 1.3 :1 in this study the removal efficiency was above 92% in both total P and PO4-P. However seawater has shown high removal efficiency compared to MgCl2. This means that sea water can be used as alternative source struvite to the place which are located near the ocean but its challenge is on transportation cost if the wastewater treatment plant is far. Also on the study done by (Shin and Lee, 1998) showed that removal efficiency of P was 95% and 97% respectively of both MgCl2 and seawater. At mixing ratio of 1:1 removal efficiency was also above 92% in this study. In the study done by (Rahman et al., 2011) found that 93% of P was removed at the ratio of 1:1 which is the same as in this study. Since hypothesis was to achieve removal efficiency higher than 90% with an increase of the molar ratio.

5.4 Total Phosphate
Removal efficiency is the same almost for both ortho phosphate and total P and it was above 92% removal in this study for both ortho and total P as shown in fig 24 and fig 25. The increasing of Mg2+ concentration is significant for achieving higher removal efficiency.

![PO₄-P removal efficiency](image_url)

Figure 25: Phosphate removal

5.5 NH4-N removal
Maximum removal efficiency for NH4-N in this study was 63% as shown at figure 23 at seawater with mixing ratio of 1.3:1 and the lowest was 48.69% with mixing ratio of 1:1 with seawater. While by using MgCl2 the removal efficiency was 63% as highest and lowest was 48% at mixing...
ratio of 1.3: 1 and 1: 1 and pH 9 and 8.5 respectively. The lowest removal efficiency is likely due to Ammonia stripping during the stirrings process. However also (Kim et al., 2007) found that removal efficiency of NH4-N from blackwater was below 50% by using both seawater and MgCl2. On the study done by Linda 2018 by using urine as source of wastewater found removal efficiency by using seawater 83% and 70% by using MgCl2.

Figure 26 Removal of NH4-N
7.0 APPENDICES

Appendix 1: Laboratory Activities
8.0 REFERENCES


ASHLEY, K., CORDELL, D. & MAVINIC, D. J. C. 2011. A brief history of phosphorus: from the philosopher’s stone to nutrient recovery and reuse. 84, 737-746.


HEINZMANN, B. J. B. 2009. P recovery in Berlin from pilot scale experiments to large scale application. 21, 28-30.


LODDER, R., MEULENKAMP, R. & NOTENBOOM, G. 2011. Fosfaatterugwinning in communale afvalwaterzuiveringsinstallaties. STOWA.


RONTELTAP, M. 2009. Phosphorus recovery from source-separated urine through the precipitation of struvite. ETH Zurich.


