

Evaluation of an Extended Aeration System for Nutrient Removal

A Case Study of a Wastewater Treatment Plant
in Kulai, Johor Baharu, Malaysia



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Water and Environmental Engineering
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by

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Picture on front page: Bandarputra WWTP. Photo by Naima Forså.

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A handwritten signature in cursive script that reads "Gerhard Barmen".

Gerhard Barmen
Local MFS Programme Officer

Preface

This report is the result of the master thesis performed by Naima Forså and Caroline Ingvar-Nilsson, both studying a Master of Science in Environmental Engineering specialising in the field of water resource management at Lunds Tekniska Högskola. The master thesis was conducted at Water and Environmental Engineering, Department of Chemical Engineering, Faculty of Engineering, Lund University. The thesis has been conducted in cooperation with the Centre for Environmental Sustainability and Water Security (IPASA) at Universiti Teknologi Malaysia (UTM), Indah Water Consortium (IWK) and the Swedish International Development Cooperation Agency, SIDA.

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Abstract

Malaysia is one of the most developed countries in Southeast Asia, and strives to be acknowledged as a high income country by the year of 2020. According to Malaysian Environmental Quality (Sewage) Regulations from 2009 there are effluent limitations regarding nutrient emission from wastewater treatment plants. The company responsible for the municipal wastewater treatment, Indah Water Konsortium, have found that the performances of nutrient removal at their wastewater treatment plants are varying and the company is interested in examining the reason for the difference. This study has investigated nutrient removal at one of Indah Water Konsortium's wastewater treatment plants in order to evaluate how well it is working and what could be done in order to improve the nutrient reduction.

The investigated wastewater treatment plant is an activated sludge plant with extended aeration and a primary treatment consisting of grit and grease removal. The characteristics of the influent wastewater is purely domestic. The plant is designed for 1216 population equivalents and at present 1160 population equivalents are connected.

The aims were to evaluate the nutrient reduction, analyse whether biological phosphorus removal called Bio-P could be possible and to give suggestions for possible upgrades and improvements of the plant. It was done by constructing a nitrogen and phosphorus mass balance. Also, analyses were performed to assess the nitrification rate, measure the amount of volatile fatty acids in the influent and basic parameters such as dissolved oxygen, pH, mixed liquor suspended solids and aerobic sludge age. Samples were taken three times a week during a five-week period starting from the 21st of March 2016.

The analyses showed that organic matter, measured as BOD and COD, were satisfactorily reduced. The nitrogen mass balances showed that nitrification and denitrification occurred, however the processes were uneven and not reliable. The results also showed that both the measured maximum and full-scale nitrification rate were very low which probably was due to low oxygen concentration and pH-levels in the aerobic tank. The mixed liquor suspended solids concentration and the aerobic sludge age was found to be enough for the bacteria to carry out the nitrification process, assimilate nutrients and for BOD-reduction.

The phosphorus mass balances showed that more phosphorus than expected was removed from the wastewater treatment plant; there was high phosphorus content in the sludge. The high removal may be due to Bio-P. Furthermore, investigations showed that there were enough volatile fatty acids in the wastewater to obtain Bio-P. If the characteristics of the wastewater are similar at other places, Bio-P could be an option for the future at wastewater treatment plants in Malaysia.

In order to upgrade the plant, calculations were made to evaluate if the size of the tank used for biological treatment is sufficient for nitrification and if there is space to incorporate an anoxic tank in order to get a pre-denitrification treatment. The results showed that with an expected nitrification and denitrification rate at the wastewater treatment plant the present volume is large enough for a pre-denitrification process. One of the main improvements that could be made at the wastewater treatment plant is to increase the nitrification rate by improving the aeration.

Keywords: Nutrients; Nitrogen; Phosphorus; Activated Sludge; Extended Aeration; Nitrification rate; Volatile Fatty Acids; Bio-P.

Sammanfattning

Malaysia är ett av Sydostasiens mest utvecklade länder och har som mål att vara ett höginkomstland år 2020. I enlighet med malaysisk lag finns det utsläppsgränser som reglerar hur mycket närsalter som får släppas ut från avloppsreningsverk. Företaget Indah Water Konsortium är ansvarigt för skötseln av den kommunala avloppsreningen i Malaysia och ansvarar för att utsläppsgränserna efterföljs. Indah Water Konsortium har problem med att närsaltsreduktionen vid deras avloppsreningsverk varierar i effektivitet och vill hitta den bakomliggande orsaken till detta. Denna studie har undersökt närsaltsreduktionen vid ett av Indah Water Konsortiums avloppsreningsverk för att analysera hur väl den fungerar och för att utvärdera om det finns förbättringsåtgärder som skulle kunna implementeras på verket.

Avloppsreningsverket som utvärderats är en aktivslamanläggning med utökad luftning samt en förbehandling med sand- och fettfång. Avloppsvattnet som renas är endast hushållsspillvattnet och inga industrier är kopplade till verket. Avloppsreningsverket är designat för 1216 personekvivalenter och under perioden som studien utfördes var 1160 personekvivalenter kopplade till verket.

Syftet med denna undersökning var att utreda hur väl näringsreduktionen fungerar, om det finns möjlighet att införa biologisk fosforreduktion (så kallad Bio-P) samt att ge förslag för tänkbar uppgradering och förbättring av verket. Detta utfördes genom att konstruera kväve- och fosformassbalanser. Även analyser av nitrifikationshastighet och koncentrationen av flyktiga fettsyror utfördes samt parametrar såsom syrehalt, pH, suspenderad substans i aktivslam och aerob slamålder mättes. Provtagning skedde på förmiddagen tre gånger i veckan under en femveckorsperiod som påbörjades den 21 mars 2016.

Analyser av organiskt material, i form av BOD och COD, visade att reduktionen var tillräcklig för att uppfylla utsläppskraven. Kvävemassbalanserna påvisade att nitrifikation och denitrifikation sker på verket men att effektiviteten av processerna var ojämna och inte helt tillförlitliga. Analyser visade också att den uppmätta maximala och fullskaliga nitrifikationshastigheten på reningsverket var mycket låg. Förmodligen på grund av låga syrekoncentrationer och lågt pH i den luftade tanken. Suspenderad substans koncentration och aerob slamåldern vid verket var tillräcklig för nitrifikation, assimilering av närsalter och för BOD-reduktion.

Fosformassbalansen visade på att det var högre fosforreduktion än förväntat och att detta kan bero på Bio-P. Vidare visade även analyserna att det var tillräckligt höga koncentrationer av flyktiga fettsyror för att kunna utföra Bio-P. Om avloppsvattnet är av liknande karaktär vid andra avloppsreningsverk i Malaysia kan detta innebära en möjlighet att använda Bio-P på fler verk i framtiden.

För att utvärdera möjligheterna till att uppgradera verket har volymberäkningar utförts. Syftet var att bedöma om tanken som används för biologisk rening var tillräcklig för nitrifikation och om det finns möjlighet att införa en anoxisk tank för för-denitrifikation. Resultatet visade att med förväntad nitrifikations- och denitrifikationshastighet är detta möjligt och att tanken är tillräckligt stor för för-denitrifikation. En möjlig förbättring för att öka nitrifikationshastigheten är att förbättra luftningen.

Table of contents

1	Introduction	1
1.1	Malaysia	1
1.2	Wastewater treatment in Malaysia	1
1.3	Aim	2
1.3.1	Research questions	3
1.3.2	Limitations	3
2	Theory	5
2.1	Short history of wastewater treatment	5
2.2	Organic matter	5
2.3	Major limiting nutrients: nitrogen and phosphorus	5
2.4	Primary treatment	6
2.5	Secondary treatment	6
2.5.1	Activated sludge	6
2.5.2	Extended aeration	7
2.6	Nitrification and denitrification	8
2.6.1	Hydrolysis of organic nitrogen	8
2.6.2	Nitrification	8
2.6.3	Denitrification	9
2.6.4	Nitrification and denitrification incorporated into an activated sludge process ..	9
2.6.5	Examples of nitrification rates	11
2.7	Phosphorus removal	11
2.8	Combined phosphorus and nitrogen removal	13
2.9	Wastewater characteristics	13
3	Material & methods	15
3.1	Literature study	15
3.2	JKI065 – Bandarputra wastewater treatment plant	15
3.3	Sampling & management of samples	19
3.4	Measured parameters	21
3.4.1	Dimensions	21
3.4.2	Flow measurements	21
3.4.3	Oxygen, pH & temperature	22
3.5	Experimental analysis	22
3.5.1	Nitrogen species	22
3.5.2	Phosphorus species	23
3.5.3	SS & VSS	23

3.5.4	Maximum nitrification rate	24
3.5.5	BOD ₅ & COD	25
3.5.6	Volatile fatty acids, VFA	26
3.6	Calculative analyses	27
3.6.1	Mass balance	27
3.6.2	Percent nitrogen & phosphorus in sludge	28
3.6.3	Hydraulic retention time, HRT	28
3.6.4	Full scale nitrification rate	28
3.6.5	Return activated sludge, RAS, flow	29
3.6.6	BOD:N:P & C/N	29
3.6.7	Aerobic sludge age, ASA	30
3.6.8	Volume dimensioning for a pre-denitrification process	30
4	Result & discussion	33
4.1	Basic parameters	33
4.1.1	Are the DO-levels high enough for biological nutrient reduction?	33
4.1.2	What are the pH-levels?	34
4.1.3	Is the MLSS concentration satisfactory for biological nutrient reduction?	34
4.1.4	Is the ASA sufficient for biological nutrient reduction?	35
4.2	Organic matter	35
4.2.1	How much BOD and COD are removed in the biological treatment?	35
4.3	Nitrogen	36
4.3.1	How much nitrogen is removed in the biological treatment?	36
4.3.2	Does nitrification take place?	37
4.3.3	What is the nitrification rate?	38
4.3.4	Does denitrification take place?	40
4.3.5	What dimensions are needed to install a pre-denitrification process at Bandarputra?	41
4.4	Phosphorus & VFA	42
4.4.1	How much phosphorus is removed in the biological treatment?	42
4.4.2	Are there any signs of Bio-P today?	43
4.4.3	Is the VFA concentration in the influent wastewater high enough to carry out Bio-P?	44
4.4.4	Is the VFA concentration in a sample affected by the storage?	44
4.4.5	Could Bio-P be an option for phosphorus removal at the WWTP?	45
4.5	Sources of errors	46
5	Conclusions	49
6	Further studies	51
7	References	53

8	Abbreviations.....	57
	Appendices.....	59
	Popular scientific summary.....	93

1 Introduction

The awareness of sustainable development is increasing around the world and for many people protection of the environment is an important matter. Water and sanitation is an essential part of human development and according to Lofrano & Brown (2010), the lack of sanitation could arguably affect humans to a larger extent than the lack of clean water.

With increased knowledge of the negative impact that disposal of nutrient-rich wastewater has on the environment, it has become important for wastewater treatment plants (WWTPs) to have an effective nutrient removal. Disposal of nutrient-rich wastewater result in eutrophication and a lack of oxygen in the recipient. During severe eutrophication, massive algae blooms occur and some algae produce toxic gas. When the algae are decomposed the oxygen is depleted. The bottom living organisms die due to oxygen depletion and fish and other organisms leaves the area or die from suffocation (EEA, 2016). The three compounds that are the main cause of this problem are organic matter, nitrogen and phosphorus.

1.1 Malaysia

Malaysia has about 30 million inhabitants. The capital is Kuala Lumpur with a population of 1.5 million. The country is divided into two parts, East Malaysia, located on the island Borneo, and Peninsular (West) Malaysia, located on the Malay Peninsula. The country is a federative constitutional monarchy and election is held every fifth year.

Malaysia is a multicultural society, about 50% of the population are Malays, 25% are Chinese and 8% are Indians. In the Muslim society about 60% are Sunni Muslims (Dahlgren, 2015). Malaysia is developing fast and is today one of the most developed countries in Southeast Asia. The government has set a goal to achieve high-income status by the year of 2020.

The case study was performed in Kulai. Kulai is a city in the southern part of Peninsular Malaysia located northeast of the city Johor Baharu which is the largest and capital city of the region. Kulai has a population of almost 64 000 inhabitants (GeoNames, 2015).

1.2 Wastewater treatment in Malaysia

In general there is a high access of clean water and sanitation facilities (The World Factbook, 2016). About 6 million tons of sewage is produced every year, it is treated and then released mainly into rivers. The main source of drinking water (98%) is surface water (APEC, 2009). To not contaminate this important source of drinking-water, proper treatment of wastewater is of great importance.

In modern Malaysia, before 1993, local authorities were responsible for the wastewater treatment and the standards of treatment varied widely. Today the Federal Government regulates the wastewater treatment industry in Malaysia. This was put into action after the Sewerage Service Act was passed in 1993. When the act was passed the Department of Sewerage Services was formed under the Ministry of Housing and Local Government and now it has the responsibility to regulate the wastewater treatment industry (Maniam, 2003). In 1994 Indah Water Konsortium (IWK) was formed and the company signed a contract with the federal government to operate, maintain and develop the sewage service in the country (JSC, 2011).

The Department of Environment is responsible for monitoring the treated wastewater effluents in Malaysia. There are two discharge standards; A and B (PU(A) 432/2009). Standard A has stricter regulations as the effluent is discharged into waters upstream of surface water supply intakes. Table 1.1 describes the effluent requirements for standards A and B (PU(A) 432/2009).

Table 1.1. Effluent requirements in Malaysia according to A and B standards (PU(A) 432/2009). Suspended solids is abbreviated SS.

Parameter	Standard A		Standard B	
	River/Stream (mg/L)	Enclosed water body (mg/L)	River/Stream (mg/L)	Enclosed water body (mg/L)
Ammonium	10	5	20	5
Nitrate	20	10	50	10
Phosphorus	N/A*	5	N/A*	10
BOD₅/COD	20/120	20/120	50/200	50/200
SS	50	50	100	100

*Not Applicable.

Today, only 38% of the WWTPs have both primary and secondary treatment, the remaining has usually a kind of primary treatment and insufficient secondary treatment. For the future, Malaysia is now investing in modern secondary treatment such as EA-processes, oxidation ditch, rotating biological contactors, sequencing batch reactors, or trickling filters (Indah Water Konsortium 2015b).

The performances of nutrient removal are varying at IWK's WWTPs depending on wastewater source, design and installation. The company is interested in examining the reasons of the differences and to find solutions for improvement. This study will investigate the nutrient removal at one of IWK's WWTPs in order to evaluate how well it is working and what could be done in order to improve the nutrient reduction.

1.3 Aim

The aim of this study was to conduct a comprehensive evaluation of the biological treatment performance in an extended aeration (EA) system, by evaluating the effectiveness of nitrogen and phosphorus removal at one of IWK's WWTPs.

The aim was furthermore to investigate whether biological phosphorus removal could be a future option for the WWTP.

At last the aim was to give suggestions for improvements of the operation and design of the WWTP.

1.3.1 Research questions

To reach the aim a set of research questions have been constructed.

Basic parameters:

- What are the dissolved oxygen-levels?
- What are the pH-levels?
- Is the mixed liquor suspended solids concentration satisfactory for biological nutrient reduction?
- Is the aerobic sludge age sufficient for biological nutrient reduction?

Organic matter:

- How much BOD and COD are removed in the biological treatment?

Nitrogen:

- How much nitrogen is removed in the biological treatment?
- Does nitrification take place?
- What is the nitrification rate?
- Does denitrification take place?
- What dimensions are needed to install a pre-denitrification process at the WWTP?

Phosphorus & volatile fatty acids:

- How much phosphorus is removed in the biological treatment?
- Are there any signs of biological phosphorus removal today?
- Is the volatile fatty acid concentration in the influent wastewater high enough to carry out biological phosphorus removal?
- Is the volatile fatty acid concentration in a sample affected by the storage?
- Could biological phosphorus removal be an option for phosphorus removal at the WWTP?

1.3.2 Limitations

The project was limited to nutrient reduction. Reduction of other parameters was not included in the project. Furthermore, the study focused on biological nutrient removal in suspended activated sludge processes.

The field study was time limited and sampling for analyses were performed for one month. Samples were taken three days a week and they were all taken around the same time of the day. The study was also limited to one WWTP in Malaysia. The analyses were limited by very basic analysis methods performed in a basic lab.

2 Theory

In order to decrease the environmental impact on wastewater recipients, minimise eutrophication contribution, avoid the spreading of diseases and remove nutrients, treatment of wastewater is essential throughout our society.

2.1 Short history of wastewater treatment

For a long period in the history of mankind, urban wastewater management was not given much consideration. Wastewater was simply disposed in streets or other urban areas where it caused serious problems for the inhabitants, with outbreaks of epidemics etc. It was not until the industrialization in the 18th century that people began to understand the importance of treatment and safe disposal of wastewater. However, initial treatment was merely a matter of “dilution is the solution to pollution”. In the 20th century more proper treatment of wastewater began and effluent standards were introduced (Lofrano & Brown, 2010).

2.2 Organic matter

Organic matter is one of the basic building blocks for living organisms and also an important energy source for many organisms (Svenskt Vatten, 2013). Organic matter in wastewater is decomposed by a variety of different microorganisms. This decomposition requires oxygen and if effluent wastewater has high organic content it can cause lack of oxygen in the receiving recipient (Gillberg *et al.*, 2003). In wastewater there are several thousands of different organic constituents. Due to the great amount of different organics it is not possible to measure individual constituents. Instead collective analyses of organic matter is made for example, by measuring the biochemically consumed oxygen during a certain period of time (biological oxygen demand, BOD) or the part that can be oxidized chemically (chemical oxygen demand, COD) (Henze *et al.*, 2000; Metcalf & Eddy, 2003).

2.3 Major limiting nutrients: nitrogen and phosphorus

Nutrients are essential to biological growth. Nitrogen and phosphorus are the two main limiting nutrients and contribute to eutrophication if discharged in too large amounts (Metcalf & Eddy, 2003). In many lakes and streams that suffer from eutrophication wastewater is the main source of these nutrients (Ansari *et al.*, 2011).

Nitrogen

The most common forms of nitrogen found in wastewater are ammonia/ammonium ($\text{NH}_3/\text{NH}_4^+$), nitrogen gas (N_2), nitrite (NO_2^-), nitrate (NO_3^-) and organic nitrogen. Organic nitrogen is organic compounds that contain nitrogen, for example amino acids. A common measurement of nitrogen is total nitrogen (Tot-N) which includes organic nitrogen, ammonia/ammonium, nitrite and nitrate. Nitrogen can also be measured as Total Kjeldahl nitrogen which includes organic nitrogen and ammonia/ammonium (Metcalf & Eddy, 2003). Nitrogen is commonly removed from wastewater using biological nutrient removal (see Section 2.6.4).

Phosphorus

The most common forms of phosphorus in wastewater are orthophosphate (Ortho-P) and polyphosphate. Orthophosphate are directly available for biological metabolism, while polyphosphate first have to be decomposed to orthophosphate. Organic phosphorus is not of any major importance in domestic wastewater, however, it can be an important constitute of in-

dustrial waste and sludge produced from wastewater (Metcalf & Eddy, 2003). A common measurement of phosphorus is total phosphorus (Tot-P) which includes the different forms of phosphate and organic phosphorus (Berntsson, 2013).

2.4 Primary treatment

The first step in a WWTP is primary treatment and the objectives of primary treatment are to remove coarse material, reduce the suspended solids (SS) and remove the organic solids by removing readily settleable solids and floating material from the incoming wastewater. This is done by a series of different processes such as screening, grit removal, sedimentation and removal of floating content, for example oil and grease (Metcalf & Eddy, 2013; Burkhard *et al.*, 2000). About 25-50% BOD, 50-70% SS and about 65% oil and grease can be removed with proper primary treatment (FAO, 2015).

Screening is usually the first step of a WWTP. The screen allows water and small particles to pass and its purpose is to remove and retain solids to protect and facilitate further treatment. Following the screen is commonly a grit removal step. The grit removal is designed to remove grit such as sand and other inorganic heavy solids from the wastewater. The removal of grit can be performed by sedimentation or by centrifugal separation. Sedimentation is usually performed by installing a primary clarifier. In the primary clarifier the velocity of the wastewater is reduced which allows for sedimentation of readily settleable solids and some of the organic matter. The sediment particles and organic matter can then be removed as primary sludge. Floating solids and liquid (for example oil and grease) can be removed by aeration, where bubbles of air (or other gas) is introduced into the wastewater allowing floating solids and liquids to attach to the bubbles and rise to the surface where the unwanted material can be removed (Metcalf & Eddy, 2003).

2.5 Secondary treatment

Secondary treatment is usually next after primary treatment and removes SS and decreases BOD, using biological treatment. One common type of secondary treatment is activated sludge (AS) where bacteria convert soluble organic matter into solid biomass, sludge. The sludge settles and is removed in order to be taken care of. Though, salts, pharmaceuticals and similar indigestible matters are poorly removed (Hammer & Hammer, 2011). This section will only describe the AS process, however, other secondary treatment processes such as trickling filters, sequence batch reactors and oxidation ditches do exist.

2.5.1 Activated sludge

In an AS process the wastewater is treated in an aerated tank where bacteria oxidize BOD and assimilate it into sludge. Bacteria do also need nutrients like nitrogen and phosphorus; these are incorporated into the sludge. In general, a ratio of BOD:N:P=100:5:1 can be assimilated in AS treatment (EMIS, 2010; Liu & Liu, 2008).

A typical flow sheet of an AS process is displayed in Figure 2.1. The wastewater enters an aerated tank where organic matter is oxidised into carbon dioxide and sludge is produced by the bacteria. Subsequently, the water is passed into a clarifier in which the wastewater and the sludge is separated. The sludge settles and to obtain a high level of bacteria in the aerated tank, a major part is recirculated back to the aerated tank. The recycled sludge is referred to as return activated sludge (RAS). The sludge not recycled is removed of the system as excess sludge and carries on to further treatment. The wastewater in the clarifier leaves the clarifier

as effluent water to recipient or proceeds to further treatment (Hammer & Hammer, 2011; Metcalf & Eddy, 2003).

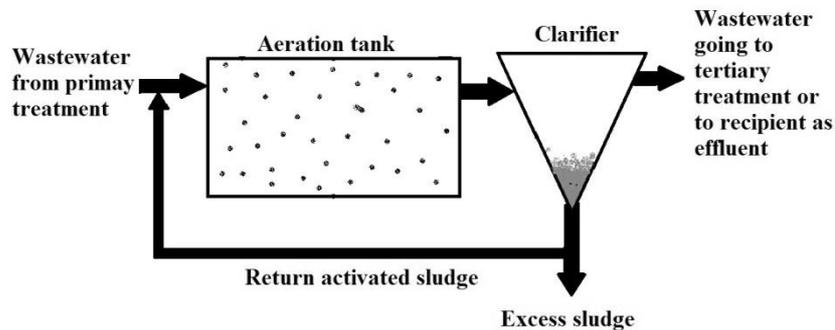


Figure 2.1. Flow chart of the activated sludge process.

The aerated tank is mixed continuously either mechanically or by diffused air to keep the bacterial sludge suspended. The SS is called mixed liquor suspended solids (MLSS) and the VSS is called mixed liquor volatile suspended solids (MLVSS) in the mixed aerated tank (Hammer & Hammer, 2011; Metcalf & Eddy, 2003). MLSS concentration in the aerated tank is usually in the range of 3 to 6 g/L (Orhon & Artan, 1994). There are several studies of AS WWTPs in different countries confirming the same range (3-6 mg/L) for cost and environmental impact optimization (Pitman, 1980; Al-Sa'ed & Tomaleh, 2012; De Gussem *et al.*, 2011). Too high MLSS cause bulking which can result in oxygen depletion or too much sludge in the clarifier which cause sludge loss. Too low MLSS concentration results in insufficient amount of bacteria and consequently no nutrient reduction.

Two important design parameters in an AS process is the aerobic sludge age (ASA) and the hydraulic retention time (HRT). ASA is the average time in days that a sludge particle spends in the aerated tank. It is defined as the ratio between the amount of sludge in the biological treatment and the amount of sludge removed each day (Gillberg *et al.*, 2003). The ASA in a conventional AS process is ranging from 3 to 10 days (Gott *et al.*, 2007). HRT is the average time the wastewater remains in the aerated tank. The HRT in an AS process is varying and can be in the range of 3 hours up to several days (Hammer & Hammer, 2011).

In the AS system assimilation of BOD, nitrogen and phosphorus is obtained according to the ratio of approximately 100:5:1. However, in influent wastewater this ratio is not commonly found. BOD is usually too low in concentration compared to the nitrogen and phosphorus concentrations (Hammer & Hammer, 2011). Therefore, further treatment has to be carried out to reduce the nitrogen and phosphorus not assimilated.

2.5.2 Extended aeration

One type of AS is EA and it is applied at the WWTP of which this study is conducted upon. The EA process has a longer ASA compared to a conventional AS process. In an EA process the sludge has an ASA longer than 10 days (Gott *et al.*, 2007). The longer ASA imply a higher BOD removal compared to conventional AS process (Water & Wastewater Engineering, 2016). The HRT for an EA process is between 24 and 36 hours (Hammer & Hammer, 2011).

2.6 Nitrification and denitrification

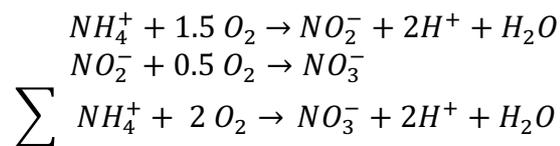
The nitrogen not assimilated is generally removed by allowing wastewater pass through alternating anoxic/aerated tanks where bacteria convert the nitrogen in the wastewater into nitrogen gas. In order to remove nitrogen three processes have to be carried out; hydrolysis of organic nitrogen, nitrification and denitrification (Metcalf & Eddy, 2003; Svenskt Vatten, 2013; Hammer & Hammer, 2011). The processes nitrification and denitrification can be incorporated in a WWTP by adding an anoxic tank to an EA system (Svenskt Vatten, 2013).

2.6.1 Hydrolysis of organic nitrogen

Bacterial decomposition of nitrogenous organic matter releases ammonium/ammonia in the wastewater and takes place already in the sewer system. About 40% of the nitrogen in the influent wastewater is ammonium and the remaining nitrogen is organic nitrogen (Hammer & Hammer, 2011). The pH in the wastewater will determine whether it is ammonium or ammonia that is produced. Ammonium is favoured by low pH and ammonia by high pH (Gillberg *et al.*, 2003).

2.6.2 Nitrification

The second step is to convert ammonium to nitrate; this process is called nitrification and occurs in two stages. First bacteria ammonia-oxidizing bacteria converts ammonium to nitrite which is then converted into nitrate by nitrite-oxidizing bacteria (Hammer & Hammer, 2011; Metcalf & Eddy, 2003; Gillberg *et al.*, 2003):



The optimal pH for nitrification is between pH 8-9 as the majority of ammonia-oxidizing bacteria only take up ammonia and not ammonium. If the pH is below 8 the nitrification is inhibited and if it is lower than 5.5 the nitrification stops. During nitrification alkalinity is reduced and this means that the pH might drop drastically during nitrification (Gillberg *et al.*, 2003). The optimal temperature for nitrifying bacteria is between 25-30°C (EPA, 2002). At temperatures of around 35-40°C the nitrification process declines rapidly towards zero (Henze *et al.*, 2000). A study performed by Wild *et al.* (1971) showed that the nitrification rate is directly proportional to the amount of nitrifiers and increases with the temperature up to 30°C which was the maximum temperature evaluated in the study. Furthermore, Wild *et al.* (1971) found that at 20°C the optimum pH for nitrification was pH 8.4.

Ammonia-oxidizing bacteria and nitrite-oxidizing bacteria are aerobic autotrophic bacteria and therefore the nitrification process needs to be aerated. For the nitrification process to work, the dissolved oxygen (DO) concentration in the aerated tank should not drop below 1-2 mg O₂/L (Gillberg *et al.*, 2003). The bacteria reducing BOD in the activated sludge process have a faster growth rate than the nitrifying bacteria. Therefore, to facilitate for the nitrifying bacteria, a low carbon-load is preferable as the heterotrophic bacteria will outcompete the autotrophic bacteria if organic material is present (Gillberg *et al.*, 2003).

In order to have nitrification the ASA have to exceed a certain period of time. This period of time is temperature dependent and decreases with increasing temperature, see Figure 2.2 (Henze *et al.*, 2000).

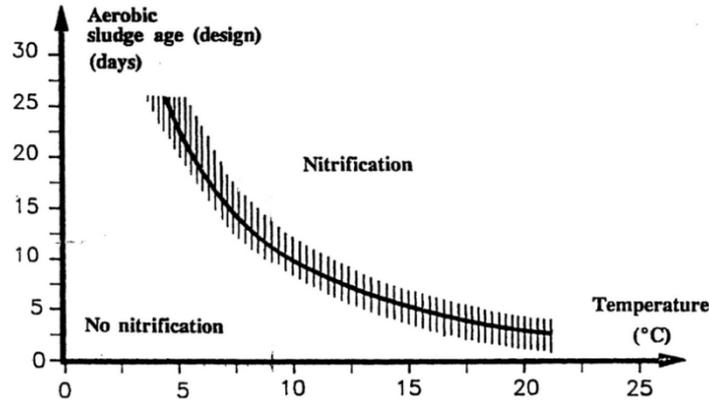
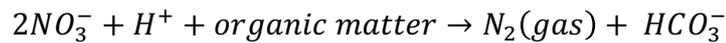


Figure 2.2. The aerobic sludge age needed as a function of temperature to reach nitrification (Henze *et al.*, 2000). Published with kind permission from Jes la Cour Jansen.

2.6.3 Denitrification

Finally, nitrogen is removed from the wastewater by denitrification, where bacteria transforms nitrate into nitrogen gas (Svenskt Vatten, 2013):



The denitrification bacteria are heterotrophic facultative anaerobic and therefore need organic matter as a substrate (Boundless, 2016). The denitrification process is performed under anoxic conditions. As there is no dissolved oxygen present the bacteria use nitrate as an electron acceptor instead of dissolved oxygen which results in the bacteria discharging nitrogen gas into the air (Hammer & Hammer, 2011).

The optimal pH for denitrification is between pH 7-9. Alkalinity is produced during the denitrification process and half the amount of the alkalinity lost during nitrification is recovered. The rate of denitrification is very dependent on the carbon source but also on the temperature; easily accessible carbon source and high temperature results in faster denitrification (Gillberg *et al.*, 2003). The rate of denitrification can therefore be increased by adding an easily accessible carbon source, e.g. methanol, to the process. The denitrification rate can vary a lot depending on the quality of the carbon source. If only the carbon content in wastewater is used for denitrification the expected denitrification rate at 30°C can range from 3-30 g NO_x/(kg VSS·h) (Gillberg *et al.*, 2003; Henze *et al.*, 2000; U.S Environmental Protection Agency, 1975).

2.6.4 Nitrification and denitrification incorporated into an activated sludge process

Several configurations can be used to incorporate the nitrification and denitrification into the activated sludge process. Two examples are pre-denitrification and post-denitrification (Figure 2.3). For both methods there are one tank with aeration and one tank without aeration where anoxic conditions prevails (Metcalf & Eddy, 2003).

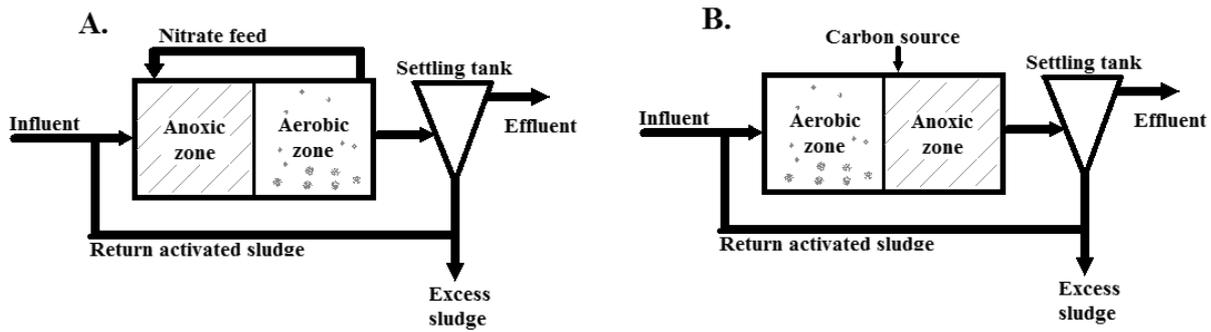


Figure 2.3. Flow scheme of A) pre-denitrification and B) post-denitrification.

Pre-denitrification

In the pre-denitrification process the anoxic tank is located before the aerated tank (Figure 2.3A). The organic matter in the incoming wastewater is used as a carbon source for denitrification and consequently giving a lower carbon load in the subsequent aerated tank where nitrification occurs. The produced nitrate is recycled back to the initial anoxic tank where it is denitrified. The amount of reduced nitrogen depends on the degree of recirculation of nitrate. A higher degree of RAS will enable a higher nitrogen reduction if there is enough organic matter. (Gillberg *et al.*, 2003). A deoxic tank can be introduced at the end of the aerated tank to make sure that the recirculated wastewater is not bringing oxygen into the anoxic tank.

The advantage of this method is that no carbon source has to be added since the BOD in the incoming water can be used for denitrification (Gillberg *et al.*, 2003). It is also energy saving as the BOD is oxidized without aeration in the anoxic tank, i.e. less oxygen is needed. The process is easy to install in already existing plants (Metcalf & Eddy, 2003). One of the disadvantages is that complete nitrate removal cannot be achieved as the aerated tank is located at the end of the process (van Haadel & van der Lubbe, 2007). However, this does not usually cause any problems as the removal is still efficient enough to reach effluent limits. Another disadvantage is that additional energy is needed for recirculation of nitrate (Hamada *et al.*, 2006).

Post-denitrification

In the post-denitrification process the aerated tank is located before the anoxic tank (Figure 2.3B). In the aerated tank carbon is oxidised and nitrate is produced. The wastewater entering the anoxic tank is rich in nitrate but poor in carbon and therefore, to achieve denitrification, an external carbon source has to be added. The carbon source added should be readily available for the bacteria for example, acetates or alcohols (Gillberg *et al.*, 2003; van Haadel & van der Lubbe, 2007). In practice, an aeration tank is often added at the end of the anoxic tank. As there may be residual organic matter from the added carbon source, the supplementary aeration tank maintains low BOD concentration in the effluent (van Haandel & van der Lubbe, 2007).

The advantage of post-denitrification is that a high proportion of nitrogen can be removed without the need of recirculation. However, addition of a carbon source is very costly (Gillberg *et al.*, 2003), as is additional aeration (Rosso *et al.*, 2008).

2.6.5 Examples of nitrification rates

Table 2.1 presents different nitrification rates from different WWTPs around the world. Table 2.1 also presents results from a nitrification rate analysis conducted at Källby WWTP prior to the field study in Malaysia. For description of the method used see Section 4.6.4. The rates in the table varies between 7.7 down to 0.8 g NH₄⁺-N/(VSS•h). The rates are in different temperature and pH intervals with different types of configurations of the WWTPs. The rate analyses also measure different types of nitrification rates at the plants. Maximum test analyses assess the maximum nitrification rate that can be achieved by the sludge and full-scale analyses assess the actual rate at which nitrification occurs at the WWTPs.

Table 2.1. Nitrification rates at different WWTPs around the world. Batch test is abbreviated (b) and full-scale nitrification is abbreviated (f).

City/ Town and country	Nitrification rate (g NH ₃ -N/(kg VSS•h))	Temperature (°C)	pH	Time of conduct	Type of plant	Type of analysis
Marlborough, U.S.A*	Max 7.7 Min 0.8	20°C	6-8.4	Oct 1969 to April 1970	Trickling filter	Pilot plant or lab tests
Nowy Targ, Poland**	Max: 4.6 Min:0.6 (g NO _x /kg VSS/h)	Max: 10-18°C Min: 6-10°C	-	Jan to Sep 2005	Sequence batch reactor	f
Beijing, China***	6.4	Ca 20°C	6-9	Oct to Nov 2005	AS	b
Källby, Sweden	3.8	20°C	8	Feb 2016	AS	b
Korea****	≈5(b) / 1.5(f) (g N/kg VSS/h)	33°C	9	-	EA	b/f
Korea****	≈5(b) / 1.5(f) (g N/kg VSS/h)	33°C	9	-	EA	b/f
Korea****	≈6(b) / 2.0(f) (g N/kg VSS/h)	33°C	10	-	EA	b/f

*(Wild *et al.* 1971) **(Morling 2008) *** (Kauffeldt & Lindblad 2006) ****(Cho *et al.* 2014).

2.7 Phosphorus removal

In wastewater, most phosphorus is dissolved in the water and do not settle which makes it difficult to remove. In conventional wastewater treatment, including both sedimentation of organically bound phosphorus in primary treatment and assimilation of soluble phosphorus in secondary treatment, about 20-40% of the influent phosphorus is removed.

Further phosphorus removal is needed. One very common technique is chemical precipitation where the phosphorus is precipitated by adding aluminium or iron coagulants. Another meth-

od is the biological phosphorus removal (Bio-P) process also called Enhanced Biological Phosphorus removal. In the Bio-P process phosphorus is removed by bacteria via biological assimilation. The difference of this assimilation compared to the assimilation of phosphorus in an AS process is that the ratio of phosphorus assimilated by these bacteria is much higher.

In order to carry out a Bio-P process an anaerobic and an aerated tank is needed together with an easily accessible carbon source. This easily accessible carbon source comes in the form of short fatty acids known as volatile fatty acids (VFA).

In the anaerobic tank bacteria take up VFA and store it as energy supply (poly-hydroxy-alcanoate) within the cell. The uptake requires energy which is obtained by degradation of poly-P to orthophosphate. The degraded phosphorus is then released into the surrounding water. This degradation leads to an increase of soluble phosphorus in the anaerobic tank (Figure 2.4). The poly-hydroxy-alcanoate stored in the cells is used as carbon source in the aerated tank for uptake of new phosphorus which results in a decrease of soluble phosphorus in the aerobic tank (Figure 2.4) (Borglund, 2004).

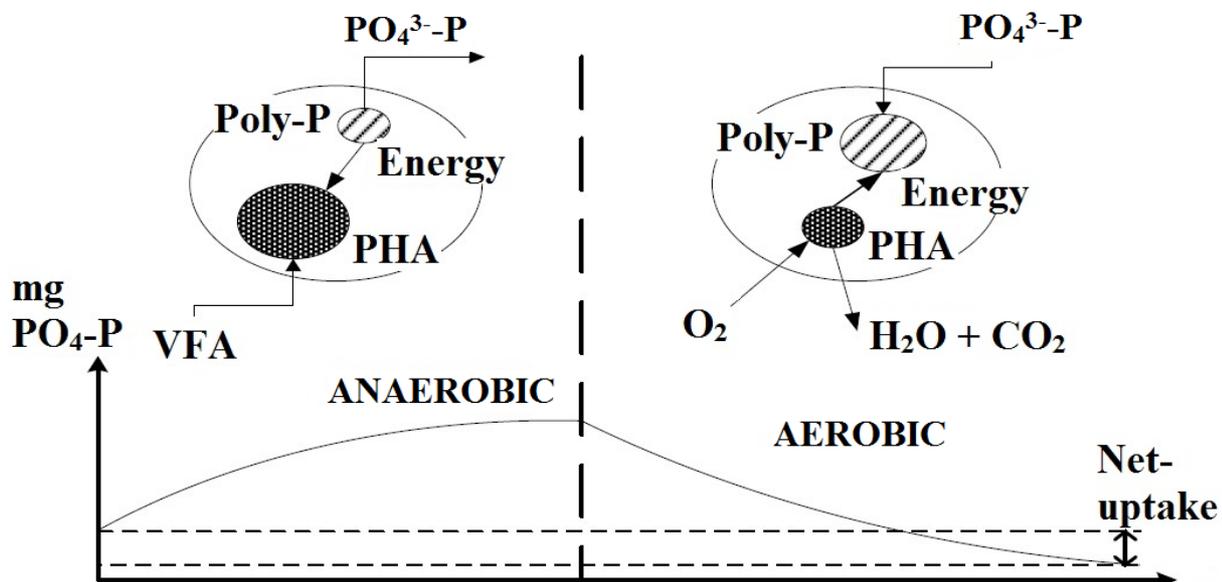


Figure 2.4. The biological phosphorus release and uptake of orthophosphate by bacteria. PHA is the abbreviation for poly-hydroxy-alcanoate (Borglund 2004). Published with kind permission from K ppalaf rbundet. Translation from Borglund (2004).

In the entire Bio-P process there is a net uptake of phosphorus since the uptake is greater in the aerobic tank than the release in the anaerobic tank. The phosphorus-filled bacteria are then removed as sludge and the phosphorus content of the wastewater decreases. The limiting factor in the Bio-P process is often the VFA content of influent wastewater. Approximately 10 to 20 mg of VFA is needed per mg PO₄³⁻-P removed. The process can reach almost 100% phosphorus removal. If nitrate and nitrite is present, denitrifying bacteria in the anaerobic tank will compete with the Bio-P bacteria for VFA which will cause less efficient Bio-P process (Borglund, 2004).

Compared to chemical precipitation the Bio-P process has some major benefits. In the Bio-P processes the usage of chemicals is reduced which is good both for environmental and economic reasons. Also, there is a decreased amount of sludge produced and the formed sludge contains less and fewer chemicals which make it easier to reuse nutrients (Jansen *et al.*, 2009).

2.8 Combined phosphorus and nitrogen removal

Since the processes of biological nitrogen and phosphorus removal are similar it is advantageous to incorporate the two processes into one sequence (Figure 2.5). There are several process configurations; University of Cape Town has developed a model which is called the UCT process. It consists of an AS process with pre-denitrification, although prior to the anoxic tank is an anaerobic tank which enables Bio-P (Figure 2.5). Since denitrifying bacteria compete with Bio-P bacteria for VFA, return sludge from the aerobic and sedimentation tank is returned to the anoxic tank to avoid nitrate in the initial anaerobic tank. To get bacteria back to the anaerobic tank a recirculation of the wastewater from the end of the anoxic tank to the anaerobic tank is carried out, again to avoid nitrate in the anaerobic tank. Consequently, the bacteria content in the anaerobic tank is low and therefore a disadvantage of this model. It is important that the denitrification is efficient and all nitrate is consumed before the wastewater is recirculated to the anaerobic tank. Nitrate decrease the amount available VFA and therefore inhibits Bio-P. To not disturb Bio-P the nitrate content recycled from the anoxic tank should be less than 0.5 mg NO₃-N/L (Borglund, 2004). The anaerobic tank is usually sized to be 10 to 20% of the aerobic tank. The anoxic tank commonly has a HRT of 0.5 to 3 hours while the aerobic tank typically has a HRT of 6 to 24 hours (Hammer & Hammer, 2011).

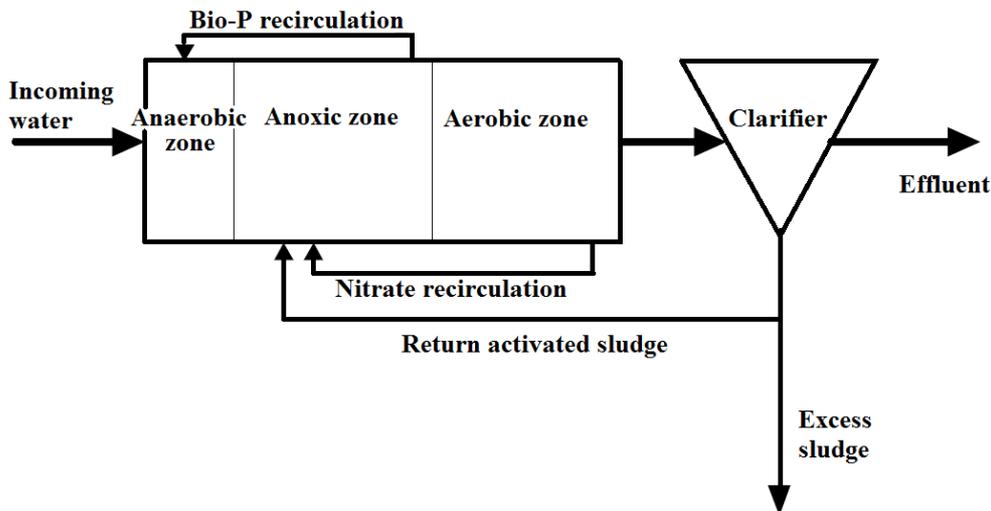


Figure 2.5. Flow scheme of the UCT process with combined nitrogen and phosphorus removal process (Borglund, 2004). Published with kind permission from Käppalaförbundet. Translation from Borglund (2004).

2.9 Wastewater characteristics

Typical characteristics of incoming wastewater are presented in Table 2.2. The parameters BOD₅, COD, total nitrogen and total phosphorus show typical concentrations for concentrated, moderated, diluted and very diluted wastewater.

Table 2.2. A presentation of typical values for different types of wastewater (Henze et al., 2000).

Parameter	Concentrated (mg/L)	Moderate (mg/L)	Diluted (mg/L)	Very diluted (mg/L)
BOD₅	350	250	150	100
COD	740	530	320	210
Total Nitrogen	80	50	30	20
Total Phosphorus	23	16	10	6

3 Material & methods

The research questions were answered by conducting a literature study and performing experimental and calculative analyses. The experimental analyses were carried out on samples from the evaluated WWTP. The calculative analyses were performed by using data obtained from the experimental analyses and/or by data obtained from the literature study. Also, measurements of some parameters were performed at the site. This section will cover how the literature study was performed, a description of the WWTP that was evaluated and how the sampling, measured parameters, experimental and calculative analyses were performed.

3.1 Literature study

Books were mainly used to deepen the knowledge of nutrient reduction, AS systems and biological phosphorus removal. The main sources were Metcalf & Eddy (2003), Hammer & Hammer (2011), Gillberg *et al.* (2003), Henze *et al.* (2000) and Svenskt Vatten (2013). A report by Borglund (2004) was also extensively used within the field of biological phosphorus removal. For further details where the books did not provide satisfactory information, articles and reports were used together with information provided by companies and organisations such as the European Union (EU) and the Food and Agriculture Organization of the United Nations (FAO).

The results of this project were evaluated by previously mentioned sources together with articles within the specific area. Articles were mainly obtained from the databases LUBsearch from Lund University and Google Scholar. Keywords from the specific subject were entered and when suitable articles were found sources used in the article were followed up for further information. Also, many journals provided suggestions for other articles within the same or similar topics.

3.2 JKI065 – Bandarputra wastewater treatment plant

The WWTP evaluated for this project is named JKI065 – Bandarputra and will be onwards referred to as Bandarputra in the report. The WWTP is located in Kulai, a district northeast of Johor Baharu. The plant was taken over by IWK on the 15th of May 2015; it is not known when the plant was built. It is a small EA plant designed for 1216 population equivalents (PE) and 1160 PE were connected to the plant at the time of the project. The sewer system connected to the plant is, just like for the rest of Malaysia, a separated system which implies that it is only carrying wastewater and no storm water except for any inward leakage that may occur. The characteristic of the wastewater reaching the plant was purely domestic and no industries known of were connected. The effluent was released to Skudai River and this type of recipient have the effluent limits according to standard A (Table 1.1).

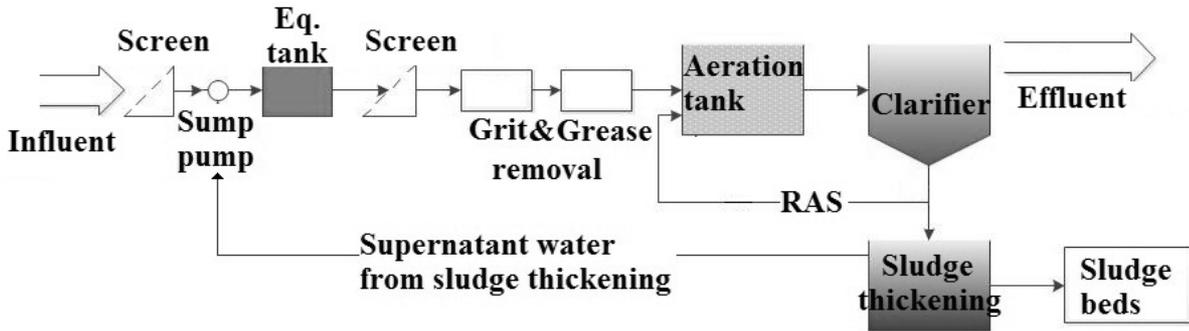


Figure 3.1. Flow chart for Bandarputra. Equalizing tank is abbreviated Eq. tank.

The treatment process at the plant is presented in Figure 3.1. The influent wastewater passes through a coarse screen (Figure 3.2) before it is pumped to an equalization tank with the purpose of providing a constant flow for the remaining part of the treatment. As the wastewater is exiting the equalization tank it goes through a second fine screen (Figure 3.3).



Figure 3.2. The influent wastewater and the first screen in the low left-hand corner.



Figure 3.3. The equalizer tank and the second screens in the right-hand corners.

Following the equalization tank are grit and grease removal tanks and then comes the biological treatment (Figure 3.4). The biological treatment is an AS process with EA. The aeration is provided via bottom aeration. Following the biological treatment is a clarifier (Figure 3.5). From the clarifier RAS is brought back to the aeration tank, excess sludge is taken out for treatment and treated wastewater leaves the plant.

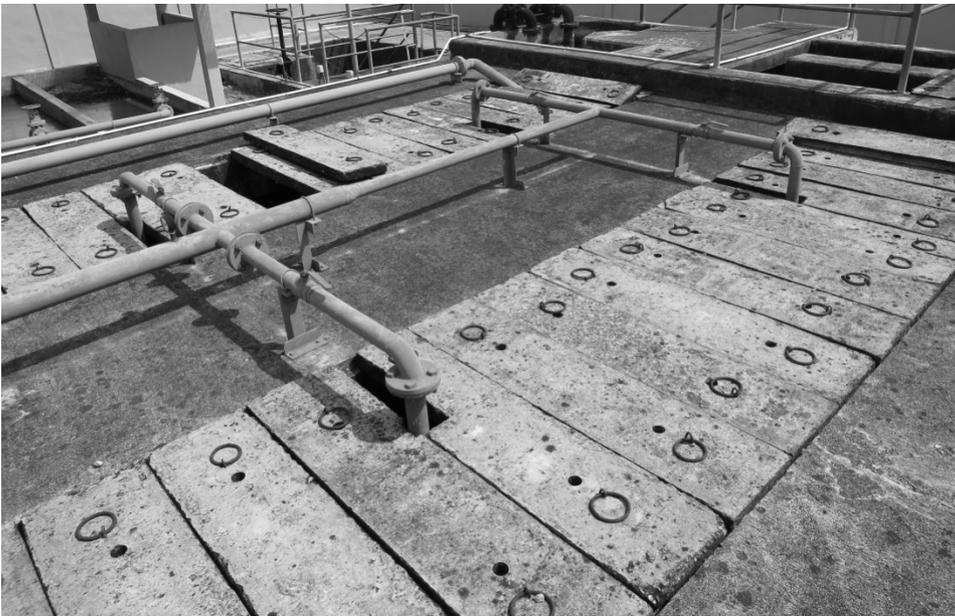


Figure 3.4. The biological treatment tank.



Figure 3.5. The clarifier of Bandarputra and the biological tank in the upper right-hand corner.

The excess sludge is treated by letting the sludge thicken in a gravitational sludge thickener and then the sludge passes on to four drying sludge beds (Figure 3.6). The sludge beds are filled manually by starting a pump and then opening a valve for each sludge bed which can be seen in the same figure. At the time of the project this was done about three to four times a week. The excess sludge was dried in the beds by infiltration and evaporation. This was possible as the sludge beds had sand/grit bottoms which allowed infiltration and a covering roof that protected the sludge from precipitation and enabling evaporation.



Figure 3.6. The sludge drying beds covered by the roof.

The operating parameters for which the plant was designed are presented in Table 3.1. Design operating parameters. These parameters were provided by the staff at IWK. It should be noted that the operating parameters might differ from the design parameters.

Table 3.1. Design operating parameters.

Process	Frequency and duration
Aeration	18 h per day using two blowers
RAS	15 min/hour
Excess sludge pump	15 min/week
Retention time aerated tank	18-20 h
Retention time clarifier	18-20 h
Average influent flow	216 m ³ /D

3.3 Sampling & management of samples

Samplings started on Monday 21st of March 2016 and then samplings were performed every Sunday, Tuesday and Thursday from the 27th of March to the 21st of April 2016. Exceptions were on April the 14th and 17th when no samples were taken.

The sampling was conducted around 10 a.m. and lasted for half an hour up to two hours. The samples were stored in a cooling box and then driven directly to the laboratory. It was a 30-minute drive from the WWTP to the laboratory. At the laboratory, the samples were stored in a fridge at 4°C until analysed. All analyses except for the maximum nitrification rate analysis were performed during the same day as the sampling; the maximum nitrification rate was performed the day after sampling.

Sampling points up to the 10th of April were: the influent (before the first screen), the equalizer tank (in-between the two screens), the beginning of the aerated tank, the middle of the aerated tank, the end of the aerated tank, the effluent and sludge entering the sludge bed. From the 10th of April and onward the sampling points at the beginning and end of the aerated tank were exchanged for the end of the grit and grease chamber and the influent to the clarifier. The other sampling points remained the same. The sampling points and the experimental analyses performed on each sample are presented in Table 3.2. For information of which result from the experimental analyses that was used for the calculative analyses, see the respective chapter.

Table 3.2. All the sampling points and the experimental analyses performed on that sample.

Sampling point	Experimental analyses
Influent	Total nitrogen, ammonium, nitrate and nitrite Total phosphorus and orthophosphate BOD ₅ and COD SS and VSS VFA
Equalizer tank	Ammonium VSS
End of grit and grease chamber	Ammonium VSS
Beginning of aerated tank	SS and VSS
Middle of aerated tank	SS and VSS
End of aerated tank	Ammonium SS and VSS Maximum nitrification rate
Influent to clarifier	Ammonium SS and VSS
Excess sludge	Total nitrogen, ammonium, nitrate and nitrite Total phosphorus and orthophosphate SS and VSS
Effluent	Total nitrogen, ammonium, nitrate and nitrite Total phosphorus and orthophosphate BOD ₅ and COD SS and VSS

Samples were taken using a bucket equipped with a handle. The samples were then poured into 1-litre bottles. When the maximum nitrification rate was to be analysed an extra sample were taken from the end of the aerated zone and poured into a 3-litre bottle.

For the samples containing sludge, both filtered and unfiltered samples were taken. The samples were filtered at the site using Macherey-Nagel No. 40 filters with a pore size of 1.2 µm.

Around 40 ml of each sample containing sludge was filtered into 50 ml plastic test tubes with lids.

3.4 Measured parameters

This section describes the materials and methods that were used to measure dimensions, flow, oxygen concentration and pH at Bandarputra. All measurements were performed at Bandarputra.

3.4.1 Dimensions

Dimensions of the aeration tank and sludge bed were measured using a measuring tape. To assess the depth of the aerated tank a cord with an attached weight were lowered into the tank and then measured.

3.4.2 Flow measurements

The flow was measured in the effluent and excess sludge with a flowmeter, Swoffer, model 2100. The flowmeter could measure several different modes; the mean flow velocity was noted and used for the calculations. A flow meter had to be used as there was no access to pump capacity and pump operation time at Bandarputra.

Influent and effluent

Influent and effluent wastewaters were assumed to have the same flow rate; the excess sludge is a minor fraction of the total flow. The influent flow was controlled by a pump which was activated by the amount of the influent wastewater. Consequently, the inflow was uneven and was not a suitable measure location. The effluent was chosen as the flow has a steadier flow since the equalization tank generates a consistent flow throughout the remaining part of the treatment. The effluent flow was measured at Bandarputra at seven occasions.

The flow meter was inserted into the middle of a squared effluent pipe and left there until the velocity measurement had stabilized. The width and depth of the pipe was noted and used to calculate the cross section of the flow where the flow meter was inserted. The flow was then assessed by multiplying the cross section area with the velocity of the flow. A mean of all flow measurements were used as result.

Excess sludge

Excess sludge was measured at Bandarputra twice. It was measured by opening one valve and measuring the velocity of the sludge entering the sludge bed from the pipe. The diameter of the pipe was measured and used to calculate the cross section area of the pipe. The cross section area was then multiplied with the velocity in order to assess the flow from the pipe. A mean from both readings were used to calculate the excess sludge flow from the pipe.

In the beginning of this field study the valves to the excess sludge pipes were opened more often than towards the end of the study. This generated two different excess sludge flows. The nitrogen mass balances were performed at the beginning of the analysis period and therefore performed during the higher excess flow. The phosphorus mass balances were conducted at the end and therefore connected with the lower flow. It was assumed that in the beginning of the study three valves were open four times a week while at the end of the study only one valve was opened four times a week. It was also assumed that the valves were open for 100 seconds.

3.4.3 Oxygen, pH & temperature

Oxygen and pH were measured at Bandarputra at five to six occasions and at different days, during different events and not always at the same measuring points. For example was additional oxygen measurements conducted in the aerated tank; one was performed before and one after aeration. A portable oxygen, temperature and pH meter, Thermo Scientific Orion 4-star, was used for the measurements.

pH and oxygen were measured in the equalizer tank and in the aerobic tank. The oxygen and pH meter was inserted into the water and left to stabilize before reading. In the equalizer tank measurements were made at half of the depth (differed from day to day) in the centre of the tank. In the aeration tank measurements were made at around one meter's depth and at four different locations presented in Figure 3.7. Measuring point 1 was located where the wastewater enters the aerobic tank. Measuring point 4 was located where the wastewater exits the aerated tank diagonally across from where the wastewater is entering. Measuring point 2 and 3 were located on the opposite side of each other between measuring point 1 and 4 (see Figure 3.7).

Temperature was measured at Bandarputra at five occasions. Temperature was only measured in the aerated tank and the measuring points were the same as for DO and pH.

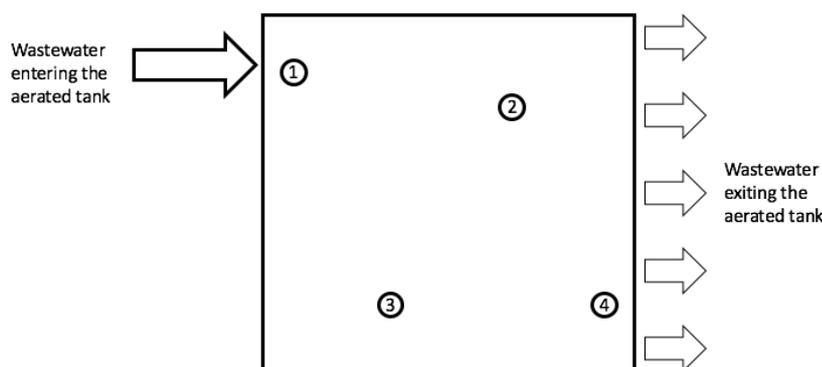


Figure 3.7. DO, pH and temperature measuring points in the aerated tank.

3.5 Experimental analysis

This section describes the materials and methods used for the experimental analyses. The experimental analyses were performed in order to assess nitrogen and phosphorus species, SS & VSS, maximum nitrification rate, BOD₅ & COD and VFA.

3.5.1 Nitrogen species

The nitrogen species analysed were ammonium, nitrate, nitrite and total nitrogen. The analyses of nitrogen species were performed by using a lab spectrophotometer, HACH DR5000. The method, range and accuracy of the nitrogen analyses are presented in Table 3.3 and whether the samples were filtered and/or non-filtered.

Table 3.3. Analysis methods used for nitrogen species.

Nitrogen species	HACH method	Range (mg/L)	Accuracy of method (mg/L)	Filtered/non-filtered sample
Ammonium	8038	0.02-2.5	+/- 0.02	Filtered
Nitrate	8171	0.1-10	+/- 0.04	Filtered
Nitrite	8507	0.002-0.3	+/- 0.002	Filtered
Tot-N High Range	10072	2-150	+/- 0.5	Filtered and non-filtered
Tot-N Low Range	10071	0.5-25	+/- 0.5	Filtered and non-filtered

3.5.2 Phosphorus species

The phosphorus species analysed were orthophosphate and total phosphorus. The analyses of phosphorus species were performed by using a lab spectrophotometer, HACH DR5000. The method, range and accuracy of the phosphorus analyses are presented in Table 3.4. The same table does also present which analyses that were performed on filtered and/or non-filtered samples.

Table 3.4. Analysis methods used for phosphorus species.

Phosphorus species	HACH method	Range (mg/L)	Accuracy of method (mg/L)	Filtered/non filtered sample
Tot-P Low Range	8190	0.06- 3.5	+/- 0.06	Filtered and non-Filtered
Tot-P High Range	10127	1-100	+/- 0.7	Filtered and non-Filtered
Orthophosphate	8048	0.02-2.5	+/- 0.02	Filtered

3.5.3 SS & VSS

The SS and VSS analyses were performed after all sampling occasions. VSS-analyses were also made from samples taken during the batch tests carried out for maximum nitrification rate analyses. Analyses were based on the procedure described by Hammer & Hammer (2001). Deviation from the procedure was that the filter was dried in an oven at 100°C for at least 3 hours (no more than 5 hours). Also, the samples were in the furnace for at least 2 hours (no more than 2.5 hours). Samples were dried in the oven on the same day as they were sampled and burned in the furnace the following weekday after sampling. When not in the oven or furnace the filters were stored in a desiccator. For a more detailed description of the SS and VSS analysis see Appendix B.

The filters used for the analysis were Whatman® glass microfiber filters, grade GF/C, circles 47 mm, cat no. 1822-047 with a pore size of 1.2 µm. Prior to the analyses, the filter was put in the drying oven for six to twelve hours and then stored in the desiccator until used for analyses. Forceps were always used when handling the filters.

Results for the MLSS and MLVSS values were based on the mean from the samples from the beginning, middle and end of the aerated tank. One analysis was carried out for each location.

As it was noticed that the weight of the filter decreased both in the oven and in the furnace, a blank sample analysis was carried out together with the SS and VSS analysis. 1000 ml of distilled water was used as a blank sample. With the help of the blank sample, mean value of lost weight was calculated for both the oven and for the furnace and then added to the weight of respective analysis.

3.5.4 Maximum nitrification rate

Analyses for maximum nitrification rate were performed three times; the sludge from the end of the aerated tank was analysed. A batch test was performed by aerating activated sludge and measuring the change in concentration of ammonium as a function of time, related to the concentration of MLVSS.

The test was started up by filling a beaker with one litre of sludge and put into a 25°C water bath. The sludge was aerated for at least 30 minutes in order to remove any impurities that might have accumulated during storage. A sample of sludge was taken out to analyse VSS. Stock solution containing ammonium, alkalinity and nutrient was added to the beaker of sludge. After the addition, the test ran for 120 min with constant aeration and stirring. One minute after the start up, a sludge sample was taken out. For the remaining time of the analysis samples were taken every 15th minute. The samples were filtered directly and then analysed for ammonium the same day (see Table 3.3). pH and temperature were noted continuously during the test to make sure that the temperature never increased or decreased more than 1°C and pH never exceeded 9 during the analysis. The test was finished by sampling for another VSS analysis. The setup for the nitrification rate analysis is presented in Figure 3.8.



Figure 3.8. Set up for maximum nitrification rate analysis.

The ammonium concentration was plotted against time and a least square linear regression was used to fit a linear equation to the trend of ammonium. The nitrification rate is calculated according to Equation 3.1:

$$v_{nit} = -\frac{K \times 60}{VSS} \quad (3.1)$$

Where:

v_{nit} = nitrification rate ($g\ NH_4^+ / (kg\ VSS \cdot h)$)

K = the slope of the linear regression line ($mg\ NH_4^+ / (L \cdot min)$)

VSS = volatile suspended solids concentration in the reactor (g/L)

A more detailed description of the analysis and chemicals, equipment and solutions used, see Appendix D.

The Environmental Protection Agency (1975) provides a theoretical correlation between temperature, BOD₅, Total Kjeldahl nitrogen and nitrification rate, which were used to estimate a theoretical maximum nitrification rate that could be achieved at Bandarputra. Total Kjeldahl nitrogen was accessed by adding up the mean concentration of organic and ammonium nitrogen. BOD₅ was the mean influent from all BOD₅ measurements and temperature the mean temperature from all measurements.

3.5.5 BOD₅ & COD

BOD₅ analyses were performed three times. The analyses are based on and mostly follow HACH standards method 8043. One deviation from the standard method was how the BOD₅-solution was prepared, see Appendix A.

The interpretation of the BOD₅ results also differs somewhat to the description in the original method. According to method 8043 the averaged results from the BOD₅-analyses have to satisfy all of the following criteria when incubated for 5 days at 20°C:

- for the blank test the maximum change of the dissolved oxygen concentration should not change by more than 0.2 mg/L,
- the remaining DO-value should be at least 1 mg/L,
- the final DO-value should be at least 2 mg/L less than the initial DO-value and
- there are no obvious anomalies.

For the blank test the maximum deviation of oxygen concentration was set to 0.3 mg/L since there were difficulties to read the exact measured oxygen content from the oxygen meter. The samples that did not match the above criteria were excluded from the result. An exception was for the effluent BOD₅ analysis from the 19th of April. This value was instead given a range within which the actual BOD₅ value should be and was not used for mean calculations.

To account for the increased uncertainties of the analysis the results for BOD₅ was rounded up to two significant figures for all result values equal to or higher than 10 mg/L and to 1 significant digit for all result values lower than 10 mg/L. For a more detailed description of the analysis, chemicals, equipment and solutions used see Appendix A.

The result of the mean BOD₅ together with the flow data and the dimensions of the aerated tank were used to evaluate if Bandarputra has a low, medium or high BOD₅ loading according to the classification provided by Degrémont (1991).

COD analyses were performed on seven occasions. The analyses were performed by using a lab spectrophotometer, HACH DR5000 and using method 8000 with a range of 20-1500 mg COD /L with an accuracy of +/- 23 mg/L. The results for COD analyses were rounded up to two significant figures for all results.

3.5.6 Volatile fatty acids, VFA

VFA analyses were performed on five occasions. Samples analysed were taken at the influent and all analyses were performed within three hours after sampling.

VFA content was measured by five-point titration. This method was based on the theoretical basis of Moosbrugger *et al.* (1993). First, the conductivity, the temperature and the pH were measured. Titration was performed from an initial pH to four pre-determined pH values (6.7, 5.9, 5.2 and 4.3, for all values ± 0.1 were acceptable) with 0.05 M hydrochloric acid. The VFA concentration was then calculated using the program TITRA5 where data obtained of the titration together with the conductivity, temperature, inorganic nitrogen and inorganic phosphorus concentration were inserted. The inorganic nitrogen concentration was set 39 mg/L and inorganic phosphorus to 12 mg/L. The set up for the VFA analysis is presented in Figure 3.9. For a more detailed description of the analysis and, chemicals, equipment and solutions used see Appendix C.



Figure 3.9. Setup for VFA analysis (the sample analysed in figure was not obtained from Bandarputra).

An analysis of VFA content on the influent wastewater from a WWTP in Helsingborg was conducted prior to the field study. This was done in order to study whether storage-time and storage-temperature influenced the concentration of VFA in the sample. The analysis started on the 2nd of February and carried on during a 12-day period. A sample of wastewater entering the biological treatment was taken and an initial VFA concentration was measured directly. The sample was then split into two samples where one of the samples was stored in room temperature and the other was stored in a refrigerator (4°C) during the remaining part of the analysis. During the first day of analysis the VFA concentration in both the cold and room tempered sample were measured another three times after the initial VFA measurements. For the remaining time the VFA concentration in both the cold and warm samples were measured once a day the same week and then another two days the following week.

3.6 Calculative analyses

This section describes the methods that were used for the calculative analyses. The calculative analyses were performed in order to calculate and assess the full-scale nitrification rate, nitrogen and phosphorus mass balances, percent phosphorus and nitrogen in sludge, RAS, HRT, ASA, BOD:N:P ratios, C/N ratios and evaluate the volume of the aerated tank to see if it is of sufficient size for nitrification and if further treatment could be incorporated.

3.6.1 Mass balance

A mass balance is based on the principle that mass cannot be created nor destroyed; however, the state of the mass may change (Metcalf & Eddy, 2003). Therefore, a mass balance analysis can be used to define what occurs in a reactor as a function of time. A mass balance is set up according to Equation 3.2.

$$\left(\begin{array}{c} \text{Accumulation} \\ \text{within system} \end{array} \right) = \left(\begin{array}{c} \text{Flow in through} \\ \text{system boundaries} \end{array} \right) - \left(\begin{array}{c} \text{Flow out through} \\ \text{system boundaries} \end{array} \right) + \left(\begin{array}{c} \text{Generation} \\ \text{within system} \end{array} \right) - \left(\begin{array}{c} \text{Consumption} \\ \text{within system} \end{array} \right) \quad (3.2)$$

The calculations in this report were based on the approximation that the WWTP was at steady state. This means that there were no accumulation, no consumption and no generation within the system boundaries. This reduces Equation 3.2 to Equation 3.3:

$$\left(\begin{array}{c} \text{Flow in through} \\ \text{system boundaries} \end{array} \right) = \left(\begin{array}{c} \text{Flow out through} \\ \text{system boundaries} \end{array} \right) \quad (3.3)$$

The system boundaries for the mass balances were the entire treatment process. Thus flow in to the system was influent wastewater and flow out of the system was effluent wastewater and excess sludge. For the nitrogen mass balance there was also a third flow out of the system in form of nitrogen gas, see Figure 3.10.

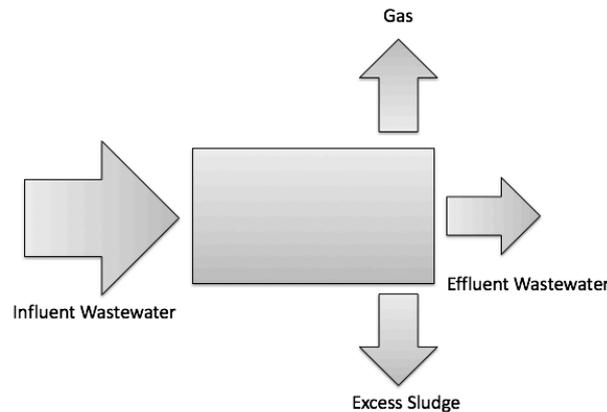


Figure 3.10. System boundary for mass balance analyses.

Nitrogen mass balance analyses were performed four times and phosphorus mass balance analyses were performed three times. To be able to find the mass that enters and exits the systems, samples were taken from influent wastewater, effluent wastewater and excess sludge and concentrations of different nitrogen and phosphorus species were analysed (Table 3.2). The mass flow was gained by multiplying the concentration with the corresponding flow rate.

Nitrogen species analysed experimentally for the nitrogen mass balance are found in Table 3.3. Total nitrogen was analysed using unfiltered samples. Organic nitrogen was calculated as

the difference between total nitrogen and the sum of ammonium, nitrite and nitrate. As it is not possible to measure nitrogen gas production, it is assumed that the amount of nitrogen lost according to the calculated mass balance is nitrogen gas produced via denitrification.

Phosphorus species analysed experimentally for the phosphorus mass balance are found in Table 3.4. Total phosphorus was analysed using unfiltered samples. The phosphorus mass balance can be used as an accuracy check to evaluate how well the mass balance is adding up; since all the parameters can be measured, i.e. there is no gas production. The error for each mass balance was calculated as the percentage and kg Tot-P/D that were missing to have 100 % phosphorus both in and out of the system.

Two nitrogen and two phosphorus mass balances were chosen to be presented. For the nitrogen mass balance, the mass balance with highest denitrification and the one with lowest and no out of range result for the analysis method was presented. For the phosphorus mass balance, the two mass balances with the smallest error was presented.

Assumptions that were made for the mass balance analyses were as follows:

- the flow rates did not change over time,
- the volume of wastewater did not change over time (i.e. it was not subjected to any evaporation, precipitation etc.),
- the wastewater was homogenous and completely mixed and
- the system was in steady state (i.e. there is no accumulation of sludge or any other parameter over time).

3.6.2 Percent nitrogen & phosphorus in sludge

Nitrogen and phosphorus content in the excess sludge was calculated by assessing the difference in total nitrogen/phosphorus between a non-filtered and a filtered sludge sample and then dividing it with the SS concentration of that sample.

3.6.3 Hydraulic retention time, HRT

The HRT was calculated for the aerated tank at Bandarputra as well as for the assessed tank volumes in the dimensioning for a pre-denitrification process. The HRT was assessed by dividing the volume of the tank with the influent flow.

3.6.4 Full scale nitrification rate

Full scale nitrification analysis was calculated using data from samples that were taken on eight occasions. Two sample points were used, before the 10th of April the two points were in the equalizer tank and at the end of the aerated tank. From the 10th of April and onwards the two points were wastewater exiting the grease chamber (entering the aerated tank) and water entering the clarifier (exiting the aeration tank). The location was changed because the two later locations were considered to be more suitable for the analysis.

The full scale nitrification rates were calculated by assessing the change in concentration of ammonium before and after the wastewater has passed the aerated tank and relate to HRT and concentration of MLVSS in the aerated tank according to Equation 3.4:

$$v_{nit} = \frac{NH_4^+_{Enter} - NH_4^+_{Exit}}{HRT * MLVSS_{mean}} \quad (3.4)$$

Where:

v_{nit} = nitrification rate ($g NH_4^+ / (kg VSS \cdot h)$)

$NH_4^+_{Enter}$ = concentration of ammonium in wastewater entering the aeration tank ($mg NH_4^+ / L$)

$NH_4^+_{Exit}$ = concentration of ammonium in wastewater exiting the aeration tank ($mg NH_4^+ / L$)

HRT = hydraulic retention time (h)

MLVSS_{mean} = volatile suspended solids concentration in the reactor ($g VSS / L$)

3.6.5 Return activated sludge, RAS, flow

The method of calculating the RAS flow was carried out with the help of a mass balance over the clarifier (see Figure 3.11).

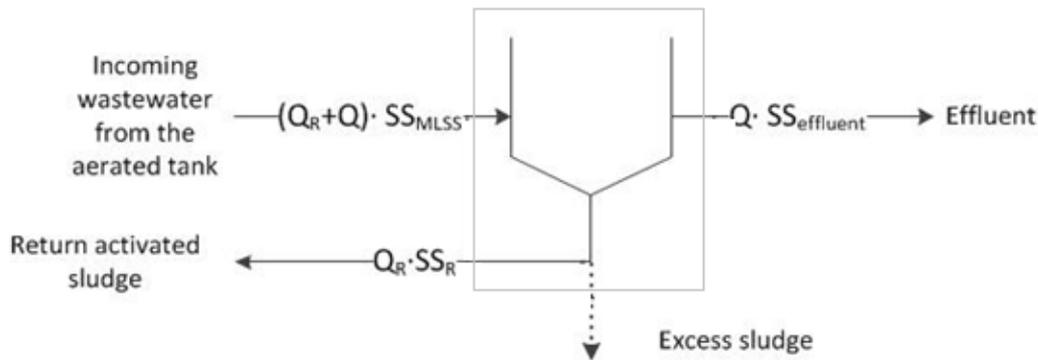


Figure 3.11. A mass balance of the clarifier was carried out in order to calculate the recirculation flow.

As influent and effluent flow was approximately the same and excess sludge flow can be neglected, the relationship for the mass balance resulted in Equation 3.5.

$$(Q + Q_R)SS_{MLSS} = Q * SS_{effluent} + Q_R * SS_R \quad (3.5)$$

Where:

Q = mean flow (m^3 / s)

Q_R = RAS flow (m^3 / s)

SS_{MLSS} = mean SS of the influent wastewater to the clarifier (g/L)

$SS_{effluent}$ = mean SS of effluent (g/L)

SS_R = mean SS of RAS (g/L)

The RAS flow was found by finding return flow, Q_R in Equation 3.5. Parameters entered in the equation were mean values for all SS and flow analyses made.

To find out how much nitrogen in percentage that can be denitrified, the RAS flow was divided with the sum of the RAS and influent flow and turned into percentage.

3.6.6 BOD:N:P & C/N

The BOD:N:P ratio in the influent wastewater was calculated by first finding the mean of all influent BOD, Tot-N and Tot-P measurements and then calculate the ratio between them. The BOD:N:P ratio of the nutrient reduction was calculated by first finding the mean difference

between influent and effluent measures of BOD, Tot-N and Tot-P and then calculate the ratio between them.

The influent BOD/N ratio was found by taking the mean influent BOD and divide it with the mean influent Tot-N. Likewise, the COD/N ratio was calculated and then the mean influent COD measurements were used instead of BOD. The influent BOD/P ratio was found by taking the mean influent BOD and divide it with the mean influent Tot-P.

Henze *et al.* (2002) presents a calculation method for the needed influent BOD/N and COD/N ratio to have denitrification for different biological treatment processes. The method includes denitrification and BOD or COD removal efficiency. The BOD-reduction was based on the BOD analyses and how much that was removed at the time of the project. The denitrification removal efficiency was based on the possible nitrogen reduction based on the RAS flow.

3.6.7 Aerobic sludge age, ASA

The ASA was calculated according to Equation 3.6:

$$ASA = \frac{MLSS * V}{SS_e * Q_e + SS_w * Q_w} \quad (3.6)$$

Where:

ASA= aerobic sludge age (D)

MLSS = mixed liquor suspended solids (kg MLSS/m³)

SS_e = suspended solids in effluent (kg SS/m³)

SS_w = suspended solids in excess sludge (kg SS/m³)

Q_e = effluent flow (m³/D)

Q_w = excess sludge flow (m³/D)

V = volume of aerated tank (m³)

The parameters needed to be able to calculate the ASA were mean values for all SS and flow analyses made as well as the measured volume of the aeration tank. Figure 2.2 was used to evaluate if the calculated ASA was sufficient for nitrification. To find the variation of ASA during the analysis period both the higher and the lower excess sludge flow rate were used for the calculation.

3.6.8 Volume dimensioning for a pre-denitrification process

To improve the nitrogen reduction a combined nitrification and denitrification process is recommended. As pre-denitrification is favourable in an already existing WWTP when installing an anoxic zone it was chosen for Bandarpur. For the pre-denitrification process two tanks are needed, one aerated tank for nitrification and one anoxic tank for denitrification. Therefore, volume calculations were carried out for the tanks needed. The sizes of these tanks were evaluated using literature values for nitrification and denitrification rates.

Dimensions of the aerobic tank were calculated using Equation 3.7 which is based on a nitrification rate provided by Gillberg *et al.* (2003).

$$V_{aerobic} = \frac{\text{Ammonium to be nitrified}}{MLVSS * \text{Nitrification rate}} \quad (3.7)$$

Where:

$V_{aerobic}$ = volume of aerobic tank needed to have nitrification (m^3)
 Ammonium to be nitrified = amount of ammonium that needs to be nitrified
 in order to reach the effluent limits (kg/D)

$MLVSS$ = mixed liquor volatile suspended solids (kg/m^3)

Nitrification rate = rate at which nitrification occurs ($kg NH_4^+ / kg VSS * h$)

The amount of nitrogen needed to be nitrified was calculated as the difference between influent Tot-N and the sum of nitrogen removed with the sludge and the amount of ammonium allowed in the effluent. The influent Tot-N was based on the highest measured value. The amount of nitrogen removed with the sludge was based on the amount of sludge produced each day multiplied with the percentage of nitrogen in the sludge. The percentage of nitrogen in the sludge was based on the lowest amount found in the analyses of nitrogen content in the sludge. The sludge production was found by multiplying the influent BOD-load with a design value that is 0.7-0.8 kg SS / kg BOD (Jansen, 1991). For the volume calculations at Bandarputra 0.7 kg SS / kg BOD was used. The effluent limits for ammonium at Bandarputra is 10 mg/L, however, for the calculations 7 mg/L was used as a conservative precaution. MLVSS was based on the mean concentration found in the aerated tank.

For the aerated tank the ASA was calculated in order to find whether the ASA was sufficient for nitrification.

Dimensions for the anoxic tank were calculated using Equation 3.8. The denitrification rate is based on literature-values from Gillberg *et al.* (2003).

$$V_{anoxic} = \frac{\text{Nitrate to be denitrified}}{MLVSS * \text{Denitrification rate}} \quad (3.8)$$

Where:

V_{anoxic} = volume of anoxic tank needed to have denitrification (m^3)

Nitrate to be denitrified = amount of nitrate that needs to be denitrified
 in order to reach the effluent limits (kg/D)

$MLVSS$ = mixed liquor volatile suspended solids (kg/m^3)

Denitrification rate = rate at which denitrification occurs ($kg NO_3^- / kg VSS * h$)

The amount of nitrate that needed to be denitrified was calculated as the difference between the amount of nitrate allowed in the effluent and the amount of nitrogen that was nitrified according to the calculations for the aerobic tank. The effluent limits for nitrate at Bandarputra is 20 mg/L, however, for the calculations 17 mg/L was used as a conservative precaution. MLVSS was obtained in the same way as for the calculation for the aerated tank.

4 Result & discussion

This study is evaluating nutrient removal and aiming to find possible improvement suggestions for the operation at Bandarputra WWTP. Therefore, this chapter presents and discusses the results from the analyses performed at Bandarputra. The chapter follows the research questions presented in the introduction.

4.1 Basic parameters

This section present and discusses the results from the analyses of basic operating parameters performed at Bandarputra.

4.1.1 Are the DO-levels high enough for biological nutrient reduction?

Measurements of DO are presented in Table 4.1. In the equalizer tank DO ranged between 0.6 to 1.4 mg/L. In the aerated tank the highest DO-levels were found at the inlet (measuring point 1). The mean DO concentration in the aerated tank was ranging from 0.5 to 0.7 mg/L. As the mean DO in the aerated tank was less than 1.0 mg/L aerobic conditions were not fulfilled and DO is therefore not satisfactory for BOD- and COD removal as well as for nitrification.

Table 4.1. DO (mg/L) measured in the equalizer tank and in the aerated tank.

Aerated tank					
Date	Measuring point 1 (mg/L)	Measuring point 2 (mg/L)	Measuring point 3 (mg/L)	Measuring point 4 (mg/L)	Mean (mg/L)
27-03-2016	0.7	0.6	0.5	0.5	0.6
29-03-2016*	0.6	0.5	0.5	0.5	0.5
29-03-2016**	0.7	0.7	0.4	0.6	0.6
03-04-2016	0.9	0.4	0.4	0.4	0.5
05-04-2016	1.2	0.5	0.6	0.6	0.7
07-04-2016	1.4	0.5	0.5	0.4	0.7
Equalizer tank					
Date:	(mg/L)				
27-03-2016	0.6				
29-03-2016	0.8				
03-04-2016	1.0				
05-04-2016	1.4				

*Measurement taken before aeration. ** Measurement taken after aeration.

Even though the method of improvement of the aeration system at Bandarputra is out of the scope for this report, some analyses were done. There are several ways in which the aeration could be optimized without investing in new or improving the aeration equipment. Optimizing aeration at a plant could be very cost effective since normally 40-75% of a WWTPs energy cost is from aeration (Rosso *et al.*, 2008).

A method to decrease the oxygen need in the aeration tank is to install a primary clarifier. A properly installed primary clarifier could achieve 30-40% BOD removal (Hammer &

Hammer, 2011) which would result in less oxygen needed in the aerated tank. Unfortunately, the primary sludge produced does not have the same characteristics as biological sludge as it is not stabilized by bacteria. Without any additional sludge treatment odor problems would arise. Therefore, an installation of a primary clarifier does also imply an upgrading of the sludge treatment.

As an installation of a primary clarifier could decrease the need of aeration, so could an installation of a pre-denitrification process. If it is possible to install a pre-denitrification process in the existing tank for biological treatment the volume that needs to be aerated would be decreased, as the tank is divided in one anoxic and one aerated tank. With a decrease in the aerated volume a decrease of the needed aeration follows. These actions could be valid not only at Bandarputra but also at other plants to reduce the amount of oxygen needed for treatment.

Another method of optimizing the aeration process could be to monitor the MLSS concentration. By keeping a low to moderate MLSS concentration, bulking and oxygen depletion are avoided.

4.1.2 What are the pH-levels?

Measurements of pH are presented in Table 4.2. In the equalizer tank pH ranged between 7.1 and 7.5. In the aerated tank the mean pH was ranging from 5.6 to 6.9. These results show that there is a drop in pH when the wastewater enters the aerated tank. Also, pH is at several occasions not in the optimum range for neither nitrification nor denitrification.

Table 4.2. pH measured in the equalizer tank and in the aerated tank.

Aerated tank					
Date	Measuring point 1	Measuring point 2	Measuring point 3	Measuring point 4	Mean
27-03-2016	5.6	5.5	5.5	5.6	5.6
29-03-2016	5.9	5.8	5.8	5.8	5.8
03-04-2016	6.9	6.8	6.8	6.8	6.8
05-04-2016	7.0	6.9	7.0	6.9	6.9
07-04-2016	6.9	6.9	6.9	6.9	6.9
Equalizer tank					
Date	pH				
27-03-2016	7.5				
29-03-2016	7.4				
03-04-2016	7.1				
05-04-2016	7.4				

4.1.3 Is the MLSS concentration satisfactory for biological nutrient reduction?

The results of the MLSS analyses measured in the aerated tank are presented in Table 4.3. The MLSS concentration was varying between 3.8 and 6.9 g/L with a mean of 5.1 g/L.

Table 4.3. MLSS and MLVSS in the aerated tank at Bandarputra.

Date	MLSS (g/L)
2016-03-27	6.52
2016-03-29	5.17
2016-03-31	4.97
2016-04-03	4.56
2016-04-05	4.93
2016-04-07	3.83
2016-04-10	4.56
2016-04-12	6.90
2016-04-17	5.35
2016-04-19	5.36
2016-04-21	4.31

For an EA process to function properly, enough activated sludge has to be present in the aerated tank. According to literature data MLSS concentrations should be in the range of 3-6 g/L (Orhon & Artan 1994). During a 20-day period, MLSS at Bandarputra exceeded 6 g/L twice. This could have an effect on the BOD reduction and nitrification process as too long periods of high MLSS can lead to bulking which can result in oxygen depletion and consequently decrease the reduction of organic matter and the nitrification process. There was no sign of bulking at Bandarputra during the sampling period. However, as the MLSS at several occasions were close to the highest recommended value it is suggested that the MLSS concentration is monitored to avoid the risk of getting bulking. This might be a problem especially at Bandarputra since oxygen levels in the aeration tank were very low (Table 4.1).

Too low MLSS concentration results in an insufficient amount of bacteria for the nitrification process and for the reduction of BOD. The MLSS concentration at Bandarputra was found to be enough for the bacteria to carry out the nitrification process, assimilate nutrients and for BOD-reduction.

4.1.4 Is the ASA sufficient for biological nutrient reduction?

The ASA at Bandarputra was varying between 34 and 93 days. For calculations of the ASA see Appendix H. The ASA found at Bandarputra were very high. In an EA process the ASA is more than 10 days (Gott *et al.*, 2007) and the ASA needed for nitrification at Bandarputra was around 3 days as the temperature measured at Bandarputra (see, Appendix I) was varying between 30 and 31°C (see, Figure 2.2). Therefore, according to the result the ASA needed to achieve biological nutrient reduction at Bandarputra was met with a very wide margin.

4.2 Organic matter

This section present and discusses the results from the analyses of organic matter performed at Bandarputra.

4.2.1 How much BOD and COD are removed in the biological treatment?

The results of the COD and BOD₅ analyses are presented in Table 4.4. The BOD and COD analyses showed an efficient reduction and the effluent limits were never exceeded during the analysis period (Table 1.1 and Table 4.4). Data from which the BOD₅ was calculated can be found in Appendix J.

The mean influent BOD₅ was 180 mg/L and according to Degrémont (1991) this classifies as low BOD₅-loading (for aerated tank dimensions and influent flow rate see, Appendix E and F). The mean BOD₅ removal efficiency was 94% which is reasonable as the BOD₅ removal efficiency at an AS plant with low BOD₅ loading should exceed 90% (Degrémont, 1991).

Table 4.4. COD and BOD₅ in the influent and effluent at Bandarputra.

Date:	COD (mg/L)		Date:	BOD ₅ (mg/L)	
	Influent	Effluent		Influent	Effluent
27-03-2016	370	30			
29-03-2016	310	30			
31-03-2016	610	40			
03-04-2016	360	70			
05-04-2016	410	60	05-04-2016	130	9
12-04-2016	470	90	12-04-2016	160	10
19-04-2016	510	30	19-04-2016	250	<10*

* Value approximated within a reasonable range.

4.3 Nitrogen

This section present and discusses the results from the analyses of nitrogen-species and nitrification rate performed at Bandarputra. This section also includes the discussion and result of the dimensioning for a pre-denitrification process at Bandarputra.

4.3.1 How much nitrogen is removed in the biological treatment?

The amount of nitrogen reduced at Bandarputra is presented in two different nitrogen mass balances: A and B, see Figure 4.1. Mass balance A was conducted on 29th of March and mass balance B was conducted on 3rd of April and the results for the two mass balances are presented in Table 4.5. Data for all the nitrogen mass balances carried out can be found in Appendix K.

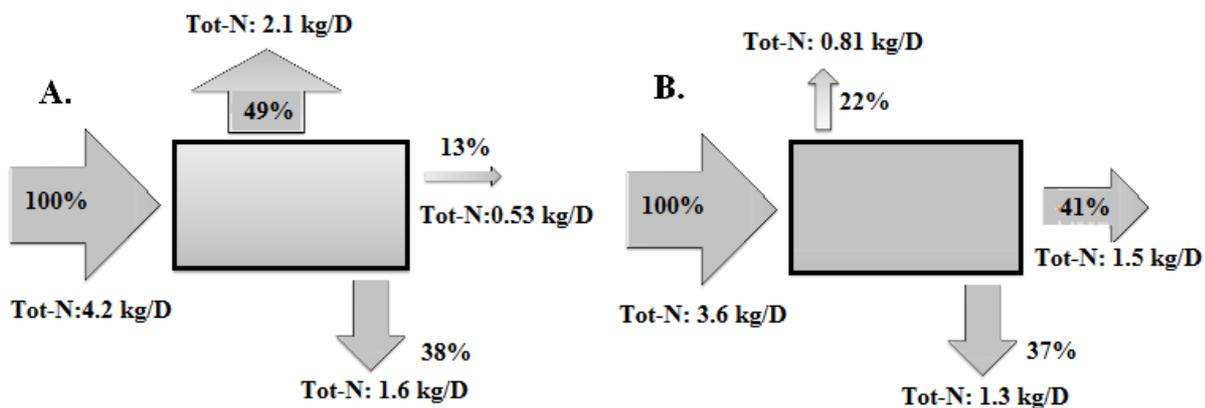


Figure 4.1. Nitrogen mass balances, A and B.

An adjustment was made to nitrogen mass balance A (denoted with an asterisk in Table 4.5). The effluent total nitrogen was unreasonable low, which is explained by an analytical error. The results were adjusted by assuming that the effluent organic nitrogen load was 0 kg/D. This assumption was based on the results of the other mass balances which all had the effluent

organic nitrogen content close to 0 kg/D (Appendix K, Table K.2). The assessed values before the adjustment can be found in Appendix K.

Table 4.5. Data for nitrogen mass balances, A and B.

Nitrogen species	Mass Balance A				Mass Balance B			
	Influent (kg/D)	Excess sludge (kg/D)	Gas (kg/D)	Effluent (kg/D)	Influent (kg/D)	Excess sludge (kg/D)	Gas (kg/D)	Effluent (kg/D)
Tot-N	4.2	1.6	2.1	0.53*	3.6	1.3	0.81	1.5
N₂	-	-	2.1	-	-	-	0.81	-
NH₄⁺	1.9	0.03	-	0.05	2.4	0.02	-	1.4
NO_x-N	0.56	0.04	-	0.48	0.06	0.05	-	0.03
Org-N	1.7	1.5	-	0.00*	1.1	1.3	-	0.06

*Adjusted value.

The results of the mass balances showed that the nitrogen reduction at Bandarputra was varying considerably. The nitrogen reduction in Mass balance A was well functioning with a total nitrogen reduction of 87% while B reduced 59%. In mass balance A almost all ammonium was reduced, only 0.05 kg per day was noted in the effluent, resulting in a complete nitrification process. The denitrification took place but was not complete as there were both nitrite and nitrate in the effluent. In mass balance B the ammonium concentration was decreasing from 2.4 kg per day in the influent to 1.5 kg per day in the effluent i.e. the nitrification process was not complete.

One explanation to the difference in reduction efficiency between the two mass balances could be the load of ammonium entering the WWTP in combination with the in general low DO content found at Bandarputra (Table 4.1). Mass balance A, with a lower influent ammonium load than B, has a complete nitrification. Mass balance B on the other hand has a higher ammonium load and incomplete nitrification. The low oxygen content inhibited the nitrification. As the ammonium load increased there was not enough oxygen for the nitrifying bacteria to convert all the ammonium to nitrate and the nitrification process became incomplete.

4.3.2 Does nitrification take place?

According to the nitrogen mass balance nitrification took place. However, the nitrification process was inconsistent and the nitrification process was at many occasions incomplete. The incomplete nitrification had the effect that the effluent limit for ammonium was exceeded more than once during the analysis period (Appendix K, Table K.2 and Table 1.1).

For autotrophic bacteria it was not possible to perform complete nitrification at the DO levels found at Bandarputra (Gillberg *et al.*, 2003). However, according to the mass balance analysis there is nitrification at Bandarputra. An explanation for this could be that nitrification was taking place at the beginning of the aerated tank as the DO concentrations at several occasions were highest at the beginning of the aerated tank (Table 4.1). The equalizer tank, located in front of the aeration tank, had higher DO-values (Table 4.1). As the wastewater went through

the aerated tank oxygen was depleted, as a result of the nitrification, BOD- and COD-reduction.

The low DO-levels at Bandarputra affects the nitrification process negatively yet, nitrification has been found to take place at DO concentrations as low as 0.5 mg/L (Stenstrom & Song, 1991). A conducted study (Zhao *et al.*, 1999) presented that heterotrophic bacteria can contribute to a significant fraction of nitrification at low DO concentrations at favorable conditions including relatively high organic loading. However, as the BOD₅ loading in this case was low, heterotrophs do most likely not play an important role in the nitrification process and can therefore not explain the observed nitrification taking place at Bandarputra.

Other factors that play a major part in the nitrification process are temperature and pH. The temperature in the wastewater was 30 +/- 1°C which is optimal for nitrification. The pH in the aerobic tank varied between pH 5.6 and 6.9 (see Table 4.2). The optimal pH for nitrification is pH 8 to 9 and when pH is lower than pH 5.5 nitrification does not take place (Gillberg *et al.*, 2003). As pH at times was close to the limit where no nitrification occurs and always under the optimal, the nitrification process was most likely affected negatively. The pH measured in the equalizer tank is higher, ranging from 7.1 to 7.5. Therefore, the pH drop in the aeration tank was most probably due to decreased alkalinity caused by the nitrification process. One way to account for lost alkalinity could be by adding lime or ash (Hammer & Hammer, 2011). Alkalinity could also be restored by incorporating a pre-denitrification system, as the preceding denitrification can recover half of the alkalinity that is lost during nitrification (Hammer & Hammer, 2011).

4.3.3 What is the nitrification rate?

The full-scale nitrification rate is presented in Table 4.6. Ammonium measurements which the calculations were based on can be found in Appendix M. The full-scale nitrification rate ranged between 0 to 0.14 g NH₄⁺/ (kg VSS•h) and the mean rate was 0.06 g NH₄⁺/ (kg VSS•h) (Table 4.6). It should be noted that at two occasions (19th and 21st of April) there were a complete nitrification i.e. almost all ammonium was oxidised in the aerated tank. These rates represent the lowest possible nitrification rate at that occasion, which imply that the full-scale mean nitrification rate could be higher. Even if the rate was higher there was still one occasion when the rate was 0 NH₄⁺/ (kg VSS•h) and two occasions when the rate was 0.02 NH₄⁺/ (kg VSS•h) which is problematic as the nitrification rate needs to be at a constant higher rate to obtain a proper nitrification process.

Nitrification rates from batch tests can be considered a maximum rate and is not expected to be found in the full-scale rate test. The maximum nitrification rates were 3.5, 3.3 and 3.1 g NH₄⁺/ (kg VSS•h). The mean maximum nitrification rate was 3.3 g NH₄⁺/ (kg VSS•h). The result of the least square linear regression together with the analysis temperature and pH range and VSS concentration can be found in Appendix L. The results based on the Environmental Protection Agency's (1975) theoretical correlation between temperature, BOD, Total Kjeldahl nitrogen and nitrification rate gave a theoretical maximum nitrification rate of 10 g NH₄⁺/ (kg VSS•h) at 30°C.

Table 4.6. Full-scale nitrification rates at Bandarputra.

Full-scale nitrification rate analyses made before the 10/4	
Date	Nitrification Rate (g NH₄⁺/(kg VSS•h))
29-03-2016	0.12
31-03-2016	0.07
03-04-2016	0.04
05-04-2016	0.02
Full-scale nitrification rate analyses made from 10/4 and onwards	
Date	Nitrification Rate (g NH₄⁺/(kg VSS•h))
10-04-2016	0.02
12-04-2016	0.00
19-04-2016	0.10
21-04-2016	0.14

According to the results the maximum nitrification rate at Bandarputra was only one third of the rate that could be obtained. This can be explained by the low DO-concentration found at Bandarputra. Nitrifiers need an oxygen content of at least 1-2 mg/L (preferably higher) while the mean DO measured at Bandarputra was only 0.5-0.7 mg/L (Table 4.1). As there were anoxic conditions in the aerated tank it was likely that the number of ammonia-oxidizing bacteria in the analysed activated sludge was very low or had a very slow nitrification rate. As sludge consists of living organisms; it needs some time to adjust to the prevailing circumstances. The sludge used to carry out the maximum nitrification rate was not used to sufficient oxygen; the maximum nitrification rate presented in the result could therefore possibly be even higher. As the maximum rate was not representative, it was not used in the volume calculations carried out at Bandarputra.

In a study performed by Cho *et al.* (2014), including both batch tests (maximum) and full-scale rates, the full-scale rates were around one third of the maximum. The mean full-scale nitrification was 0.06 g NH₄⁺ / (kg VSS•h) (Table 4.6). This means that the full-scale nitrification rate at Bandarputra is 55 times lower (based on mean values) than the batch test rate. This exceptionally low full-scale nitrification rate is most likely explained by the low DO concentration affecting the performance and/or concentration of ammonia-oxidizing bacteria at Bandarputra.

Furthermore, the substrate composition is important for the nitrification process. To reduce the competition from BOD-reducing bacteria a low carbon load is needed. The results of the BOD/N ratio analyses show that the BOD/N ratio of the influent wastewater at Bandarputra was 3.2. Studies have been made on different types of wastewater where a decrease in the BOD/N ratio resulted in faster nitrification (Choubert *et al.*, 2015; Hu *et al.*, 2009). According to Gillberg *et al.* (2003) the numbers of nitrifying organisms increase exponentially when the BOD/N decreases. A way to increase the nitrification rate at Bandarputra could be to decrease the BOD/N ratio entering the biological treatment. One possible way to do this would be to install a primary clarifier. This has been discussed earlier with the focus that the BOD removal in a primary clarifier would reduce the oxygen needed in the biological treatment. The BOD reduction in a primary clarifier would also have the additional benefit of a lower

BOD/N ratio entering the biological treatment which, could lead to an improved nitrification process.

4.3.4 Does denitrification take place?

As the WWTP is not designed for denitrification it was not expected but according to the mass balances performed at Bandarputra denitrification occurred. The two mass balances A and B had a denitrification that reduced 49 and 22% of the influent nitrogen (Figure 4.1). According to the results from the RAS flow analysis a nitrogen reduction of 73% is possible at Bandarputra (for calculation of the RAS flow see, Appendix F). Comparing the possible nitrogen reduction with the reduction from the mass balances it can be seen that the results for the mass balances are plausible. The reason of the lower denitrification than the possible 73% can be explained by the incomplete nitrification found in three out of four mass balances (Appendix K). This conforms to the fact that the denitrification was highest for nitrogen mass balance A which was the only mass balance with complete nitrification. It is therefore important to remember that the denitrification process is dependent on a well-functioning nitrification process.

Other analyses made in this report indicates that denitrification occurs. The results of the BOD:N:P ratio analysis representing the difference between influent and effluent, i.e. the mean treated load, at Bandarputra was 100:21:4. If nutrients would have been removed simply by assimilation this ratio would have been 100:5:1. Four times the nitrogen was therefore removed at Bandarputra than expected by only assimilation. As the nitrogen is not assimilated to this extent and the content in the effluent was considered, it must be removed from the wastewater via denitrification as nitrogen gas.

Contrary to nitrification, denitrification requires high carbon content. The result show that the mean BOD load entering Bandarputra was considered to be low, while nitrogen was considered to be in moderate concentrations (Table 2.2, Table 4.4 and Table 4.5) resulting in a low BOD/N ratio of 3.2. Due to the low BOD/N ratio, it might be difficult to have a satisfactory denitrification process. Using the calculation method provided by Henze *et al.* (2002) a BOD/N ratio in the influent of at least 3.9 to 6.8 is needed for denitrification. However, BOD analyses were only performed three times and the highest measurement is 53% higher than the lowest. If the BOD/N ratio would have been based on the highest BOD-value alone it would have been 4.5 which most likely would be enough for denitrification. Therefore, C/N ratios based on BOD might be unreliable in this case. COD measurements were made at several occasions and for the COD/N ratio with the same parameters as previously the COD/N ratio would have to be at least 5.2-9.7 in the influent. The COD/N ratio at Bandarputra was 7.7, consequently a well-functioning denitrification would most probably be possible.

As there were anoxic conditions in the aerated tank at Bandarputra, denitrification was possible. All processes occurred simultaneous in the aerated tank. However, if the nitrification process is improved this includes improvement of the aeration which would make denitrification difficult, as the process requires anoxic conditions. Therefore, a well-functioning nitrification process at Bandarputra would imply severe obstacles for denitrification. In order to achieve well-functioning nitrification and denitrification, the nitrification process has to be improved as well as there has to be an addition of an anoxic tank. This can be done for example by installing a pre-denitrification process.

4.3.5 What dimensions are needed to install a pre-denitrification process at Bandarputra?

One way to improve the nitrogen reduction at Bandarputra could be to install a pre-denitrification process. In order to evaluate whether it is possible, dimensions of an anoxic and an aerated tank were calculated. As the maximum and full-scale nitrification rates were not representative due to low DO- and pH-levels, literature values of nitrification rates were used instead. The calculations and parameters used to find the volumes for the aerobic and anoxic tanks are presented in Appendix N.

The mean temperature of the wastewater at Bandarputra was 30°C and according to Gillberg *et al.* (2003) a nitrification rate of 4 g NO₃-N/ (kg VSS•h) could be expected at this temperature. This rate is in most cases rather conservative at such a temperature. With the given nitrification rate the volume of the aerated zone for a pre-denitrification process at Bandarputra would need to be 8 m³ and the ASA would be ranging from 1.5 to 4 days (depending on the variation of the excess sludge flow). The result showed that the ASA needed at Bandarputra was 3 days, meaning that if the excess sludge flow is high an aerated tank of 8 m³ is not sufficient for nitrification. Therefore, a volume of 8 m³ may not be satisfactory for nitrification. An aerated tank of 16 m³ would be needed to have an ASA that does not decline 3 days (Appendix N). This volume gives an ASA ranging from 3 to 8 days which would be sufficient for nitrification.

The dimensions of an anoxic tank was also calculated using literature data, according to Gillberg *et al.* (2003) the lowest nitrification rate expected at 30°C is 3 g NO_x/(kg VSS•h). With this denitrification rate the anoxic tank at Bandarputra would be 7 m³.

The volume of the anoxic tank is dimensioned according to the effluent limits. The effluent limits for nitrate is 20 mg/L. However, as a conservative precaution the volume was dimensioned for an effluent limit set to 17 mg/L. Thus, about 50% of the influent nitrogen has to be denitrified (Appendix N). According to the result the RAS flow enables a 73% nitrogen reduction. The RAS flow was therefore sufficient for the pre-denitrification process and does not have to be exchanged or upgraded.

With an aerated zone of 16 m³ and an anoxic zone of 7 m³ the total volume for a pre-denitrification process would be 23 m³. The volume of the aerated zone at Bandarputra is 185 m³. Even though this result is based on a lot of uncertainties and assumptions the calculated volume is still significantly smaller than the volume of the existing aerated tank. Thus, a pre-denitrification process could presumably be installed in the existing aerated tank.

If an anoxic zone is installed in the existing aerated tank at Bandarputra the BOD-reduction and sludge stabilization could be affected as the BOD-load in the aerated tank would increase. If a pre-denitrification process with an anoxic tank of 7 m³ is installed at Bandarputra the aerated tank volume would decrease from 185 to 178 m³. Even with the volume decrease the BOD-load in the aerated tank would still be considered low (assuming that the influent-BOD is consistent with the result). The anoxic zone could even be twice the size needed for the pre-denitrification and the BOD-load in the aerated zone would still be considered low. Consequently, an installation of a pre-denitrification process at Bandarputra could maintain the high BOD-removal and the sludge would have time to stabilize. Thus, no upgrading of the sludge treatment would be required.

Throughout this section the benefits of installing a pre-denitrification system at Bandarputra has been discussed. These benefits include the decreased need for aeration and the recovering of alkalinity to maintain a higher pH for the nitrification process. Yet, maybe most importantly the installation of a pre-denitrification process could increase the nitrogen removal at Bandarputra, which would not only help to fulfill the effluent limits, but it would be most beneficial for the recipient and can lead to less nutrient pollution.

4.4 Phosphorus & VFA

This section present and discusses the results from the analyses of phosphorus-species, VFA concentrations and how storage affect VFA concentration in a sample. This section also includes the result and discuss Bio-P and whether Bio-P could be an option for phosphorus removal at Bandarputra.

4.4.1 How much phosphorus is removed in the biological treatment?

The amount of phosphorus reduced at Bandarputra is presented in two different phosphorus mass balances A and B, see Figure 4.2. Results of the two mass balances are presented in Table 4.7. Data for all the phosphorus mass balances can be found in Appendix O.

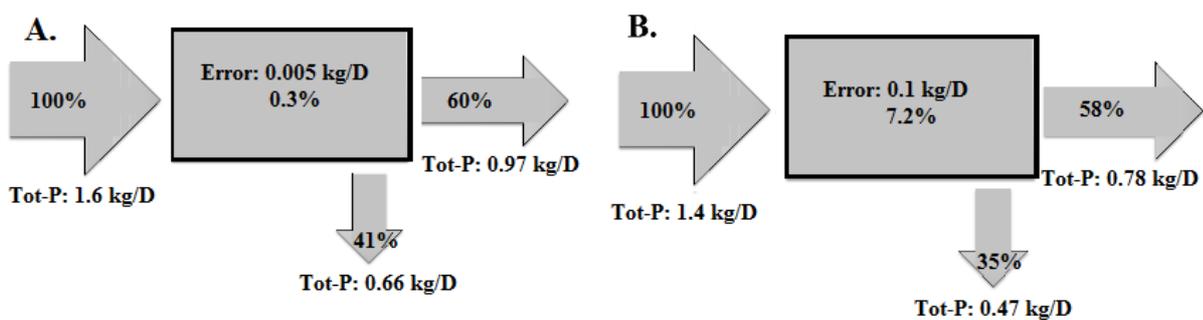


Figure 4.2. The phosphorus mass balances, A and B.

Mass balance A has a small deviation of 0.3%, which results in an error of 0.005 kg phosphorus per day. Mass balance B has a deviation of 7%, which results in an error of 0.1 kg phosphorus per day. The phosphorus reduction was not varying considerably as both mass balances have about the same fraction of phosphorus exiting with the effluent, 58% and 60% respectively.

Mass balance A has the smallest deviation of all analyses that were carried out at Bandarputra and is therefore regarded as the most reliable. It should be noted that the total phosphorus in the excess sludge was based on a value which was out of range. However, as the result is based on two tests which were only 1 and 6% over the range, the result was considered to be accurate.

Table 4.7. Data of the phosphorus mass balances, A and B. Total phosphorus is abbreviated Tot-P and orthophosphate is abbreviated Ortho-P.

Phosphorus species	Mass Balance A			Mass Balance B		
	Influent (kg/D)	Excess sludge (kg/D)	Effluent (kg/D)	Influent (kg/D)	Excess sludge (kg/D)	Effluent (kg/D)
Tot-P	1.6	0.66*	0.97	1.4	0.47	0.78
Ortho-P	0.94	0.03	0.65	0.93	0.01	0.58

*Based on a value which was out of range when analysed.

4.4.2 Are there any signs of Bio-P today?

In the two phosphorus mass balances A and B, the phosphorus removal was ranging from 35 to 41% (Figure 4.2). According to Minnesota Pollution Control Agency (2006), about 20% phosphorus removal is expected in a conventional AS processes. With both primary and secondary treatment 20 to 40% phosphorus removal is possible (see section 2.7). With Bio-P, Borglund (2004) state that a reduction of 100% phosphorus is possible while Minnesota Pollution Control Agency (2006) mentions a lower range, 80 to 90%. Bandarputra is an EA process with no primary treatment for the phosphorus. Therefore, a 20% phosphorus removal would be expected but as the phosphorus removal was higher it can be assumed that Bio-P takes place. What further strengthen this assumption is the fact that the DO-levels are very low and therefor anaerobic conditions which is needed for the Bio-P process was met.

The result of the influent BOD:P ratio at Bandarputra was 100:11, as the ratio for assimilation is regarded to be 100:1 it is obvious that not all phosphorus can be removed by assimilation. When the value of the mean effluent was removed from the mean influent, i.e. the ratio was only based on the mean treated load in the WWTP, the ratio was 100:4. Comparing this ratio with the assimilation ratio (BOP:P=100:1), four times more phosphorus than the expected was removed in the treatment, something that could be explained by the presence of Bio-P.

There could be further indication of Bio-P in the sludge. The result showed that the total phosphorus content in the sludge was 3.5% for phosphorus mass balance A and 3.6% for mass balance B. The mean phosphorus content in the sludge was 3.5% (Appendix O, Table O.2). About 1.5 to 2% is expected in a conventional AS process according to Minnesota Pollution Control Agency (2006) and 2 to 3% according to Strom (2006). In a WWTP with a Bio-P process, the phosphorus content in sludge can range between 5 to 30% (Minnesota Pollution Control Agency, 2006) while Strom (2006) mentions that the phosphorus content in Bio-P sludge is about 5%. This indicate that a part of the phosphorus removal was carried out through a Bio-P process as the result was higher than both of the two given sources for conventional AS processes.

The result showed that there was an additional uptake of phosphorus taking place compared to if only assimilation was carried out. Bio-P may be one possible explanation for this, however there are other plausible explanations. The additional phosphorus removal could be due to chemical precipitation by metal ions in the wastewater. There may be industries connected to the WWTP which released aluminium or iron. The metals react with the phosphorus, then sediment and it is removed as excess sludge. This would explain the high phosphorus content in the sludge and the removal percentage. There was no data available regarding if such metals were or were not present in the wastewater. However, as only domestic wastewater is treated at Bandarputra these metal ions are most likely not present in the wastewater.

Denitrifiers are heterotrophic bacteria and are in need of a carbon source, e.g. VFA and an electron acceptor, nitrate. When nitrate is present the denitrifying bacteria compete with the Bio-P bacteria for VFA and this may reduce the efficiency of Bio-P. Three out of four nitrogen mass balances had a low amount of nitrate and nitrite in both the influent and effluent wastewater (Appendix K). As the nitrification rate is very low, the production of nitrate is low which favours the Bio-P process. Hence, an improvement of the nitrification process would most likely mean that the Bio-P process at Bandarputra would stop or decrease substantially. Also, as an improvement of the nitrification would imply that the aeration has to be improved. With an improved aeration there would be no anaerobe conditions in the tank which is needed for the Bio-P process to work. Though, as both the phosphorus and the nitrogen removal are important, installing a combined nitrification-, denitrification- and Bio-P process would be advantageous.

4.4.3 Is the VFA concentration in the influent wastewater high enough to carry out Bio-P?

The results of the VFA analyses from the influent wastewater are presented in Table 4.8. The VFA concentrations ranged between 41 and 110 mg/L on the different days of sampling. Data from all the five point titrations can be found in Appendix P.

Table 4.8. VFA in the influent at Bandarputra (mg/L).

Date	VFA (mg/L)
21-03-2016	83
29-03-2016	48
31-03-2016	66
03-04-2016	58
19-04-2016	110
21-04-2016	41

A condition needed for the possibility of Bio-P removal is the presence of VFA, as VFA is the energy source used during anaerobic conditions. In order to have Bio-P, 10-20 mg/L of VFA is needed per milligram of phosphorus removed. Therefore, additional 2 to 11 mg/L phosphorus removal was possible with a Bio-P process at Bandarputra compared to removal by only assimilation. With the VFA-concentration found at Bandarputra a phosphorus reduction of 0.25 to 0.84 kg/D was expected to be removed if Bio-P occurred which was in the range of the phosphorus removal in the mass balances (Table 4.7). This also supports the possibility that Bio-P was taking place in the plant.

4.4.4 Is the VFA concentration in a sample affected by the storage?

The results from the pre-study conducted on the cold and room tempered samples of wastewater entering the biological treatment from Helsingborg are presented in Figure 4.3. The initial VFA concentration was 35 mg/L. The concentration in the room tempered sample was 0 mg/L after 7 days. The cold sample had a VFA concentration of 12 mg/L after 12 days. Numerical results of the analysis can be found in Appendix P, Table P.7.

The analysis showed that VFA concentration declined quickly after sampling in both the cold and room tempered sample. The results also showed that the storage temperature of the sample had a major impact on the initial decline. The decline was more rapid in the room tempered sample compared to the cold sample.

All the VFA-analyses performed at Bandarputra were conducted within three hours after sampling. Consequently, the VFA-concentration did most probably decrease during the transport and storage prior the analyses. The true VFA concentration in the influent wastewater at Bandarputra could therefore be higher than shown by these results.

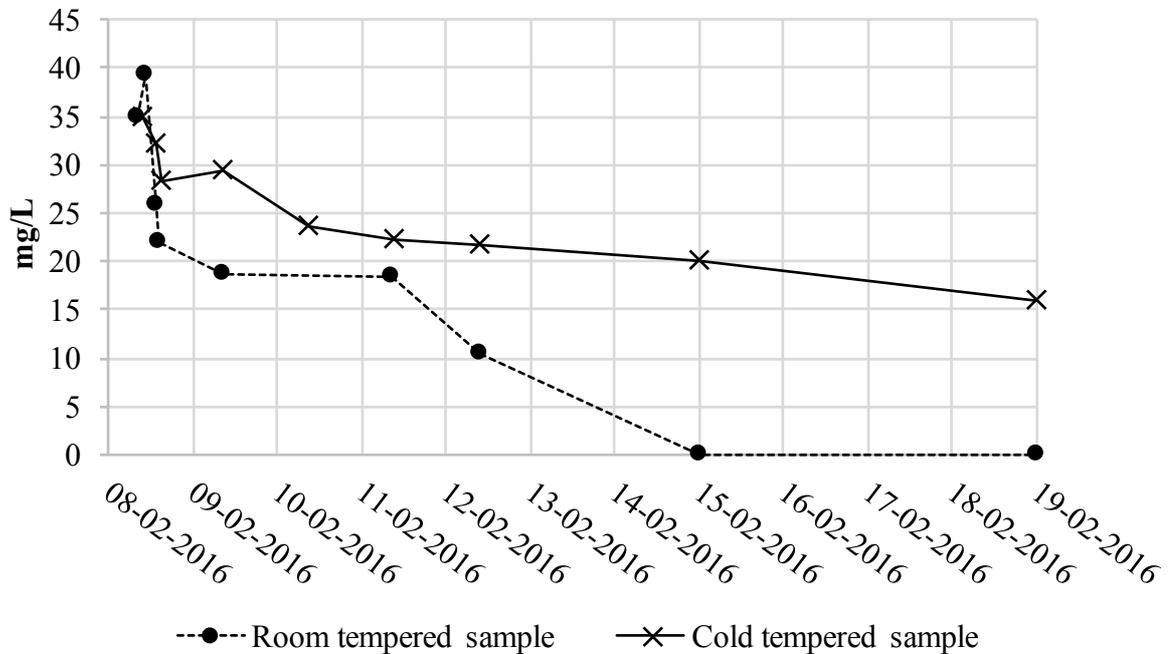


Figure 4.3. Decrease of VFA concentration as a function of time in a cold and a room tempered sample.

4.4.5 Could Bio-P be an option for phosphorus removal at the WWTP?

The result of this project shows that the total phosphorus in the effluent ranged from 12 to 16 mg/L and most of the phosphorus exits as orthophosphate. According to Malaysian regulations there are no effluent limits regarding phosphorus when the recipient is a moving water body. It can therefore be difficult to argue for the incorporation of phosphorus removal in the treatment process. However, effluent limits change and as Malaysia continues to develop and strive for the goal of achieving high income status it is likely that in the future there will be effluent limits and higher requirements for phosphorus removal too. It can therefore be an advantage for the future to know about different possibilities for phosphorus reduction.

At Bandarputra the VFA-content in the wastewater was sufficient to have biological phosphorus removal. There are many advantages with using the Bio-P process instead of installing a chemical treatment. It is better economically as there is no need to buy expensive chemicals and it is better for the environment. Also, there is less sludge produced and the sludge does not contain chemicals from the precipitation which simplifies the recycling (Jansen, et al., 2009). However, Bio-P is a more advanced process and requires more resources and education than an ordinary wastewater plant.

If the aeration at the WWTP would be improved this would most probably decrease the effects of Bio-P as the process need anaerobic conditions. Along with increased aeration the

nitrate content would also increase. As there is no anaerobic tank the nitrate would reduce the available VFA which would decrease Bio-P. In order to get a treatment that includes a reliable and efficient phosphorus reduction an upgrading of the treatment process at Bandarputra is needed, e.g. by installing a Bio-P process.

If a Bio-P process would be installed at Bandarputra, there would have to be three separate tanks, one tank with anaerobic conditions, one with anoxic conditions and one with aerobic conditions. According to the results a pre-denitrification process at Bandarputra including an anoxic and aerobic tank would only have to be 23 m³. Even though this result is based on many uncertainties and assumptions the calculated volume is still a lot smaller than the volume of the existing aerated tank (185 m³). To be able to upgrade the pre-denitrification process to a Bio-P process an addition of an anaerobic tank would be needed. According to Hammer & Hammer (2011) the anaerobic tank in a Bio-P process would have to be 10-20% of the volume of the aerated tank. As the total volume of the pre-denitrification process is a lot smaller than the existing aerated tank it is most likely that, even with all uncertainties and assumption, it would be possible to add an anaerobic tank to the treatment. Thus, enabling Bio-P at Bandarputra.

All wastewater is unique. However, it can be suspected that domestic wastewater has similar constituents to other domestic wastewaters in the area. If this is the case, it is most likely that Bio-P would be an option for many of IWK's WWTPs.

4.5 Sources of errors

The flow measurement has several uncertainties due to the instrument and approximation regarding the dimensions of the flow. The flow measurements are the main source of error in this project as it is used in most calculations. The instrument did at some occasions show obviously incorrect values. As the flow in the outlet was not constant due to algae and similar obstacles it was difficult to do an approximation of the flow. The cross-sectional area where the flow was measured is also providing uncertainties as it was difficult to measure the exact depth and width of the flow.

The influent and effluent flow rate was measured at the effluent outlet as the equalizer tank should provide a rather constant flow through the WWTP. However, according to the result the flow varies at the different days of measurements (Appendix F, Table F.1). This could be due to irregularities in the flow throughout the week, yet the flow was measured around the same time each day and both the lowest and highest flow rate was measured on a Tuesday. Another explanation of the irregularities could be that the equalizer tank is not providing an even flow rate through the WWTP. Independent of the flow variations it adds more uncertainties, as a mean flow was used for the calculations.

The samples were conducted on Tuesdays, Thursdays and Sundays around 10 am. The wastewater is domestic, therefore normally a higher amount of wastewater is produced during mornings, evenings and weekends. The weekend of the private sector in Malaysia is on Saturday and Sunday while the weekday for the public sector is on Friday and Saturday. Since the wastewater loads and flows vary throughout the day and also during the week/weekend, the analysis might not be fully representative throughout the day and the week. Though, the WWTP did have an equalizer tank which should even out the effluent flow making it rather constant throughout the week.

The SS analyses were conducted in an oven at 100°C for at least 3 hours instead of, according to the method, at 105°C for at least 1 hour. This might result in the filters not being properly dried and consequently not a fully correct measurement. This error would influence the recirculation ratio, the ASA, volume calculations etc. As VSS is based on SS among others, this may have an impact on analyses such as the nitrification rate (full-scale and maximum) etc.

There will always be sources of errors, which can explain the reason for a mass balance to not add up fully. A mass balance does, for example not include variations in time as all measurements are a snapshot of the exact moment when the samples were taken. Furthermore, the exact flows were hard to assess. The nitrogen mass balances performed at Bandarputra indicate that denitrification is occurring. However, the actual amount of produced nitrogen gas is not measured but rather calculated which means that the calculated amount of nitrogen gas also contains all the analytical errors. However, it is not believed that the calculated amount of nitrogen denitrified is just presenting the analytical errors as this would imply very large errors.

In phosphorus mass balance A, there is a value based on data that were out of range. As it is out of range the value is only an indication rather than a correct value. It implies that the value can be both higher and lower than the given value. For most over range data the values were lower than the real value. Still, the over range data were 101 and 106 mg/L and the range of the analysis was up to 100 mg/L, therefore it does not add an unreasonable source of error by including it in the report.

In nitrogen mass balance A, the analyses of total nitrogen in the effluent resulted in a value that is physically impossible and therefore it had to be adjusted. If not adjusted, it would have resulted in a negative value of the effluent organic nitrogen. Effluent organic nitrogen levels in the other mass balances performed (See Appendix K) present values very close to zero. Therefore, to correct for the error the organic nitrogen was set to zero and total nitrogen was calculated based on the selected value of organic nitrogen and the data for ammonium, nitrite and nitrate. This might have a major effect on the result of mass balance A, as the effluent total nitrogen could be much higher than the corrected value and therefore this result should be used with great care. See Appendix K for the correct data.

In the analyses pillows of reactive powder were used; these powder pillows were sometimes contaminated with moisture. There were also some powder pillows of which the expiration date was overdue, these bags of pillows were not used but the bags might have been mixed or accidentally taken from the wrong bag. Both the moisture inside the powder pillows and the pillows with expired date may have impacted the result.

The BOD, nitrogen and phosphorus analyses were conducted on different dates as all the analyses were time consuming and therefore not possible to perform on the same day. Therefore, a mean of each analysis were used when the BOD:N:P, BOD/P and C/N ratio was calculated. As there are daily variations in all of the species the ratio would be different if all the data were conducted on the same day.

As always when conducting calculations, laboratory work, approximations, assumptions etc. there will always be the human reliability to consider, such as the samples may have been mixed up, the wrong installations in the spectrophotometer or unclean equipment.

5 Conclusions

Biological treatment performance:

There was an efficient reduction of organic matter and effluent limits of BOD₅ and COD were never exceeded during the analysis period. The MLSS concentration and ASA were sufficient for biological nutrient reduction and nitrification.

The nitrogen reduction at Bandarputra occurred through assimilation, nitrification and denitrification. However, the nitrification was inconsistent and at many occasions incomplete. The varying consistency of the nitrification process was primarily explained by low DO-levels but also by low pH-levels in the aerated tank. The low DO-levels enabled denitrification; however, the denitrification process is dependent on the preceding nitrification which resulted in varying consistence of the reduction of nitrogen through nitrification and denitrification.

The phosphorus evaluation showed that a high percentage of the influent phosphorus was reduced. Based on the high phosphorus removal ratio, high content of phosphorus in the sludge and the high influent VFA content there were most probably already occurring additional uptake of phosphorus via Bio-P.

Biological phosphorus removal as a future option:

The influent VFA-concentration at Bandarputra was satisfactory for a Bio-P process and consequently Bio-P is an option for the plant. Volume calculations on the plant showed that the aeration tank was spacious for its purpose and there might be possible to install an anaerobic tank in the existing aerated tank.

Suggestions for improvements of the operation and design:

To improve the nitrification, the aeration must be increased. However, improvement of the aeration would affect the denitrification which would probably diminish. Consequently, a more stable and reliable process constructed for nitrogen removal is recommended to achieve a high and even nitrification and denitrification, for example a pre-denitrification process. According to the result it would be possible to install a pre-denitrification process in the existing aerated tank at Bandarputra.

A pre-denitrification process does not reduce phosphorus as it is not designed for Bio-P. A so called UCT-process is a pre-denitrification process with integrated Bio-P. This could be an option in the future at Bandarputra. However, running a plant designed for Bio-P demands resources and education.

6 Further studies

It is recommended to do further studies of BOD at Bandarputra WWTP. The analysis was conducted three times at the Bandarputra WWTP. As BOD is an important parameter in the analyses and several analyses are based upon BOD it is crucial to receive realistic and trustworthy data.

Flow measurements are another recommended study to proceed with. As the flows represent a certain time from specific days and is based on a mean value it is a major source of error. Especially the excess sludge was difficult to measure, only two measurements were made. A suggestion is to calculate the flow with the help of pump data using pump capacity and pump operation time instead of a flowmeter.

Throughout the day and the week people have different routines, this imply that the produced wastewater varies along with the time of the day and the week. For further studies an analysis of the variation throughout the day and week would be of interest, e.g. to do an ammonium and flow analysis every second hour on both a weekday and one day during a weekend.

Conducting a study of the full-scale nitrification rate would also be of interest for further studies in order to improve the process. As the full-scale nitrification is much lower than the maximum nitrification rate, it is probably possible to improve the full-scale rate which would improve the amount of nitrogen possible to denitrify.

Another recommendation is to evaluate the low DO concentration in the aeration tank. In general, there were anoxic conditions in the aerated tank, which inhibits the system. A low concentration of oxygen inhibits the nitrification process and the reduction of organic matter.

An evaluation of the incoming carbon is also recommended as assimilation need carbon, Bio-P need VFA and denitrification also need easily degradable carbon for their process. With the information it is possible to predict to what extent the different processes can treat the wastewater and whether additional carbon source is needed for pre-denitrification etc.

It was found that the VFA concentration in a sample is affected by how it is stored and for how long it is stored. However, these results are based on a single analysis with two different storage modes of the sample. In order to evaluate further and to get a deeper knowledge of how the storage affect VFA concentration further analyses with samples stored at other temperatures are suggested.

Finally, this report indicates that it is possible to install a combined denitrification and Bio-P process in the existing aerated tank. Though, it would be recommended to do a pilot test on site before the design of an anoxic and anaerobic tanks with device are installed. As the data and time for this project is limited further research is needed.

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8 Abbreviations

ASA	Aerobic Sludge Age
Bio-P	Biological Phosphorus Removal Process
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EA	Extended Aeration
HRT	Hydraulic Retention Time
IWK	Indah Water Konsortium, the company that is responsible for the municipal wastewater treatment in Malaysia
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
NO _x -N	Nitrate and Nitrite
Org-N	Organic Nitrogen
Org-P	Organic Phosphorus
Ortho-P	Orthophosphate
PE	Population Equivalent
RAS	Return Activated Sludge
SS	Suspended Solids
Tot-N	Total Nitrogen
Tot-P	Total Phosphorus
UTM	Universiti Teknologi Malaysia
VFA	Volatile Fatty Acids
VSS	Volatile Suspended Solids
WWTP	Wastewater Treatment Plant

Appendix A: BOD₅ analysis

Sample:

Influent and effluent wastewater

Equipment:

300 ml BOD flasks with stopper
Magnetic stirrer
Oxygen meter - YSI model 57
Parafilm

Reagents:

BOD-solution:

For every litres of distilled water 1 ml of the following solutions were added:

- Phosphate, buffer solution
- Magnesium sulphate solution
- Calcium chloride solution
- Ferric chloride solution

Performance:

1. The BOD-solution was prepared the day before the analysis and aerated overnight.
2. A known amount of sample was put in to a 300 ml BOD-flask. The flask was then filled to the top with BOD-solution by slowly adding the solution at the inner side of the flask to avoid air bubbles.
3. The initial oxygen concentration was measured in the sample while being stirred using a magnetic stirrer.
4. The stopper was inserted in to the flask and parafilm was used to cover the top to avoid air sipping into the flask.
5. The sample was incubated in a refrigerator for 5 days at 20°C.
6. After 5 days of incubation (+/- 4h) the oxygen concentration was measured in the sample while being stirred, with a magnetic stirrer.
7. BOD₅ was calculated according to HACH method 8043.

Appendix B: SS & VSS analysis

Sample:

Influent water, beginning, middle and end of the aeration tank, influent to the clarifier, excess sludge and effluent. Also, samples from the batch test carried out for maximum nitrification rates analyses.

Equipment:

Whatman Grade GF/C Glass Microfiber Filters
Analytical balance
Vacuum pump
Vacuum Tubing
Filter Holder
Flask with angled tabulations
Aluminum tin
Forceps
Distilled water
Desiccator
Drying oven
Furnace

Performance:

1. All contact with the filter was carried out with forceps.
2. Prior to the analyses, the filter was put in the drying oven for six to twelve hours and then stored in the desiccator until used.
3. The filter holder, flask, tube and pump were mounted.
4. The filter was scaled on an analytical balance.
5. The sample was then filtered through the filter with the help of the mounted filter equipment and then placed onto aluminum tin.
6. The sample was left to dry in an oven at 100°C for three to four hours.
7. After the sample was left to cool in the desiccator and then weighted, for SS calculations.
8. The next coming weekday the sample was burned in a furnace at 550°C for two hours.
9. The sample was left to cool in the desiccator and then weighted, for VSS calculations.
10. With the help of the filter weight, the amount of sample, the weight after the drying oven and the furnace the SS and the VSS was calculated using equation B.1 and B.2.

$$SS = \frac{w_{100^{\circ}\text{C}} + w_{\text{oven loss}} - w_{\text{filter}}}{v} \quad \text{B.1}$$

Where:

SS = suspended solids [g SS/ml]

w_{sample} = the weight of the sample after being in the oven at 100°C [g]

w_{filter} = the weight of the filter [g]

$w_{\text{oven loss}}$ = mean of the filter loss of a blank filter after being in the oven at 100°C [g]

v = the volume of the sample filtered [ml]

$$VSS = \frac{w_{100^{\circ}\text{C}} + w_{\text{oven loss}} - w_{550^{\circ}\text{C}} + w_{\text{furnace loss}}}{v} \quad \text{B.2}$$

Where:

VSS = volatile suspended solids (g SS/ml)

w_{100°C} = the weight of the sample after being in the oven at 100°C (g)

w_{550°C} = the weight of the sample after being in the furnace at 550°C (g)

w_{oven loss} = mean of the filter loss of a blank filter after being in the oven at 100°C (g)

w_{furnace loss} = mean of the filter loss of a blank filter after being in the oven at 550°C (g)

v = the volume of the sample filtered (ml)

Appendix C: VFA analysis

Sample:

Influent wastewater

Equipment:

Beaker for 50 ml of sample
Magnet stirrer
Conductivity-meter
pH-meter
Thermometer
Burette
Computer program TITRA5

Reagents:

0.05 M HCl

Performance:

1. 0.05M HCl was prepared.
2. About 50ml of the sample was poured into a beaker, amount noted.
3. The pH meter was inserted into the sample and kept there during the whole analysis
4. The sample was stirred with a magnetic stirrer, then after 20 seconds without stirring initial pH, temperature and conductivity was measured.
5. The sample was then titrated using 0.05M HCl to pH = 6.7; 5.9; 5.2 and 4.3 with an accepted deviation of +/-0.1. It was made sure that the pH-level was stable before turning off the stirrer, after 20 seconds without stirring the pH and the volume of used HCl was noted.
6. The amount of inorganic phosphorus and nitrogen was estimated based on phosphorus and nitrogen analyses made for the mass balance analysis. The result was then analysed using the program TITRA5. The program calculates the alkalinity, the VFA and the systematic pH error. As the alkalinity was not of interest, hence the inorganic sulphide was set to zero.

Appendix D: Maximum nitrification rate analysis

Sample:

Sludge taken from the end of the aerated tank

Equipment:

Beaker for 1 liter of sludge
Water bath
Stirrer
Air pump
Diffuser
pH-meter
Thermometer
Syringe with tube
Funnel
Test tubes with stopper
Filter paper, Macherey-Nagel, MN 640 md
Hach method 8038 to measure Ammonium
Equipment to do VSS analysis (see Appendix B)

Reagents:

Stock Solution (contain 5 mg NH₄-N /ml):

(NH ₄) ₂ SO ₄	5.9 g
NaHCO ₃	16.8 g
KH ₂ PO ₄	1.1 g
Distilled water	Top up to 250 ml

Performance:

1. A stock solution was prepared at the beginning of the analysis period and used for all the analyses. The stock solution was stored in a 4°C refrigerator. Before analysis the stock solution was temperate to room temperature before it was used.
2. The beaker was filled with 1 liter of sample. The beaker with sample was put into the water bath (25°C) and left to temperate while stirred and aerated for 30 minutes.
3. Sample for VSS was taken.
4. When the right temperature was reached (25 +/- 0.5 °C), 10 ml of stock solution per liter sample was added.
5. After addition of the solution samples were taken every 15th minutes with start at t=1 min. The samples were filtrated directly to cease the activity of the nitrifying bacteria.
6. The analysis proceeded 120 minutes. When last sample was taken, sample for VSS was taken.
7. Analysis for ammonium was carried out (see Table 3.3) on all samples.
8. VSS analysis were performed
9. The nitrification rate was calculated.

Appendix E: Dimensions of the aerated tank and sludge beds

Dimensions of the aeration tank and sludge beds are presented in Table E.1. The volume of the aeration tank is 185 m³ and the volume of each sludge bed is 2.8 m³.

Table E.1. Dimensions of the aeration tank and sludge beds.

Tank	With (m)	Length (m)	Depth (m)	Volume (m³)
Aeration tank	5.9	6.1	5.1	185
Sludge Beds	1.3	4.5	0.5	2.8

Appendix F: Flow rates

This section presents the data of the influent, effluent and excess flow rate.

The result of the measured flow rates are presented in Table F.1. The influent and effluent flow rate was 65,880 L/D (Table F.1). The excess sludge flow rate for the nitrogen mass balance it was 3,850 L/D and for the phosphorus mass balance 1,540 L/D.

Table F.1. Flow rates measured at Bandarputra.

Location	Flow rate (L/D)
Influent & effluent	65,880
Excess sludge (for nitrogen mass balance)	3,850
Excess sludge (for phosphorus mass balance)	1,540

The data that was obtained and used for the flow rate analysis are presented in Table F.2 and Table F.3.

Table F.2. Measured flow rates and mean flow rate for effluent flow.

Date	Measured velocity (m/s)	Effluent pipe height (m)	Effluent width (m)	Cross section area of effluent pipe (m²)	Flow rate L/D
03-04-2016	0.32	0.01	0.25	0.0025	69120
03-04-2016	0.30	0.01	0.25	0.0025	64800
05-04-2016	0.25	0.01	0.25	0.0025	54000
07-04-2016	0.29	0.01	0.25	0.0025	62640
10-04-2016	0.30	0.01	0.25	0.0025	64800
27-03-2016	0.35	0.01	0.2	0.002	60480
29-03-2016	0.40	0.01	0.25	0.0025	86400
31-03-2016	0.30	0.01	0.25	0.0025	64800
Mean Flow Rate (L/D)	65880				

Table F.3. Measured flow rates and mean flow rate for excess sludge flow.

Excess sludge for nitrogen mass balance			
Measured speed of water (m/s)	Diameter of pipe (m)	Flow Rate (m ³ /s)	Actual Flow rate (L/D)
3.52	0.09	0.0225	3850
3.54			

Actual Flow rate is based on the assumption that 3 pumps are operating 4 times a week for 100 seconds*.

Excess sludge for phosphorus mass balance			
Measured speed of water (m/s)	Diameter of pipe (m)	Flow Rate (m ³ /s)	Actual Flow rate (L/D)
3.52	0.09	0.0225	1283
3.54			

Actual Flow rate is based on the assumption that 1 pump is operating 4 times a week for 100 seconds*.

*When a pump is running for 100 seconds the sludge bed are filled to a height of 0.40 m.

According to the result the RAS flow was calculated to 181,000 L/D, which is 275% of the influent flow. A nitrogen reduction of 73% is possible. Data used to calculate the RAS flow is found in Table F.4. The RAS flow is calculated in Equation F.1 according to Equation 3.5.

Table F.4. Data used for RAS flow calculation

Parameter	Data	Raw data found in
SS _{MLSS} (g/L)	5.1	Appendix G
SS _{Effluent} (g/L)	0.02	Appendix G
SS _R (g/L)	7.0	Appendix G
Q (L/D)	65 880	This section

$$\frac{65\,880(\text{L/D}) * 0.02(\text{g/L}) - 65\,880(\text{L/D}) * 5.1(\text{g/L})}{5.1(\text{g/L}) - 7.0(\text{g/L})} = 180\,997 (\text{L/D}) \quad F.1$$

Appendix G: SS & VSS

In this section data from the SS analyses are presented.

Data for MLSS and MLVSS in the aerated tank is presented in Table G.1. The results are based on a mean from samples taken from the beginning, middle and end of the aerated zone see, Section 4.5.3. The mean MLSS and MLVSS in the aerated tank were 5.1 and 4.1 g/L.

Table G.1. MLSS and MLVSS in the aerated tank.

Date	MLSS (g/L)	MLVSS (g/L)
2016-03-27	6.52	5.25
2016-03-29	5.17	4.12
2016-03-31	4.97	3.94
2016-04-03	4.56	3.60
2016-04-05	4.93	3.95
2016-04-07	3.83	3.06
2016-04-10	4.56	3.60
2016-04-12	6.90	5.52
2016-04-17	5.35	4.24
2016-04-19	5.36	4.23
2016-04-21	4.31	3.39

Data for SS and VSS in the excess sludge is presented in Table G.2. The mean SS and VSS in the excess sludge were 7.0 and 5.6 g/L.

Table G.2. SS and VSS in the excess sludge.

Date	SS (g/L)	VSS (g/L)
2016-03-27	6.70	5.45
2016-03-29	7.39	5.84
2016-03-31	5.35	4.27
2016-04-03	5.24	4.19
2016-04-05	4.72	3.78
2016-04-07	3.99	3.19
2016-04-10	4.09	3.35
2016-04-12	14.24	11.20
2016-04-19	9.76	7.72
2016-04-21	8.46	6.74

Data for SS in the effluent is presented in Table G.3. The mean SS in the effluent wastewater was 0.018 g/L.

Table G.3. SS in the effluent wastewater.

Date	SS (g/L)
2016-03-27	0.009
2016-03-29	0.012
2016-03-31	0.015
2016-04-03	0.028
2016-04-05	0.018
2016-04-12	0.044
2016-04-19	0.005
2016-04-21	0.011

Appendix H: ASA calculations

This section presents how the ASA at Bandarputra was calculated. Data used for the ASA calculations are presented in Table H.1. The ASA was calculated in Equation H.1 and H.2 according to Equation 3.6.

Table H.1. Data used for the ASA calculations.

Parameter	Data	Raw data found in
MLSS (kg MLSS /m ³)	5.1	Section 4.1.4
SS _e (kg SS/m ³)	0.018	Appendix G
SS _w (kg SS/m ³)	7.0	Appendix G
Q _e (kg SS/m ³)	65.9	Appendix F
Q _w (m ³ /D)	4 & 1	Appendix F
V (m ³)	185	Appendix E

$$\frac{5.1(\text{kg MLSS /m}^3) * 185(\text{m}^3)}{0.018(\text{kg SS/m}^3) * 65.9(\text{kg SS/m}^3) + 7.0(\text{kg SS/m}^3) * 4(\text{kg SS/m}^3)} = 33.7 (D) \quad H.1$$

$$\frac{5.1(\text{kg MLSS /m}^3) * 185(\text{m}^3)}{0.018(\text{kg SS/m}^3) * 65.9(\text{kg SS/m}^3) + 7.0(\text{kg SS/m}^3) * 1(\text{kg SS/m}^3)} = 93.3 (D) \quad H.2$$

Appendix I: Temperature

Measurements of temperature in the aerated tank are presented in Table I.1. It was noted that the temperature was constant in the entire tank and therefore no data for the different measuring points are presented.

Table I.1. Temperature of the wastewater in the aerated tank.

Date	Temperature (°C)
2016-03-27	30
2016-03-29	30
2016-04-05	30
2016-04-07	30
2016-04-19	31

Appendix J: BOD₅

In this section data that was obtained and used for the BOD₅ analysis are presented in Table J.1, Table J.2 and Table J.3. VFA data from the Helsingborg pre-study is presented in Table P.7.

Table J.1. Data of the BOD₅ analysis from the 5th of April.

05-04-2016	Sample added (ml)	Dilution factor	Initial DO (mg/L)	Final DO (mg/L)	BOD (mg/L)
Blank		0	7.7	7.4*	0.3
Influent	10	30	7.6	3.3	129**
Influent	5	60	7.5	5.2	138**
Effluent	50	6	7.5	5.8*	-
Effluent	100	3	7.5	4.4	9.3**

*Result that did not satisfy the criteria of the analysis. ** Used in the report, with the accuracy of two significant digits for result larger or equal to ten or with 1 significant digit for results less than 10.

Table J.2. Data of the BOD₅ analysis from the 12th of April.

12-04-2016				Initial DO (mg/L)			Final DO (mg/L)			BOD ₅ (mg O ₂ /L)			Mean BOD
Sample	Sample added (ml)	Dilution Factor	Sample:			Sample:			Sample 1	Sample 2	Sample 3	Mean BOD	
			1	2	3	1	2	3					
Blank	0	1	7.8	7.8	7.7	7.7	7.5	7.4	0.1	0.3	0.3	0.1**	
Influent	10	30	7.5	7.5	7.4	2.4	2.1	2.4	153	162	150	155**	
Influent	5	60	7.7	7.6	7.6	4.8	5	5	174	156	156	162**	
Influent	2	150	7.6	7.7	7.6	6.3	5.9	6.4	195*	270*	180*	-	
Effluent	20	15	7.7	7.7		6.4	6.5		19.5*	18*	0*	-	
Effluent	50	6	7.6	7.7	7.6	5.4	5.3	5.3	13.2	14.4	13.8	14**	
Effluent	100	3	7.5	7.5	7.6***	2.9	2.6	2.9	13.8	14.7	14.1	14**	

* result that did not satisfy the criteria of the analysis. ** were used in the report, with the accuracy of two significant digits. *** has a dilution factor of 3.092.

Table J.3. Data of the BOD₅ analysis from the 19th of April.

19-04-2016				Start DO (mg/L)			Stop DO (mg/L)			BOD ₅ (mg O ₂ /L)			Mean BOD (mg O ₂ /L)
Sample	Sample added(ml)	Dilution Factor	Sample:			Sample:			Sample 1	Sample 2	Sample 3	Mean BOD (mg O ₂ /L)	
			1	2	3	1	2	3					
Blank	0	0	7.8	7.7	7.7	7.5	7.2	7.5	0.3	0.5*	0.2	0.2**	
Influent	2	150	7.2	7.6	7.6	5.6	5.8	5.9	255*	315*	300*	-	
Influent	5	60	7.6	7.6	7.6	3.3	3.7	3.9	264	252	240	252**	
Effluent	50	6	7.7	7.7	7.7	7.2	7.3	7.4	3.6*	4.2*	3.6*	-	
Effluent	100	3	7.8	7.8	7.8	6.9	7.2	7.3	3*	2.7*	2.4*	-	

* Result that did not satisfy the criteria of the analysis. ** Were used in the report, with the accuracy of two significant digits for result larger or equal to ten or with 1 significant digit for results less than 10.

Appendix K: Nitrogen mass balance

In this section data that was obtained and used for the nitrogen mass balance analysis are presented in Table K.1 and Table K.2.

Table K.1. Concentrations of the different nitrogen species measured for calculation of mass balance.

29-03-2016	Ammonium (mg/L)	NO_x (mg/L)	Tot-N (mg/L)	Org-N (mg/L)
Influent	29.33	8.45	63.00	25.21
Excess Sludge	7.67	10.42	406.00	387.92
Effluent	0.78	7.34	1.00	-7.12
31-03-2016	Ammonium (mg/L)	NO_x (mg/L)	Tot-N (mg/L)	Org-N (mg/L)
Influent	38.92	1.28	58.00	17.80
Excess Sludge	0.58	8.82	320.00	310.60
Effluent	10.17	0.42	10.40	-0.19
03-04-20	Ammonium (mg/L)	NO_x (mg/L)	Tot-N (mg/L)	Org-N (mg/L)
Influent	36.92	0.85	55.00	17.24
Excess Sludge	5.75	14.02	348.00	328.23
Effluent	21.00	0.42	22.40	0.98
05-04-2016	Ammonium (mg/L)	NO_x (mg/L)	Tot-N (mg/L)	Org-N (mg/L)
Influent	27.75	0.04	49.00	21.21
Excess Sludge	11.25	6.04	280.00	262.71
Effluent	26.13	0.42	26.55*	0.00

*Value is out of range.

Table K.2. Calculated values for the nitrogen mass balance.

29-03-2016	Ammonium (kg/D)	NOX (kg/D)	Tot-N (kg/D)	Org-N (kg/D)	% Tot-N (kg/D)	Nitrogen in Sludge
Influent	1.93	0.56	4,150	1.66	100%	7.4%
Excess Sludge	0.03	0.04	1,563	1.49	38%	
Effluent	0.05	0.484	0,066	-0.47	2%	
Denitrification	-	-	2,522	-	61%	
31-03-2016	Ammonium (kg/D)	NOX (kg/D)	Tot-N (kg/D)	Org-N (kg/D)	% Tot-N (kg/D)	Nitrogen in Sludge
Influent	2.56	0.08	3.82	1.17	100%	6.1%
Excess Sludge	0.00	0.03	1.23	1.20	32%	
Effluent	0.67	0.03	0.69	-0.01	18%	
Denitrification	-	-	1.90	-	50%	
03-04-2016	Ammonium (kg/D)	NOX (kg/D)	Tot-N (kg/D)	Org-N (kg/D)	% Tot-N (kg/D)	Nitrogen in Sludge
Influent	2.43	0.06	3.62	1.14	100%	6.9%
Excess Sludge	0.02	0.05	1.34	1.26	37%	
Effluent	1.38	0.03	1.48	0.06	41%	
Denitrification	-	-	0.81	-	22%	
05-04-2016	Ammonium (kg/D)	NOX (kg/D)	Tot-N (kg/D)	Org-N (kg/D)	% Tot-N (kg/D)	Nitrogen in Sludge
Influent	1.83	0.00	3.23	1.40	100%	5.2%
Excess Sludge	0.04	0.02	1.08	1.01	33%	
Effluent	1.72	0.03	1.75*	0.00	54%	
Denitrification	-	-	0.40	-	12%	

*Value is based on result that was out of range.

Appendix L: Maximum nitrification rate

The temperature and pH range, VSS concentration and calculated nitrification rate for the different dates at which the maximum nitrification rate analyses were performed are presented in Table L.1. The result of the least square linear regression describing the decrease of ammonia over time with R^2 values are presented in Figure L.1.

Table L.1. Temperature and pH range, VSS concentration and calculated nitrification rate for the different dates at which the maximum nitrification rate analyses were performed.

Date	Temp (°C)	pH	VSS (g/L)	Nitrification rate (g NH ₄ ⁺ /(kg VSS•h))
27-03-2016	25.1–25.7	6.5–8.6	2.2	3.5
29-03-2016	24.9–25.2	6.8–8.7	2.8	3.3
03-04-2016	25.4–25.6	8.1–8.8	3.5	3.1

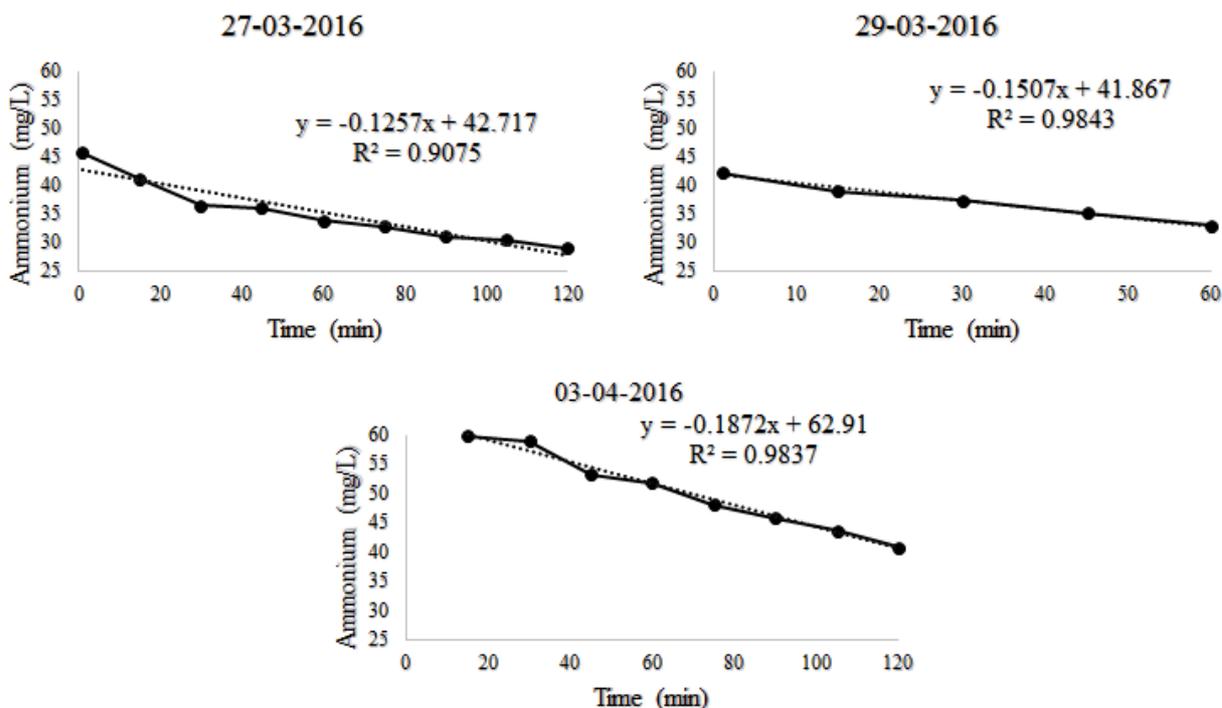


Figure L.1. Ammonium concentration as a function of time. Solid line describes actual decrease while dotted line describes linear regression. Equations for linear regression with R^2 -value are presented in each graph.

Appendix M: Full-scale nitrification rate

Data used in the full-scale nitrification rate calculations are presented in Table M.1. The results of the HRT analyses for the aerated tank at Bandarputra showed that the HRT was 72 days.

Table M.1. Full-scale nitrification rate.

Full-scale nitrification rate analyses made before the 10/4

Date	Ammonium concentration in equalizer tank (mg/L)	Ammonium concentration at the end of aerated tank (mg/L)	Nitrification Rate (g NH ₄ ⁺ /(kg VSS•h))
29-03-2016	34.0	2.7	0.12
31-03-2016	30.3	10.6	0.07
03-04-2016	35.7	27.5	0.04
05-04-2016	33.8	29.5	0.02

Full-scale nitrification rate analyses made from 10/4 and onwards

Date:	Ammonium concentration at the end of grease chamber (mg/L)	Ammonium concentration in-fluent to clarifier (mg/L)	Nitrification Rate (g NH ₄ ⁺ /kgVSS•h))
10-04-2016	43.8	39.0	0.02
12-04-2016	32.9	31.4	0.00
19-04-2016	26.4	0.20	0.10
21-04-2016	29.8	0.20	0.14

Appendix N: Volume calculations

The needed parameters for the calculation of the aerobic and the anoxic tank volume are presented in: Table N.1. Influent BOD₅ was the mean of all the measured influent BOD₅ values multiplied with the influent flow. Sludge production (kg SS/D) was the sludge production (kg SS/kg BOD) multiplied with the influent BOD₅.

Table N.1. Parameters used for volume calculations.

Parameter	Data	Raw data found in
MLSS (kg/m ³)	5.1	Appendix G, Table G.1
MLVSS (kg/m ³)	4.0	Appendix G, Table G.1
ASA (D)	3	Section 5.1.4
Influent BOD ₅ (kg/D)	12	Appendix F, Table F.1 and Section 4.2.1, Table 4.4
% nitrogen in sludge	6.4	Appendix K, Table K.2
Flow (L/D)	65880	Appendix F, Table F.1
Sludge production (kg SS /kg BOD)	0.7	Section 3.6.8
Sludge production (kg SS/D)	8.4	-

Aerated Zone Volume

Data and the assumptions made to find the amount of nitrogen that needs to be nitrified are presented in Table N.2. The amount of nitrogen disappearing with the sludge was the amount of sludge produced each day multiplied with the percentage of nitrogen in the sludge. The amount of nitrogen allowed in the effluent was obtained by multiplying the allowed effluent concentration with the effluent flow.

Table N.2. Data and assumptions made to find the amount of nitrogen that needs to be nitrified.

Parameter	Data	Raw data found in
Highest Tot-N in influent wastewater (kg/D)	4.2	Appendix K, Table K.2
Lowest nitrogen content in sludge (%)	5.2	Appendix K, Table K.2
Nitrogen disappearing with sludge (kg/D)	0.43	Appendix N, Table N.1
Allowed in effluent - set to 7 mg/L (kg/D)	0.46	-
Nitrification rate (Gillberg <i>et al.</i> , 2003)	4 g NO ₃ -N/(kg VSS•h)	-

The amount of nitrogen that needs to be nitrified is calculated in Equation N.1:

$$4.2 \text{ (kg/D)} - 0.46 \text{ (kg/D)} - 0.43 \text{ (kg/D)} = 3.3 \text{ (kg/D)} \quad N.1$$

The volume of the aerobic tank is calculated according to Equation 3.7 in Equation N.2:

$$\frac{3.3 \text{ (kg/D)}}{\left[\frac{4 \text{ (g NO}_3\text{-N/(kg VSS} \cdot \text{h))} \cdot 24 \text{ h}}{1000 \text{ (g/kg)}} \right] \cdot 4.0 \text{ (kg/m}^3\text{)}} = 8.3 \text{ m}^3 \quad N.2$$

Anoxic Zone Volume

Data and the assumptions made to find the amount of nitrogen that needs to be denitrified are presented in Table N.3. Nitrogen in the effluent was obtained by multiplying the allowed effluent concentration with the effluent flow.

Table N.3. Data and assumption made to find the amount of nitrogen that needs to be nitrified.

Parameter	Data	Raw data found in
Nitrogen that has been nitrified (kg/D)	3.3	Appendix N, Equation N.1
Allowed in the effluent - set to 17 mg/L (kg/D)	1.1	-
Denitrification rate (Gillberg <i>et al.</i> , 2003)	3 g NO ₃ -N/(kg VSS•h)	-

The amount of nitrogen that needs to be denitrified is calculated in Equation N.3:

$$3.3 \text{ (kg/D)} - 1.1 \text{ (kg/D)} = 2.1 \text{ (kg/D)} \quad N.3$$

According to the result 2.1 kg/D nitrogen has to be nitrified. This is 66% of the nitrogen that was nitrified and 51% of the influent nitrogen.

The volume of the anoxic tank is calculated according to Equation 3.8 in Equation N.4

$$\frac{2.1 \text{ (kg/D)}}{\left[\frac{3 \text{ (g NO}_x\text{-N/(kg VSS} \cdot \text{h))} \cdot 24 \text{ h}}{1000 \text{ (g/kg)}} \right] \cdot 4.08 \text{ (kg/m}^3\text{)}} = 7.2 \text{ m}^3 \quad N.4$$

Appendix O: Phosphorus mass balance

In this section data that was obtained and used for the phosphorus mass balance analyses are presented in Table O.1 and Table O.2.

Table O.1. Concentrations of the different phosphorus species measured for calculation of mass balance.

12-04-2016	Ortho-P (mg/L)	Tot-P (mg/L)
Influent	13.6	24.7
Excess Sludge	19.7	517.5*
Effluent	9.5	14.7
19-04-2016	Ortho-P (mg/L)	Tot-P (mg/L)
Influent	14.1	20.5
Excess Sludge	10.2	366.0
Effluent	8.9	11.9
21-04-2016	Ortho-P (mg/L)	Tot-P (mg/L)
Influent	8.7	16.9
Excess Sludge	12.5	302.8
Effluent	13.2	15.6

*Value is out of range.

Table O.2. Calculated values for the phosphorus mass balance.

12-04-2016	Ortho-P (kg/D)	Tot-P (kg/D)	% Tot-P (kg/D)	Phosphorus in Sludge
Influent	0.90	1.63	100%	3.5%*
Excess Sludge	0.025	0.67*	41%*	
Effluent	0.63	0.97	60%	
Error		-0.005	-0.3%	
19-04-2016	Ortho-P (kg/D)	Tot-P (kg/D)	% Tot-P (kg/D)	Phosphorus in Sludge
Influent	0.93	1.35	100%	3.6%
Excess Sludge	0.01	0.47	35%	
Effluent	0.58	0.78	58%	
Error		0.10	7%	
21-04-2016	Ortho-P (kg/D)	Tot-P (kg/D)	% Tot-P (kg/D)	Phosphorus in Sludge
Influent	0.57	1.11	100%	3.4%
Excess Sludge	0.02	0.39	35%	
Effluent	0.87	1.02	92%	
Error		-0.30	-27%	

*Value is based on result that was out of range.

Appendix P: VFA

In this section data that was obtained and used for the VFA analyses are presented in Table P.1, Table P.2, Table P.3, Table P.4, Table P.5 and Table P.6. The results from the pre-study conducted on the cold and room tempered samples from Helsingborg are presented in Table P.7

Table P.1. Data and the result of VFA analysis from the 21st of March.

Date: 21st of March

pH	pH, titrated	Volume (ml)
6.7	6.695	1.13
5.9	5.915	2.9
5.2	5.2	3.95
4.3	4.338	4.87
Volume of Sample (ml)		50
Temperature, start (°C)		25.4
Temperature, stop (°C)		26.2
Conductivity (µS/cm)		827
pH, start		7.315
Inorganic N (mg/L)		39
Inorganic P (mg/L)		12
pH error		-0.16
Short-chain fatty acid (mg/L)		83.2

Table P.2. Data and the result of VFA analysis from the 29th of March.

Date: 29th of March

pH	pH, titrated	Volume (ml)
6.7	6.713	0.64
5.9	5.84	1.71
5.2	5.215	2.24
4.3	4.284	2.81
Volume of Sample (ml)		46
Temperature, start (°C)		24.5
Temperature, stop (°C)		23.7
Conductivity (µS/cm)		581
pH, start		7.364
Inorganic N (mg/L)		39
Inorganic P (mg/L)		12
pH error		0.02
Short-chain fatty acid (mg/L)		48.3

Table P.3. Data and the result of VFA analysis from the 31st of March.

Date: 31st of March

pH	pH, titrated	Volume (ml)
6.7	6.703	0.82
5.9	5.921	2.16
5.2	5.178	2.97
4.3	4.318	3.67
Volume of Sample (ml)		48
Temperature, start (°C)		27.4
Temperature, stop (°C)		-
Conductivity (µS/cm)		570
pH, start		7.484
Inorganic N (mg/L)		39
Inorganic P (mg/L)		12
pH error		-0.19
Short-chain fatty acid (mg/L)		66.2

Table P.4. Data and the result of VFA analysis from the 3rd of April.

Date: 3rd of April

pH	pH	Volume (ml)
6.7	6.721	0.86
5.9	5.911	2.27
5.2	5.187	3.09
4.3	4.324	3.77
Volume of Sample (ml)		50
Temperature, start (°C)		28.5
Temperature, stop (°C)		30
Conductivity (µS/cm)		484
pH, start		7.418
Inorganic N (mg/L)		39
Inorganic P (mg/L)		12
pH error		-0.11
Short-chain fatty acid (mg/L)		58

Table P.5. Data and the result of VFA analysis from the 19th of April.

Date: 19th of April

pH	pH, titrated	Volume (ml)
6.7	6.71	0.25
5.9	5.878	1.67
5.2	5.17	2.5
4.3	4.297	3.5
Volume of Sample (ml)		47
Temperature, start (°C)s		26
Temperature, stop (°C)		25
Conductivity (µS/cm)		593
pH, start		6.773
Inorganic N (mg/L)		39
Inorganic P (mg/L)		12
pH error		0
Short-chain fatty acid (mg/L)		104.5

Table P.6. Data and the result of VFA analysis from the 21st of April.

Date: 21st of April

pH	pH	Volume (ml)
6.7	6.7	0.36
5.9	5.915	1.69
5.2	5.207	2.51
4.3	4.33	3.18
Volume of Sample (ml)		64
Temperature, start (°C)		26.6
Temperature, stop (°C)		26.1
Conductivity (µS/cm)		427
pH, start		6.911
Inorganic N (mg/L)		39
Inorganic P (mg/L)		12
pH error		0.01
Short-chain fatty acid (mg/L)		40.9

Table P.7. Change of VFA as a function of time in cold and room tempered sample.

Date	Time after first analysis	VFA-concentration cold Sample (mg/L)	VFA-concentration warm sample (mg/L)
08-02-2016	Initial	35	35
08-02-2016	2h	32	39
08-02-2016	5-5.5h	28	26
08-02-2016	6-6.5h	29	22
09-02-2016	1d	24	19
10-02-2016	2d	22	-
11-02-2016	3d	22	18
12-02-2016	4d	20	11
15-02-2016	7d	16	0
19-02-2016	11d	12	0

Evaluation of extended aeration system for nutrient removal

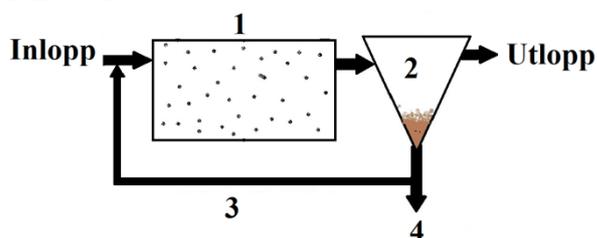
An investigation of a wastewater treatment plant in Skudai, Johor Baharu area, Malaysia
By: Naima Forså & Caroline Ingvar-Nilsson, 2016

Bakterier, våra strävsamma rengörare!

Malaysia förbättrar och uppgraderar sitt avloppsvattensystem. Biologisk rening kan vara en hållbar framtida lösning för landets avloppsreningsverk, vilket är fullt möjligt med mindre ombyggnation och förbättringar visar en fallstudie.

Bakterier och alger behöver, såsom andra organismer bl.a. kväve och fosfor för att växa. Dessa näringsämnen är begränsande i naturen men finns i höga koncentrationer i avloppsvatten. Stora mängder näringsämnen i naturen från exempelvis avlopp kan leda till övergödning och obalans i ekosystemen. För att kunna njuta av våra sjöar, åar och bäckar måste avloppsvatten renas, t.ex. genom biologisk rening.

Flertalet biologiska reningsmetoder finns, bl.a. aktivslamanläggning, se figur 1. Slammet är aktivt p.g.a. dess innehåll: levande organismer såsom bakterier. Ett malaysiskt avloppsreningsverk nära staden Johor Baharu med denna typ av rening var föremål för en fallstudie.



Figur 1. Processchema av aktivslam processen

Reningen består av en stor luftad bassäng (1) med bakterier som kalasrar på avloppsvatten samtidigt som de reducerar näringsämnen. Nästa bassäng delar slammet och vattnet (2). Det renade vattnet fortsätter till recipient som sedan leder ut i det malaysiska havet. Slammet recirkuleras till luftningsbassängen (3) eller behandlas (4). Även om bakterierna vid verket som undersökts inte fick tillräckligt med syre fungerade det ändå bra för dess ändamål: att rena från organiskt material som den gjorde med bravur. Hela 94 % av det organiska materialet reducerades.

Såsom vi människor behöver näringsämnen i lagom mängd, behöver bakterier en speciell sammansättning av näringsämnen. Men så är det sällan, vanligtvis finns det mycket kväve och fosfor kvar i vattnet. Bakterierna kan inte äta upp alla näringsämnen. Mer rening behövs! Kväve i vatten skapar övergödning medan kväve i luft är ofarligt. Idén är att omvandla kvävet i vattnet till kvävgas vilket kan utföras av ett gäng speciella bakterier.

Kväve kommer till reningsverket vanligtvis som ammonium. I luftade miljöer kan ammonium omvandlas till nitrat m.h.a. speciella bakterier, processen kallas nitrifikation. Därefter kan nitraten bli kvävgas under anoxiska (inget fritt syre) förhållanden och det kallas denitrifikation. Och upp i luften försvinner kvävet! På verket var nitrifikationen hämmad p.g.a. den låga syrehalten. Detta hade i sin tur påverkan på denitrifikationen som inte kunde omsätta allt kväve till kvävgas.

Men, fosfor då? Lösningen heter bakterier! Denna speciella typ av bakterie kan ta upp extra mycket fosfor som sker i alternerade aeroba och anaeroba bassänger och processen kallas Bio-P. Fosforen hade högre reduktionsgrad än förväntat vilket kan förklaras av Bio-P.

Nitrifikation, denitrifikation och Bio-P kan installeras i en och samma process. Har man tur kan man till och med göra detta i en befintlig aktivslamanläggning om det finns tillräckligt med plats för att alla processer kan ske samt lite ombyggnation och anpassningar till de olika processerna. Enligt utförda beräkningar finns det plats för både nitrifikation och denitrifikation. Det skulle förbättra reduktionen av kväve samt göra den mer stabil.

