UPPSALA
UNIVERSITET

UPTECW14014
Examensarbete 30 hp
April 2014

Reduced Energy Consumption and Improved Treatment using Intermittent Aeration at the Ja-Ela/Ekala Wastewater Treatment Plant in Sri Lanka

Minskad energiförbrukning och förbättrad rening genom intermittent luftning på Ja-Ela/Ekala avloppsreningsverk i Sri Lanka

Johanna Berg

ABSTRACT

Reduced Energy Consumption and Improved Treatment using Intermittent Aeration at the Ja-Ela/Ekala Wastewater Treatment Plant in Sri Lanka

Johanna Berg

The Ja-Ela/Ekala wastewater treatment plant in Sri Lanka is running with a load and incoming flow far below design values. In order to cope with the unnecessary energy consumption through the aeration system and optimize the treatment results, the plant was during it's commissioning period (September 2011 to June 2012) operated with intermittent control of the aeration system and compared to continuous operation. Through sampling and recording run-time of the blowers it was found that intermittent control lowers the energy consumption with 80-90 % and improves the treatment with respect to all important pollutants.

Keywords: Wastewater Treatment, Intermittent Aeration Control, Activated Sludge Process, Sri Lanka

Department of Information Technology, Uppsala University
Box 337, SE-751 05, Uppsala, Sweden

REFERAT

Minskad energiförbrukning och förbättrad rening genom intermittent luftning på Ja-Ela/Ekala avloppsreningsverk i Sri Lanka

Johanna Berg

Ja-Ela/Ekala avloppsreningsverk i Sri Lanka har en belastning och ett inkommande flöde långt under dimensionsvärden. För att hantera den onödiga energiförbrukningen genom luftarsystemet och optimera reningen drevs anläggningen under dess idrifttagning (september 2011 till juni 2012) med kontinuerlig respektive intermittent styrning av luftningen. Provanalyser samt datasamling av luftarnas drifttid visar att man genom intermittent styrning kan sänka energiförbrukningen med 80-90 % och samtidigt förbättra reningen med avseende på alla viktiga föroreningsparametrar.

Nyckelord: Avloppsvattenrening, Intermittent Luftning, Aktivslamprocess, Sri Lanka

Institutionen för informationsteknologi, Uppsala universitet
Box 337, 751 05 Uppsala, Sverige

PREFACE

This project report, covering 30 credits, is the result of a master thesis work at the Water and Environmental Engineering Programme at Uppsala University, Sweden. The project idea was found after a visit to Sri Lanka and the Ratmalana/Moratuwa and Ja-Ela/Ekala Wastewater Disposal Project during spring 2010 and a re-visit for the commissioning of the treatment plant in Ja-Ela in the end of 2011.

Acknowledgements

I would like to thank my supervisors Mr Staffan Indebetou, process engineer at Purac (Läckeby Water Group) and Dr. Stig Morling Senior Process Advisor from SWECO International and my subject reviewer Prof. Bengt Carlsson from Uppsala University institute of Information Technology for the assistance and feedback through-out the project, Purac and Mr Christer Andersson (project manager for the Ratmalana/Moratuwa and Ja-Ela/Ekala Wastewater Disposal Project) for giving me the opportunity to participate in the commissioning of the treatment plant and Mr Kjell-Anker Olsen and Mr Upul Perera, my colleagues, for guidance and good company during my visit in Sri Lanka.

The Examiner of this Master Thesis is Prof. Allan Rodhe at Uppsala University, Department of Earth Sciences.

Thanks

Johanna Berg

UPTECW14014

POPULÄRVETENSKAPLIG SAMMANFATTNING

Minskad energiförbrukning och förbättrad rening genom intermittent luftning på Ja-Ela/Ekala avloppsreningsverk i Sri Lanka

Johanna Berg

Sri Lanka är ett land under utveckling. Efter många år av inbördeskrig och tsunamikatastrofen 2005 börjar landet ta form med ny infrastruktur och miljömedvetenhet. Tyvärr råder fortfarande orättvisor. Segregering och maktkamp gör att utvecklingen går väldigt långsamt och ofta i fel riktning. Mycket av det som byggs kommer från internationella investerare och bistånd.

När det kommer till vatten- och avloppsvattenrening drivs ett antal, både små- och storskaliga projekt runt om på ön. 2007 påbörjades ett Sida-finansierat avloppsvattenreningsprojekt för rening av industriellt processvatten och hushållsvatten från förorterna Ja-Ela och Ratmalana till huvudstaden Colombo. Båda dessa områden har i dagsläget vattendrag, vilka p.g.a. dålig avloppsvattenrening är högt kontaminerade. Projektet, *Ratmalana/Moratuwa and Ja-Ela/Ekala Wastewater Disposal Project*, vilket består av två reningsverk för 36 000 (med möjlighet till utbyggnad för 73 000 p.e) respektive 100 000 (med möjlighet till utbyggnad för 178 000 p.e) personekvivalenter är ett samarbete mellan den statliga VA-myndigheten vilken är uppdragsgivare, SWECO (Swedish Consultants), som övervakar projektet och det danska företaget Pihl som är entrepenörer med svenska Purac AB som underentrepenör.

Under ett besök till projektplatsen i Ja-Ela under våren 2010 och ett återbesök för idriftsättningen av reningsverket i september 2011 lades grunden för detta examensarbete. Ja-Ela är ett stort industriområde med bl.a. textilfabriker, ett av Sri Lankas största slakterier och andra livsmedelsfabriker samt ett större bostadsområde vilka alla kommer att koppla på sig till det nya nätet. Under idriftsättningen märktes dock snart att endast några få av de planerade kunderna av olika skäl är tänkta att ansluta sig till nätet, samt att de enskilda fabrikerna generellt bidrog med mindre belastning än förväntat. Flödet och belastningen in till verket är idag långt under vad det är dimensionerat för och detta har medfört att onödigt mycket energi går åt för att behandla det inkommande vattnet.

Då vattnet kommer in till verket genomgår det mekanisk rening och biologisk rening. Den mekaniska reningen består av ett mekaniskt rensgaller och ett sandfång. Den biologiska reningen består av tre bassänger med olika biologiska miljöer och processer för att rena vattnet från fosfor, kväve och organiskt material. De olika förhållandena i bassängerna skapas på grund av olika syrehalt. Mängden lättåtkomligt syre gynnar olika sorters bakterier vilka i sin tur skapar sitt eget reningssteg och medverkar i reningen genom nedbrytning av organiskt material och filtrering av vattnet.

Den första biologiska bassängen är anoxisk, vilket innebär att där finns syre, men inte i löst form. Här sker sista steget i reningen av kväve. Den andra bassängen är anaerob (helt syrefri) och är designad för att rena fosfor. I den sista bassängen, vilken benämns aerob, tillsätts syre genom ett luftningssystem och här sker första steget i kvävereningen. För att reningen ska fungera är det viktigt att bassängerna bibehåller dessa miljöer så att alla steg fullföljs.

Problemet som påträffats vid reningsverket i Ja-Ela är att det är designat för större flöde med högre belastning än vad som i dagsläget kommer in. Överdimensioneringen medför att mycket energi går till spillo då verket drivs.

Den mest energikrävande delen av driften är luftningssystem. I detta examensarbete har en optimering av luftningssystemet studerats. Optimeringen skulle vara sådan att energianvändningen hos verket minimeras men att reningsnivån hos vattnet bibehålls eller förbättras samt att luftningssystemet ej tar skada.

För att får ner energiförbrukningen infördes intermittent luftning, dvs. att luftningen styrs med paus/drift-styrning. Prover togs kontinuerligt och analyserades på utgående vatten. Olika på/av-tider hos luftarna studerades och jämfördes med initialfallet utan uppehåll.

Resultaten visar att man med intermittent luftning kan minska energiförbrukningen med 80-90 % och att reningen av vattnet dessutom förbättras. Idag används intermittent luftning på avloppsreningsverket i Ja-Ela och verket kommer att fortsätta med denna drift tills flödet och belastningen på verket är tillräcklig.

TABLE OF CONTENTS

1. INTRODUCTION

In September 2011, the JE-WWTP (JE-WWTP) in Sri Lanka started to receive process water from factories in the Ekala Industrial Area and municipal wastewater from the adjacent Nivasipura Housing Scheme. The treatment includes biological removal of organic material, nitrogen and phosphorus. Today, the incoming load is still far below the design capacity and the evident drawback is that the plant is operated with average results and poor energy efficiency, due to ”over-aeration”.

This study investigates the way to solve this problem and how to most appropriately operate over dimensioned biological wastewater treatment plants with regards to energy efficiency and treatment results.

Intermittent aeration, a method with history of improving treatment and decreasing energy consumption when implemented in wastewater treatment plants similar to JE-WWTP, was tested during a period and compared to the conventional continuous aeration.

1.2 AIM

The objective of this thesis was to study the effect of intermittent controlled aeration on treatment and power consumption and to compare it with the effects of continuous aeration. Further, laboratory data was evaluated toghether with on-site measurements, in order to optimize the aeration time intervals with the main objective of minimizing power consumption.

The hypothesis was that intermittent aeration will lower the energy consumption, without exceeding restricted values of effluent concentrations.

2. BACKGROUND

2.1 SRI LANKA AND THE "RATMALANA/MORATUWA AND JA-ELA/EKALA WASTEWATER DISPOSAL PROJECT"

This chapter summarizes facts about Sri Lanka and the on-going wastewater disposal project in the suburbs of their capital Colombo, as well as the background of this final thesis work that was implemented in Sri Lanka, February to August 2012.

2.1.1 History of Sri Lanka and the present Environmental Situation

In 1948 Sri Lanka obtained political independence, leaving behind over a century of British rule. The independence movement was soon followed by conflicts between the Sinhalese majority and the Tamil population, an ethnic, religious and political independence struggle, which lasted over 25 years.

In 1983 war broke out between the Sri Lankan government and the Tamil separatist militant organization LTTE. The on-and-off war did not end until 2009 and the many years of political riots have prevented the island's environmental development, both technically and in terms of knowledge about environmental impacts (CBC, 2012).

At present the Sri Lankan government has an overall policy of improving the living conditions of the citizens and has implemented several development programs around the island, including urban and rural water supply projects and urban sewerage projects. Sri Lanka is now slowly making progress towards being a more developed country. In the fields of water supply and sanitation, this involves keeping water reserves clean from toxics and pathogens and putting less stress on the environment, which in turn results in increased environmental and public health (Ministry of Urban Development and Water Supply, 2005).

The National Water Supply and Drainage Board (NWSDB) of Sri Lanka has since their establishment in 1975, worked towards serving the nation with sustainable water and sanitation solutions. The NWSDB plays a significant role in achieving the Millennium Development Goal, partly by increasing their investments in sewerage facilities. (Ministry of Urban Development and Water Supply, 2005).

2.1.2 Ja-Ela/Ekala Wastewater Treatment Project

One of NWSDB's on-going programs is the Ratmalana/Moratuwa and Ja-Ela/Ekala Wastewater Disposal Project, which started in 2007. Both the Ja-Ela/Ekala area (Figure 1) in the northern suburbs of Colombo, the commercial capital of Sri Lanka, and the Ratmalana/Moratuwa area in the southern part of the greater Colombo, have water bodies which, due to lack of sewage facilities, are heavily contaminated. The project, which includes two activated sludge based treatment plants for treating 36 000 (73 000 in final stage) and 100 000 (178 000 in final stage) person equivalents, is financed by the Swedish International Development Agency (Sida) and the project is monitored by Swedish consultants SWECO*,* with the Danish company Pihl as contractors and Swedish Purac as sub-contractors (NWSDB, 2007).

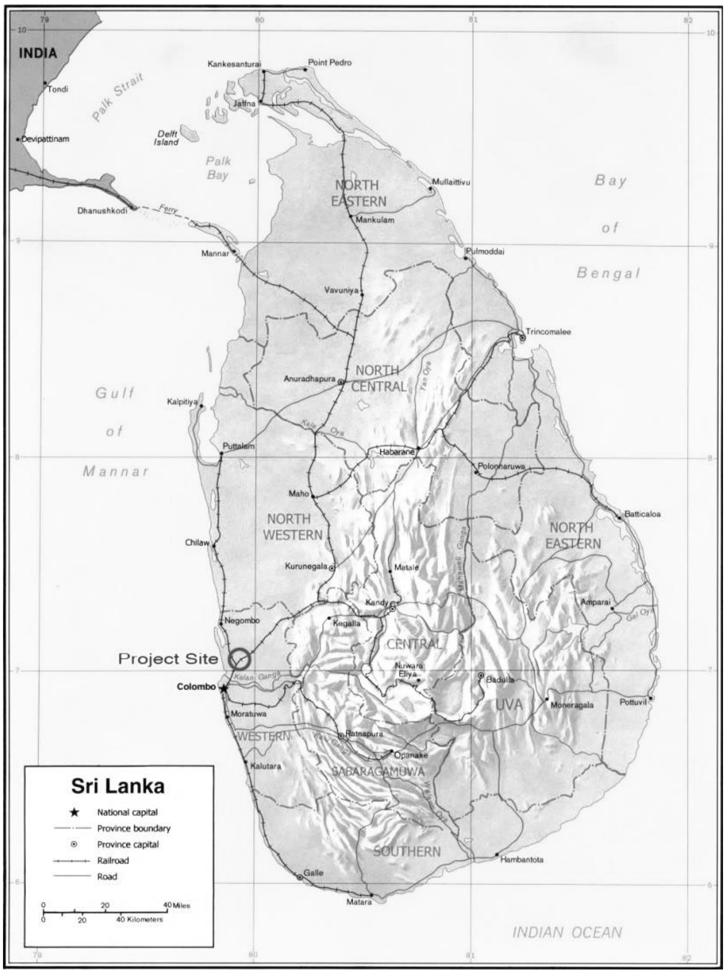


Figure 1. Sri Lanka with the Ja-Ela/Ekala project site marked out

Ja-Ela/Ekala, the project site where this thesis was implemented, is a major industrial area, including textile/garments, chemical, metal finishing, food and asbestos factories. At present, households in the area dispose domestic wastewater into the ground via septic tanks - polluting the ground water - and industries dispose their wastewater into ditches (Ministry of Urban Development and Water Supply, 2005).

2.2 FUNDAMENTALS OF WASTEWATER AND WASTEWATER TREATMENT

2.2.1 Wastewater Characteristics

The principal constituents of concern in wastewater treatment are suspended solids, nutrients, heavy metals, biodegradable organics, pathogens, refractory organics, dissolved organics and priority pollutants. These are, along with other parameters, used to determine the characteristics of wastewater (Metcalf et al., 2004). During the commissioning of a wastewater treatment plant, a selection of parameters is analysed on the influent and effluent in order to study the progress of the treatment. The purpose of measuring these parameters is explained in detail below.

Physical Characteristics

The total solid material found in wastewater is composed of settleable matter, colloidal matter, floating matter and dissolved matter, all of which can be arranged into two main groups depending whether they are suspended or dissolved. For further analysis the solids are classified as volatile or fixed (Metcalf et al., 2004).

Other physical characteristics of wastewater are turbidity, particle size distribution, colour, absorption, temperature, conductivity and density. These are, for example, used when characterising the freshness of the wastewater and its biological activity. Many of the characteristics are in some way interrelated and rarely do all of them need to be measured (Metcalf et al., 2004).

Chemical Characteristics

The chemical characteristics of wastewater can be analysed by studying a wide range of inorganic and organic parameters. Here the inorganic non-metallic constituents are distinguished from the metallic constituents and the organic compounds of interest are categorized as either individual or aggregate (Metcalf et al., 2004).

Inorganic non-metallic constituents

Among the inorganic non-metallic constituents, pH (hydrogen-ion concentration) is an important quality parameter. For the biological treatment to be optimal, pH should be (6-9). Lower or higher hydrogen-ion concentrations will render the biological treatment process less effective (Metcalf et al., 2004).

Alkalinity is the sum of the concentrations of hydroxides, carbonates and bicarbonates. Wastewater is normally alkaline, which helps buffering against pH changes; therefore alkalinity level is very important where chemical and biological treatment is applied (Metcalf et al., 2004).

Nitrogen, phosphorus and sulphur are the three most essential nutrients for growth of micro-organisms. Regulating the concentration of each element in combination with soluble oxygen and organic matter is a way to control bacterial and algal growth (Metcalf et al., 2004).

Nitrogen is present in wastewater as ammonia, nitrate and organic nitrogen and is during the process converted between these forms (Metcalf et al., 2004). Within this project, the total of these, tot-N is measured along with nitrate and ammonia.

Also phosphorous appears in different forms and is measured as tot-P (org and inorganic) and orthophosphate. Orthophosphate is an inorganic compound, which appears dissolved in wastewater and represents the largest fraction of the influent (Metcalf et al., 2004).

Inorganic metallic constituents

There is a delicate boundary for metals being either essential or toxic. Many metals, such as copper, iron and zinc are in trace quantities necessary for biological life. Other for example mercury and cadmium should be avoided even in small doses, since they are highly bio accumulating and will, if they reach an eco-system, accumulate through-out the food chain, disrupting the productivity of living organisms. Some metals are found naturally in the ground and can add into the wastewater through pipe-leakages. To avoid high levels of metals in the wastewater it is important to work upstream, that is to communicate with the industries and help them come up with supplements (Metcalf et al., 2004).

Aggregate organic constituents

Organic compounds in fresh wastewater typically contain proteins, carbohydrates, oil, grease and urea along with a large number of different synthetic compounds in small quantities (Metcalf et al., 2004).

A common laboratorial method to determine the aggregate organic content in wastewater is the 5-day biochemical oxygen demand (BOD_5), a measure of the amount of oxygen used in the biochemical oxidation of organic matter (Metcalf et al., 2004).

Another method used to determine the organic content is the chemical oxygen demand (COD) test, where the oxygen equivalent of the organic material that can be chemically oxidized is measured (Metcalf et al., 2004). The main advantage with the COD-test compared to the BOD-test is the time required to analyse the result, which is approximately 2 h compared to the 5 days of a complete BOD test.

Individual organic compounds

Priority pollutants, which are established by the government, are known or suspected to be carcinogenic, mutagenic or very toxic. Examples of these can be volatile organic compounds, which have boiling points less than $100^{o}C$, disinfection by-products, agricultural chemicals such as pesticides and herbicides, and a variety of new compounds (antibiotics, drugs, hormones etc.) (Metcalf et al., 2004).

Biological Characteristics

To be able to prevent pathogenic organisms from spreading diseases and to control the decomposition of organic matter, it is of great importance to know how microbes interact with wastewater when designing a treatment plant. There are huge numbers of micro-organisms found in wastewater, including bacteria, fungi, algae and viruses. Some of them are responsible for treating the water, as for example the nitrifying bacteria and phosphorus accumulating bacteria mentioned in the next section, while others such as Ascaris or Vibrio Cholerae can be the cause of escalating epidemics (Metcalf et al., 2004).

Micro-organisms grow only if the environment is suitable. Growth conditions vary from species to species and can be optimized by regulating the main growth factors; water, elementary nutrients, energy source, temperature (see Figure 2), oxygen and pH (see Figure 3). The growth is also dependent of the presence/absence of inhibitors such as: pesticides, heavy metals, tensides etc (Metcalf et al., 2004).

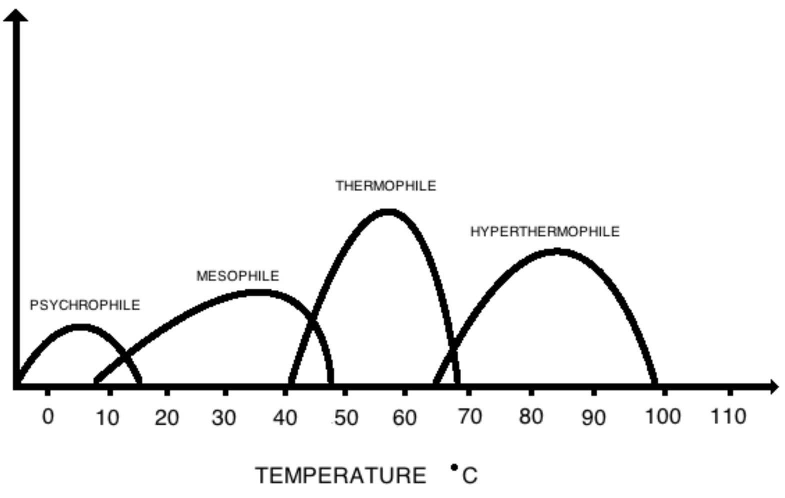


Figure 2. The temperature dependence of bacterial growth rate (after Text book of bacteriology, 2012)

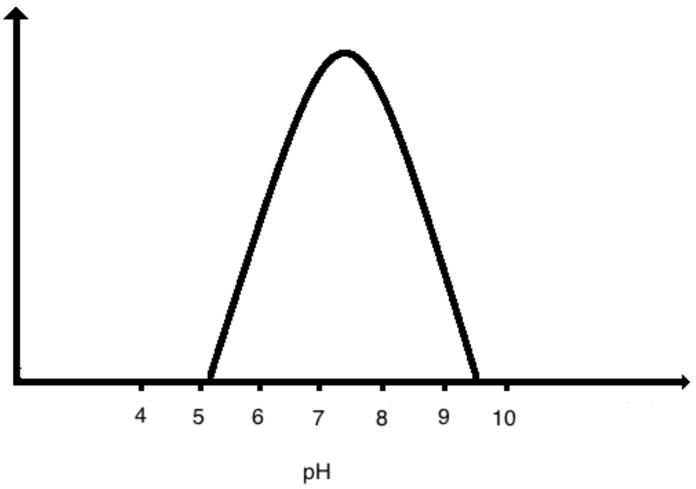


Figure 3. The pH dependence of bacterial growth rate (after Text book of bacteriology, 2012)

2.2.2 Sludge characteristics

The sludge characteristics are of great importance for the biology of the plant, especially for a plant running with the activated sludge process (Indebetou, 2007).

The sludge characteristics should generally be analysed daily by measuring the sludge content (suspended solids, SS [mg/l] and the sludge volume (SV [ml/l]); the volume of settled solids in an Imhoff cone after 30 min. These two can then be used to calculate the sludge volume index (SVI [ml/g]), which describes the actual sedimentation properties of the sludge (Indebetou, 2007). The SVI is calculated according to equation

(1).

$$SVI = 1000*SV/SS \qquad (1)$$

SVI values can then be characterised as:

0-100 ml/g	Good settling
100-125 ml/g	Fair settling
125-150 ml/g	Poor settling
150-	Bad settling, bulking sludge

(ATV-DVWK, 2000)

Having a good settling sludge makes it easier to separate sludge from the water.

2.2.3 Nitrogen cycle

Nitrogen is found in various chemical forms in the environment, including organic nitrogen, ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-) and nitrogen gas and the convertions between these can be carried out through both biological and non-biological processes, see Figure 4. Many of these convertions are done by micro-organisms, either to be able to accumulate the nitrogen or to gain energy from the process (University of Missouri Extension, 2012).

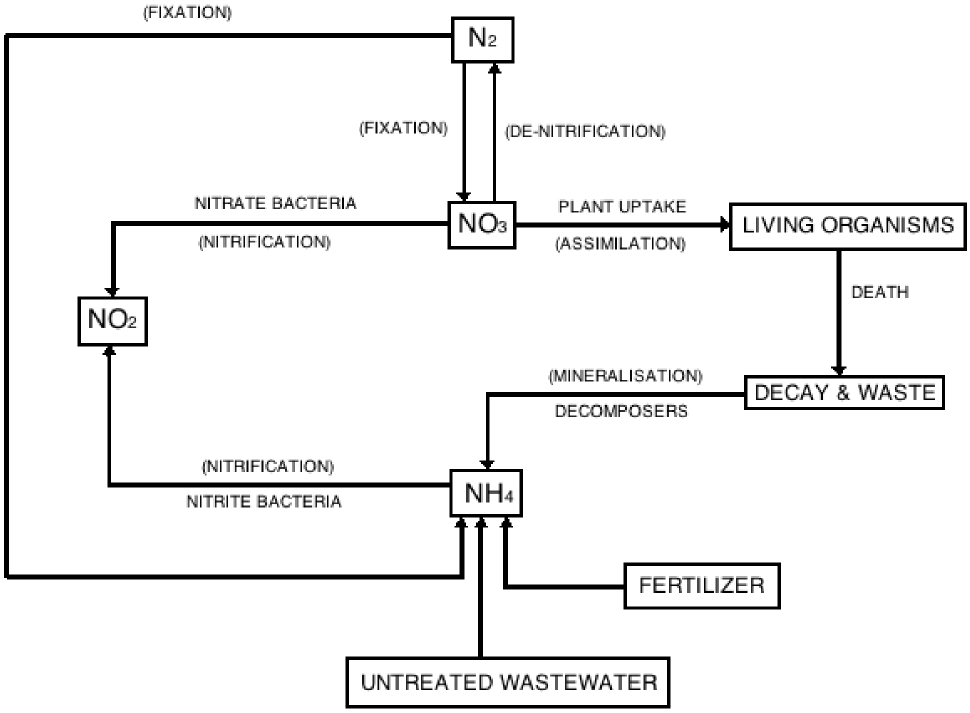


Figure 4. The Nitrogen Cycle (after Österlund, 2004)

In the atmosphere, nitrogen is inert and is converted into biologically usable forms by nitrogen fixing bacteria. These forms are in turn accessible to plants through symbiosis with the bacteria. The nitrogen uptake by plants is called assimilation. The waste organic material is through a process called mineralization, broken down by decomposers back into ammonium (University of Missouri Extension, 2012).

Under aerobic conditions autotrophs oxidize ammonium into nitrate, through a two-step biological process called nitrification. In the first stage, nitrosomonas convert ammonia into nitrite and next nitrite is oxidized into nitrate by nitrobacts (University of Missouri Extension, 2012).

When nitrate in turn is present in an anoxic environment, it can through biological reduction be used by facultative bacteria for respiration. This process is called denitrification and leaves nitrogen in form of nitrous oxide and nitrogen gas, and thereby completes the nitrogen cycle (University of Missouri Extension, 2012).

Fresh wastewater mainly consists of nitrogen in form of ammonium. Discharges of untreated wastewater burdens the recipient water bodies, causing problems such as eutrophication and oxygen deficiency (Svenskt Vatten, 2010).

2.2.4 The activated sludge process

At present, the activated sludge process is the most common technique used for biological wastewater treatment (Svenskt Vatten, 2010). It can be made as simple as an aerated basin followed by a sedimentation basin as shown in Figure 5.

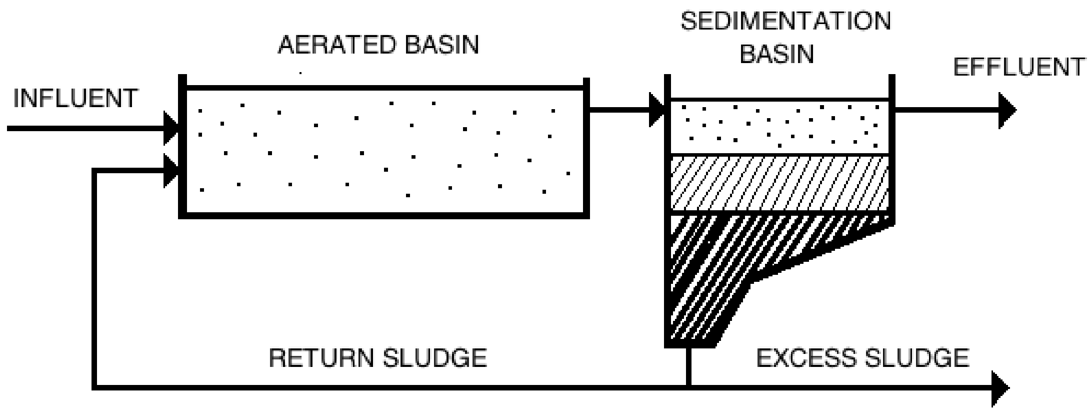


Figure 5. A conventional treatment plant with the activated sludge process

Treatment with activated sludge is based on degradation by micro-organisms. Feeding on organic material and nutrients from wastewater, the biomass grows in an aerated basin and together with the organic material; they compose the activated sludge in the system. The principle of the activated sludge process is that the retention time for the sludge is longer than that for wastewater and the fundamental unit is the biomass flocks created in the process. This is where biological activity takes place. Through sedimentation, sludge is separated from outgoing water. Some of it is re-circulated, to keep a constant amount of biomass in the system, and the micro-organisms will gain a longer retention time than the surrounding water. In a properly working activated sludge system, organic material can be reduced by 90-95% and nitrogen and phosphorous-removal can also be added to the systems (Driscoll, 2008).

The importance of micro-organisms in the activated sludge process

Micro-organisms include bacteria, fungi, algae and protozoa and they all have a significant role in the degradation process of organic material (Svenskt Vatten, 2010). They either degrade or convert compounds and play an important role in sludge properties. In a treatment plant mainly bacteria takes care of the biological treatment, but also other microbes are of importance, as for example the macro animals, continuously filtering the water (Svenskt Vatten, 2010).

As mentioned in 2.2.1.3 the most limiting factors for biological growth is access to nutrients and favourable temperature. Also the pH-level and presence of toxic compounds will effect (Svenskt Vatten, 2010).

Activated sludge contains a mix of hundreds of different micro-organisms. This mixed-culture occurs spontaneously through competition over substrate and nutrients while surviving pH, temperature conditions and fluctuations. The most competitive will grow and form activated sludge (Driscoll, 2008).

The sedimentation basin is the most critical step in the activated sludge process. This is where the sludge should be separated from the treated wastewater and re-circulated back into the system, i.e. flock building and sinking bacteria will be favoured while the rest is flushed out of the system. It is favourable to have an activated sludge with good sedimentation properties; high sedimentation rate and which leaves a dense sludge (Driscoll, 2008).

Micro-organisms are associated with both fine and poor sludge quality. The sedimentation depends on the flock characteristics that in turn largely depend on micro-organisms. An example is flocks with too much filamentous bacteria, which may result in foaming and sludge swelling. On the other hand, too little filamentous bacteria in a flock will give small flocks that are difficult to separate from outgoing water (Indebetou, 2007).

Around 10-30 % of the incoming nitrogen is assimilated in the sludge, since the bacteria use nitrate and ammonium for growth. The rest will leave the system as nitrogen gas (Svenskt Vatten, 2010).

The nitrification bacteria extract energy from ammonium and nitrite. Nitrification is the sum of two processes that occurs in sequence. Nitrifiers are autotrophs, which is why they grow and reproduce slowly. Fixing carbon from the atmosphere is energy consuming and only a small fraction of the gained energy can be used for growth. Their generation time can vary from 8 h to several days. This makes the nitrification the limiting step in the nitrogen cycle (Svenskt Vatten, 2010).

De-nitrification bacteria are heterotrophs and are favoured by simple, easily degradable organic compounds (Svenskt Vatten, 2010).

When applying pre-denitrification in wastewater treatment, the anoxic part of the biological step is executed before the aerobic, which implies that the water/sludge from the aerated basin has to be recycled to the anoxic zone to complete the nitrogen cycle. An advantage with this kind of solution is that no external carbon needs to be added, since the carbon in the influent can be used as an energy source in the denitrification. The nitrogen reduction in a pre-denitrification process will be between 50-80% (Svenskt Vatten, 2010).

When biological nitrogen reduction is introduced to a treatment plant, the design is often based on the required volume for the nitrification. The sludge age is the most critical factor in the activated sludge process and it is vital that the reproduction time of the nitrifying bacteria is always below the sludge age, since the nitrifying bacteria (autotrophs) grow slower than the bacteria degrading the organic material (heterotrophs) in the activated sludge process (Svenskt Vatten, 2010).

About 30 % of the incoming phosphorous is separated through biological growth. Also in the clarifier there are on-going biological processes. If the sedimentation becomes anaerobic one has to be aware of possible phosphorous release and periodically the phosphorous concentration will be larger in outgoing water than in incoming (Svenskt Vatten, 2010).

2.2.5 Biological phosphorous removal

Since phosphorous is not found in any gaseous state, the only way to remove it from wastewater is through the sludge. The main principle of biological phosphorous removal is that organisms in the sludge assimilate phosphorous in order to build up their cell. The amount of phosphorous assimilated depends on the amount of volatile fatty acids (VFA) in the wastewater. This is the reason for by-passing some raw influent directly to the anaerobic basin (Svenskt Vatten, 2010).

During anaerobic conditions, phosphorous accumulating bacteria will uptake and store easily degradable organic material in their cells as organic polymer. This process requires a lot of energy, which can be extracted from the hydrolysis of, stored earlier, polyphosphates into phosphate. The phosphate in turn will then be transported out of the cell, increasing the phosphorous concentration in the wastewater. However, when the sludge later on in the biological treatment process is exposed to aerobic conditions, the bio-P bacteria will use the stored organic material to grow and to store phosohorous. Overall, there will be an excess uptake of phosphorous (Svenskt Vatten, 2010), see Figure 6.

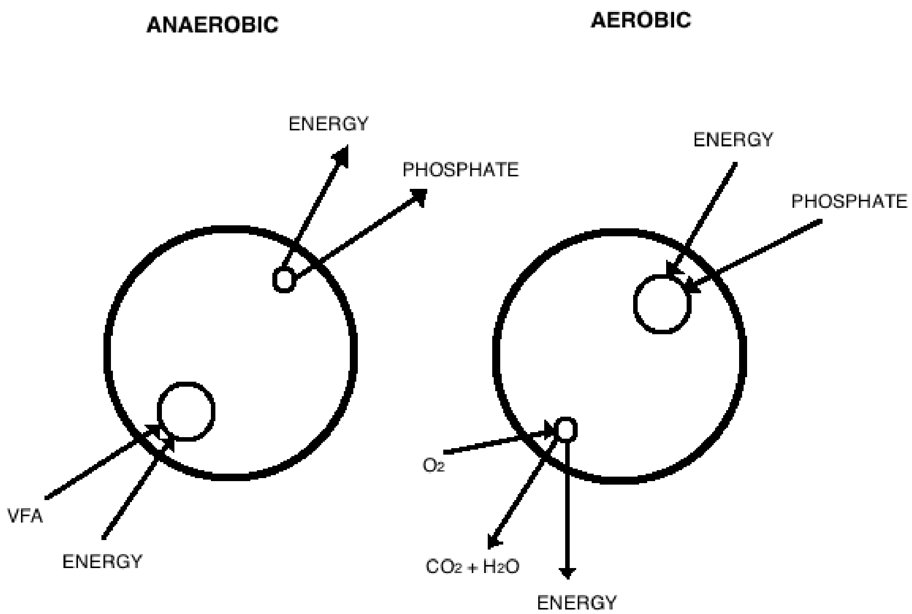


Figure 6. The principle of biological phosphorous removal

For the bio-p process to function properly, the amount of easily degradable organic matter is critical. To control the phosphorous uptake, it is important that the sludge is not further exposed to anaerobic conditions, where the phosphorous might again be released (Svenskt Vatten, 2010).

2.3 PROCESS DESCRIPTION FOR JE-WWTP

The wastewater collection network in Ja-Ela/Ekala consists of 30 km pipes and 5 pump stations, see appendix 1.

The pre-treatment of wastewater in the treatment plant is mechanical and includes screening and grit removal. The second part of the treatment is biological and is followed by a clarifier. From there water flows to an outlet pump station in which chlorination is possible. The effluent is finally discharged into the river Dandugam Oya.

Excess sludge (from the activated sludge process) is pumped to a belt filter press for dewatering and is, after being stored in a container, transported away for final disposal**.** See Appendix 2 for a scheme over the process design.

2.3.1 Primary treatment

Wastewater is led by gravity to the treatment plant. It first enters the reception chamber, which is equipped with a bypass filter that enables the bypass of incoming flow directly to the outlet pumping station. This can be used in situations when incoming flow is greater than the capacity of the treatment, for example after a heavy rain.

The first step in treatment is to remove larger particles such as paper, rags etc. This is done by two automatic fine screens, which will catch any matter above 3 mm in size. The screenings, before they are rinsed off, will themselves act as screens and thereby increase the efficiency of the mechanical treatment. A level switch automatically controls the rinsing of the screens. Removed screenings are transported away by a screw conveyor for further treatment and disposal.

The water from the fine screens is led into a distribution chamber where it is divided into two streams leading to the grit traps**.** In the distribution chamber pH is measured and will give alarm at low and high values**.** The grit removal involves removal of sand and other heavy particles. A submerged mixer controls that only heavy particles will settle while suspended organic matter is kept in suspension for secondary treatment. The mixer is frequency controlled, enabling optimization of the separation. Settled grit is removed by a submerged pump and transported away with a screw conveyor for further treatment before disposal.

A bypass controls the flow so that the biological treatment is fed with maximum flow of Q-design, which is the flow designed for the maximum pressure the pipes can manage as well as the maximum flow that the biological processes can keep up with. It is also of importance that the flow doesn’t fall too low below this value, since this can cause corrosion on the pipes and problems in the biological treatment process (Indebetou, 2012).

2.3.2 Secondary treatment

From the grit traps the water is led to the biological step, which consists of three different basins with conditions that favour specific biological processes. The water enters the biological treatment through a split box, dividing it into two streams. The main stream is leading to the first biological step and sthe econd stream of 0-50% of the flow is leading directly to the second biological basin.

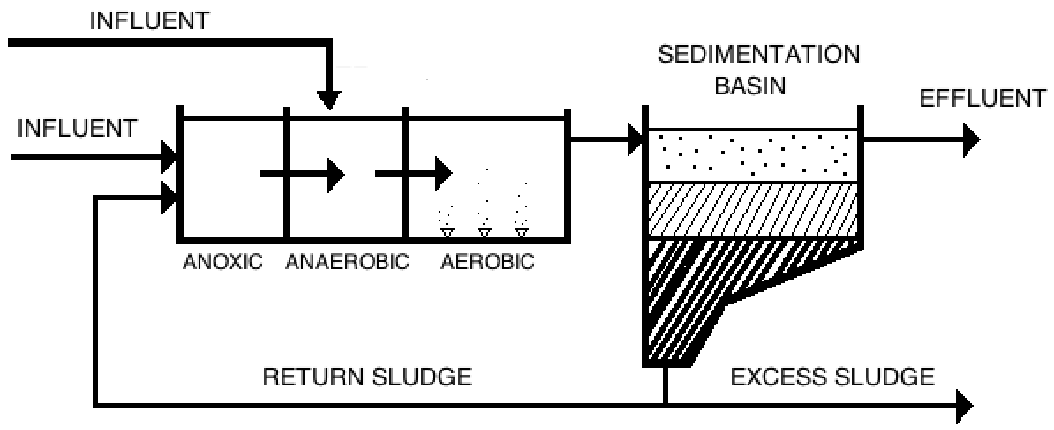


Figure 7. The biological treatment chain at JE-WWTP

The biological treatment is based on the activated sludge process (see 2.2.4), which involves re-cycling of sludge to give the micro-organisms the optimal conditions and time for growth and digestion (see Figure 7).

1) Anoxic Basin

The anoxic basin is first in order of the three biological basins. It has an inlet both for fresh wastewater and for re-circulated activated sludge (return sludge).

Entering water is mixed with the recycled sludge, containing nitrate. Since the basin is anoxic (no dissolved oxygen) this enables de-nitrification to occur according to (2).

$$\text{Org. material} + NO_3 \rightarrow N_2 + CO_2 + H_2O \qquad (2)$$

Nitrogen is released from the wastewater as nitrogen gas.

The anoxic basin is equipped with submerged agitators to maintain a good contact between substrate and microbes as well as for keeping the sludge in suspension.

2) Anaerobic Basin

The second biological basin is anaerobic and is designed to remove phosphorus (see 2.2.4.1).

3) Aerobic Basin

In the last basin of the biological treatment, nitrification will occur. That is, ammonia and organic nitrogen will convert into nitrate, see (3).

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+ \quad (3)$$

This is a natural step in the nitrogen cycle and it will be followed up by de-nitrification in the first basin, where nitrate converts into nitrogen gas.

When metabolising organic matter, the microbes consume oxygen and release carbon dioxide and water. For the microbes to grow and create activated sludge flocks, there is also a demand of nutrients (Svenskt Vatten, 2010). An oxygen supply system controls and adjusts the oxygen content in the wastewater. The system consists of a DO-sensor measuring the dissolved oxygen in the aerated basin signalling to the automatic control system which in turn controls the dissolved oxygen level through the submerged air blowers in the basin. For optimum degradation, the oxygen content should be kept around 1,5-2 mg/l (ATV-DVWK, 2000).

4) Clarifier

The biological basins are followed by clarification in a sedimentation basin where sludge flocks are separated from water by gravity. There is a travelling bridge scraper under continuous operation. During operation, settled sludge is lifted up by siphon action into a sludge channel, leading to the first biological basin where the nitrate will convert into nitrogen gas and complete the nitrogen cycle. Excess sludge is regularly taken out and transported away for dewatering in a belt filter press. The amount of excess sludge taken out has a significant role in the biological treatment process.

Before final discharge to the Dandugam Oya river, the effluent will pass the outlet pumping station and chlorination contact basin where a flow meter registers outgoing flow. In case of epidemic diseases in circulation around the area, sodium hypochlorite can be added here for disinfection.

Figure 8 shows an example how the concentrations of ammonia, nitrate and phosphate varies throughout the biological treatment in the JE-WWTP. The increase of nitrate and decrease of ammonia in the inlet of the anoxic basin is a result of incoming re-circulated sludge, rich in nitrate and very low ammonia concentration (see proportions in the sedimentation tank).

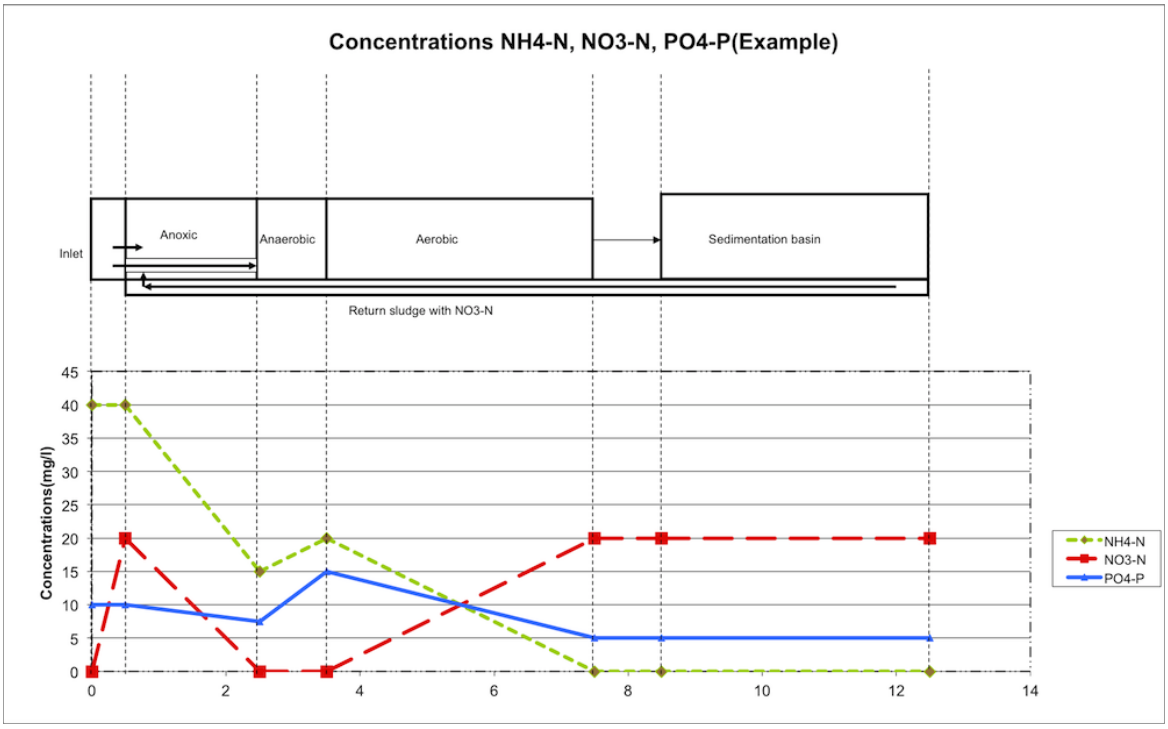


Figure 8. An example of the variations in parameter concentration through-out the biological treatment in JE-WWTP (Indebetou, 2007)

2.4 COMMISSIONING THE JE-WWTP

The start-up and commissioning period of a wastewater treatment plant is intended for optimizing the treatment process. Machinery is checked upon and adjusted while operating data and laboratory test results are studied to combine and select operational parameters entailing the best performance. When commissioning a plant, its operation is optimized by regulation of the control parameters. In this plant, the most essential control parameters are the oxygen content in the biological basins and the sludge age (Indebetou, 2007).

2.4.1 Oxygen content

All steps in the biological treatment are dependent of the oxygen content in the respective basins. The dissolved oxygen concentration is therefore considered a key control parameter in the system (Indebetou, 2007). By keeping a consistent oxygen concentration a selective bacteria culture will breed. Since the amount of oxygen should differ from basin to basin and the flow is recycled, it is vital to consider this when adjusting mixers and air blowers. For example, the oxygen level should be kept slightly lower at the end of the nitrification tank than at the beginning. The pressure from the blowers is indirectly controlled by biological activity in the nitrification basin and the oxygen set-point in this basin is fixed to 2 mg/l. Further, for optimum de-nitrification conditions, the DO-concentration in the anoxic basin should not exceed 0.5 mg/l and in the anaerobic basin it should be kept as close to 0 mg/l as possible (Indebetou, 2007).

2.4.2 Sludge age

The sludge age, i.e. the average retention time for a micro-organism, needed in a biological system depends on the biological activity. A process should be designed so that the sludge age enables complete nitrification. When the rate of nitrification is known, and thereby the required sludge age, the nitrification can be maximized by adjusting suspended solids and dissolved oxygen concentrations in the basin. To maintain a good BOD reduction the sludge age should be at least 3 days.

The process in the JE-WWTP is designed for a total sludge age of 8 days (Indebetou, 2007). The total sludge retention time (SRT) is calculated according to (4).

$$SRT = (V_a * SS_a) / (Q_{es} * SS_{es}) \quad (4)$$

SRT = Solids Retention Time (sludge age), days

V_a = Volume of activated sludge basin, m^3

SS_a = the amount of sludge in the activated sludge basin, kg TSS/m^3

SS_{es} = the amount of sludge in the excess sludge, kg TSS/m^3

Q_{es} = flow of waste sludge, m^3/days

(ATV-DVWK, 2000)

Waste activated sludge

By regulating the amount of excess sludge taken out of the system one can control the growth and amount of active bio-mass in the process and thereby maintain a stable sludge age and suspended solids-concentration in the activated sludge basins (Indebetou, 2007).

F/M-ratio

The food to micro-organism ratio (kg BOD/kg SS, d) is inverse proportional to the sludge age and describes the daily amount of organic matter the micro-organisms in the system are fed. Thus, the longer sludge age, the lower F/M-ratio (ATV-DVWK, 2000). The relationship can be calculated from (5)

$$F:M = (BOD * Q_{in}) / (SS * V_a) \quad (5)$$

Where, BOD and SS are given as concentrations, Q_{in} is the incoming flow and V_a is the activated sludge volume.

To obtain full nitrification, the ratio should be around 0,1-0,2 kg BOD/kg SS,d (ATV-DVWK, 2000).

The control parameters mentioned above are studied through a number of laboratory wastewater and sludge analyses. The frequency of the tests and parameters to be tested were chosen so that they do not overlap, though still give a clear understanding of the state of the process.

2.5 INTERMITTENT CONTROL OF THE AERATION SYSTEM

Control of the aeration system in a biological treatment plant is of great importance since the concentration of dissolved oxygen is directly related to the treatment and its efficiency (biological growth and activity).

Intermittent operation can be applied when there is an excess of dissolved oxygen in the biological system. As insufficient amounts of dissolved oxygen render nitrification, an excess of dissolved oxygen in the aerated basin, will in turn, through the return sludge interrupt the denitrification and the phosphorous reduction in the anoxic and anaerobic basins.. The aeration system is also often the most energy consuming department in a wastewater treatment plant (Dotro, 2011) i.e an optimization can both improve the treatment and keep down the maintenance costs. The aeration can be either time set or controlled by online measurement of parameters like DO, $NH4^+$ or SS in the aerated basin (Dotro, 2011).

Intermittent aeration has through out the years been studied in different applications and successfully applied in many treatment plants with different configuration. It was introduced and developed in the 1950’s (applied in oxidation ditches) and became popular in the 1980s when many plants were built to operate in this mode to promote biological nitrogen removal and to save energy (Stig Morling).

Today, intermittent aeration in WWTP's in order to save energy and improve the treatment exists in several plants in for example Sweden and Denmark where this operation mode has been implemented in full scale facilities, for example Nykvarnsverket in Linköping (Tekniska Verken, 2012) and Stadskvarn in Skövde (Skövde Kommun, 2009).

The main difference between these plants and the JE-WWTP is that they are equipped with mixers in the aerated basins in order to obtain better contact between water and sludge and thereby allows a faster process.

There are also more simple examples of successful intermittently aerated plants. For example the Songjiang municipal wastewater treatment plant in China (Xia, 2002) with a single biological reactor (sequencing batch reactor) where anaerobic, anoxic and aerobic conditions are created in the same tank by regulating the airflow.

The approach at JE-WWTP, having a continuously fed, intermittently aerated activated sludge plant, can be seen as a combination of sequencing batch reactor and a conventional activated sludge plant (Dotro, 2011).

Several studies have been devoted to intermittent aeration. In “Intermittent aeration in Biological Treatment of Wastewater” the operational optimum of the aeration time was determined from the BOD5 removal after a certain period of treatment. Finding that an optimization of the air-liquid contact time can give a 27 -58 % saving on the unit energy consumption, the study concludes that an appropriate intermittent aeration cycle can give a substantial energy saving while also an adequate treatment is maintained (Doan et.al,2009).

In the full scale bioreactor Sant Celoni WWTP (Barcelona, Spain), a similar study (Optimization of intermittent aeration in full scale wastewater treatment plant biological reactor for nitrogen removal) was done, where the optimal configuration of aeration control was based on COD and nitrogen removal. Also here it was found that intermittent aeration favors the treatment of both COD and Nitrogen and gives a major reduction of the energy consumption (Habermeyer et.al, 2005)

In many of the WWTP's where related strategies have been applied, the results have been similar; intermittent aeration has been energy saving and treatment effective, especially regarding nitrogen and phosphorous removal (Dotro, 2011).

In 1992 the Danish company Kruger, successfully introduced STAR, an online control system, which combined with the SCADA system, can be tailored to adjust control of biological treatment processes (VA-Ingenjörerna, 2009).

There are different applications of the STAR control, but they all include intermittent aeration and insures 10-20 % energy reduction for aeration and 20-30 % reduction of effluent nitrogen. STAR is considered suitable for flexible operation, i.e very high or very low loads compared to design (Kruger, 2009).

In April 2009, there were over 30 plants operating with STAR (Kruger, 2009), amongst which the following improvement of treatment and operation results has been presented:

- Ede WWTP, Netherlands: Tot -N reduction of 50 % and improved P-treatment (Jörgensen, 2011)

- Eksjö WWTP, Sweden: 10 % energy reduction and improved N-treatment (VA-Ingenjörerna, 2009)

- Nykvarnsverket, Sweden: Tot-N reduction of 36 % (Sehlén, 2013)

2.5.1 The process background to the introduction of intermittent control at JE-WWTP

Another major consequence of having low incoming flow is that the return sludge flow has to be kept high in relation to the incoming flow, in order to avoid that the syphon action in the sedimentation basin does not get interrupted. If the syphon pipes clogg, eventually anaerobic conditions will develop in the sedimentation basin and problems like floating sludge might occur. However, keeping a high return sludge flow brings up the concentrations of dissolved oxygen in the anaerobic and anoxic basins and in turn interrupts the biological processes here. By using intermittent aeration (i.e. over time introducing less oxygen to the system) the return sludge flow can be kept at the same rate without risking too high dissolved oxygen concentrations in the anoxic and anaerobic basins.

Moreover, implementing intermittent control of the aeration system does allow lower return sludge flow since more sludge is kept in the aeration basin (the sludge settles in the basin when blowers are paused) and the syphon pipes thereby will need less pressure.

To sum up: intermittent aeration introduces less oxygen (but still enough) to the system and allows a lower return sludge flow, keeping down the dissolved oxygen concentrations in the anoxic and anaerobic basins.

When introducing intermittent aeration to JE-WWTP constraints on aeration and non-aeration time have to be taken into consideration to prevent the blowers from damage and to keep good contact between the sludge and wastewater so that nutrients and bacteria can interact. Favouring the blowers would be to keep long non-aeration periods, but with regards to the biological activity these can not be kept too long. Since there are not any mixers, already within a couple of minutes the sludge settles to the bottom of the basin and will not be able to interact with the wastewater. Keeping a too long non-aeration period is also a risk for too low oxygen concentrations in effluent.

A manufacturing constraint from the blowers installed at the JE-WWTP is that they can start maximum 6 times/hour. Through the automatic control system another constraint has been set so that the non-aeration period can not exceed 99 minutes. This is a question of system security, to avoid that any operator might set longer periods.

3. METHOD

3.1 LITERATURE STUDY

This master thesis was initiated through a background study of biological wastewater treatment through the activated sludge process and its control parameters, problems that might occur during commissioning and how to avoid/prevent these.

3.2 WASTEWATER ANALYSIS AND RECORDING OF DATA COLLECTED ON SITE

Composite samples of 24 h from the inlet and outlet were analysed on a daily basis along with sludge samples from excess sludge and the nitrification basin. A number of selected parameters (given in Table 1 together with the name of the test-kit) were studied and recorded throughout the commissioning in order to control the progress and quality of the treatment and follow the behaviour of the process when changes in the control system were made.

The analyses were carried out in the JE-WWTP on-site laboratory using Hach-Lange cuvette kits and Hach Lange DR5000 spectrophotometer. The test methods for each parameter are given in Table 1.

Table 1. Test methods from Hach- Lange used for analysis of wastewater

Parameter	**Test-kit**
BOD	LCK 555
COD on influent	LCK 514
COD on effluent	LCK 314
Total N on influent	LCK 338
Total N on effluent	LCK 238
NH_4-N	LCK 303
PO_4-P	LCK 348
Nitrate	LCK 340
Total P	LCK 338

Tests on sludge volume, suspended solids and dry solids on fresh and treated wastewater, fresh sludge and dewatered sludge were carried out according to international standards (Metcalf et al., 2004).

The results were presented as a comparison of energy consumption and treatment results during continuous and intermittent operation mode of the aeration system.

3.3 EVALUATION AND ADJUSTMENTS THROUGH THE AUTOMATIC CONTROL SYSTEM

Together with the wastewater analysis, adjustments on the plant process were made through the automatic control system SCADA (supervisory control and data acquisition) and evaluated parallell with laboratorial analyses to find the most appropriate running conditions of the plant with respect to effluent water quality and energy consumption. Through the SCADA, machinery can be set in automatic operation mode, i.e frequencies, flows, running time etc. is controlled to satisfy set-points and to reach a balance in the process. The logic scheme in Figure 9 illustrates how the operation of the blowers, set in intermittent mode, depends on the DO level in the aerated tank and the time that passes while in run/pause mode. The DO levels and time limits that determines the operation of the blowers are manually adjusted in the SCADA, to find outgoing wastewater of good quality.

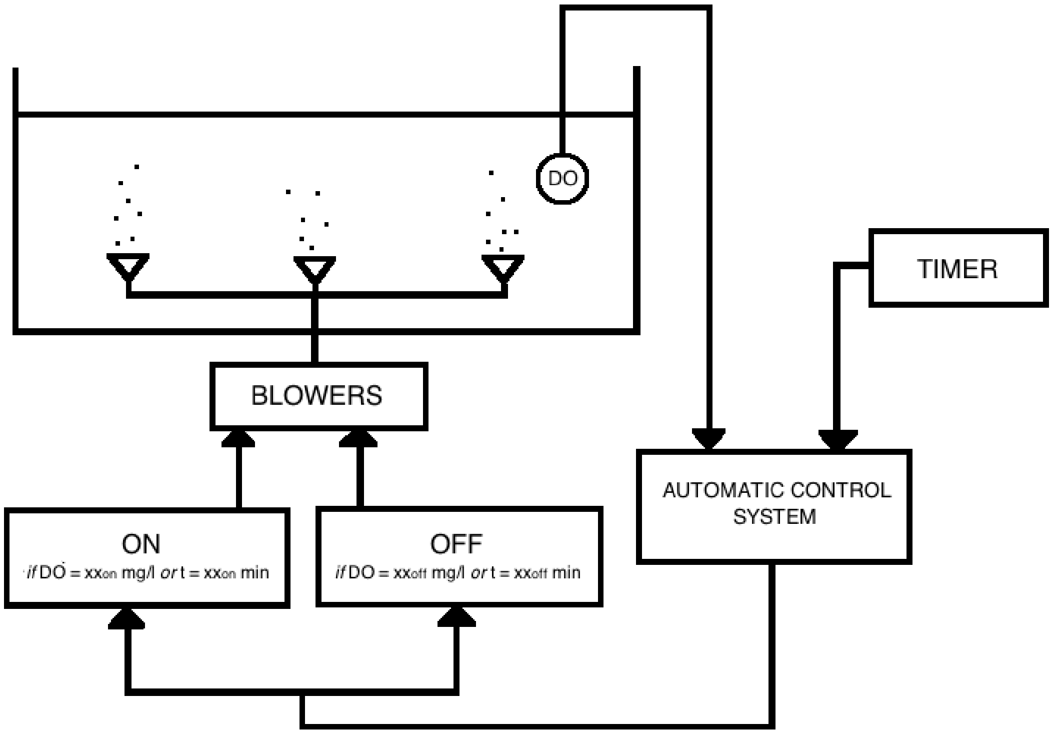


Figure 9. Regulation of the aeration system

4. RESULTS AND OBSERVATIONS

The JE-WWTP has been receiving wastewater since September 2011. In October 2012, the plant still operated with an incoming flow and load far below design values. Table 2 shows design and current values of incoming flow and load (the parameters which are analysed on incoming wastewater) compared to the design values. The current value is shown as either median or mean (the most appropriate, from a statistical perspective with regards to number of samples and outstanding results) value of samples taken from January 2012 through April 2012. The full record of sample analysis on influent can be found in Appendix 3. The return sludge flow was set to 100 % of incoming flow and the excess sludge flow was adjusted by a valve controlled by the SS-concentration in the return sludge.

Table 2. A comparison of design and current loads and incoming flow of the JE-WWTP

Parameter	Design Value	Current Value	Current value as % of design value
Flow	7250 m^3/d	903.1 m^3/d	12.4 %
COD	6135 mg/l	495.5 mg/l	8 %
BOD_5	2191 mg/l	180 mg/l	10.5 %
Tot-N	441 mg/l	57.4 mg/l	13,1 %
Tot-P	104 mg/l	8.2 mg/l	8,7 %
SS	2421 mg/l	120 mg/l	5 %

The first 8 months during commissioning, the plant was running under continuous aeration of the aerobic basin, which resulted in abundant concentrations of DO and high energy consumption. In May 2012, intermittent control of the aeration system was introduced. Samples were taken during both continuous and intermittent operation and the results are presented and discussed in section 4.2 and 4.3.

Together with the samples, the process was controlled by continuous recording of dissolved oxygen and suspended solids through on-line instruments in the aerated basin. The data was collected in the SCADA system where it is available for further analysis.

During both the continuous and intermittent operation, the blowers were running at minimum speed and the power of the blowers were approximately 60 kW, i.e. during continuous aeration the blowers consumed 1440 kWh/d. The restrictions set on outgoing water from JE-WWTP, can not be exceeded more than 3 times out of 8 during the the plants testing period of 2 months. The consent values for each measured parameter are presented in Table 3.

Table 3. The ruling consent values from wastewater discharged from the JE-WWTP

Parameter	Limit (mg/l)
COD	<120
BOD_5	<25
Tot-N	<30
NH_4-N	<10
Tot-P	<5
SS	<35

4.1 CONSEQUENCES OF LOW FLOW

The problems associated with an excessively low incoming flow to a wastewater treatment plant are often a combination of mechanical and biological complications. Since the equipment installed is designed for a much higher flow than what is present, the plant has to be operated with equipment on minimum frequencies, intermittent modes and some parts even in complete rest (OFF) mode, which can be damaging and/or shortening the lifetime of the equipment. The constraints from the mechanical side can in turn also often affect the process and vice versa; constraints from the process side can sometimes require that some equipment is run in other than their natural mode. Following below are some consequences, which have been met in JE-WWTP, due to low flow through the system.

- Low flow allows sedimentation in the channels, creating anaerobic conditions on the bottom of the channels and eventually problems with floating sludge appear. This has been ”detected” in the inlet channels and caused problems with the screens.
- The amount of sand arriving to the plant is less than calculated, due to sedimentation and accumulation in the gravitational lines. Problems in turn has occured with the screen washing which is dimensioned for larger amounts than what is effectively present.
- The treatment plant has two sand traps, but only one can be in operation. The sand traps are equipped with a mixer and a pump which, if kept in stand-by, can be damaged by corrosion.
- The minimum flow of the outlet pumps is too high for the system, hence they cannot run continuously. Regularly switching ON/OFF the outlet pumps reduces

their lifetime.

- The sludge is thin and excess sludge can not be taken out continuously. The outtake has to be done manually, which requires more work and good process understanding from the operators.

4.2 TREATMENT RESULTS AND ENERGY CONSUMPTION WITH CONTINUOUS AERATION

The plant was operated with continuous aeration from the first days of commissioning in September 2011 until April 2012. Samples were taken through-out the period, however in this evaluation only samples taken from January 2012 through April 2012 were considered. The statistical figures from these test results were calculated from the full analysis report given in Appendix 4 and are presented in Table 4.

Table 4. Statistical data of pollutants in outgoing water during continuous aeration

	No of observ. (nos)	Mean value (mg/l)	Median value (mg/l)	Max value (mg/l)	Min value (mg/l)	Standard deviation (mg/l)	Standard error (mg/l)
COD	26	48.1	45.6	73.1	37	9.13	1.79
BOD_5	14	5.5	4.05	11.0	2.00	2.98	0.80
Tot-N	23	10.4	9.1	27.8	5.5	4.78	1.00
NH_4-N	10	2.0	1.3	4.5	0.43	1.55	0.49
Tot-P	15	4.6	4.1	8.0	3.4	1.42	0.43
SS	14	9.1	11.0	18.0	4.0	4.2	1.12

Overall, the discharge values during continuous aeration were far below the ruling consent levels. However, the continuous aeration in combination with the low load resulted in unnecessarily high concentrations of dissolved oxygen of 5 -7 mg/l and energy was thereby wasted through the aeration system.

The low load forced the system to maintain a high solids retention time (SRT) and high flow of return sludge.

It should also be noted that, even though the discharge of total phosphorus was below the consent value, the concentration was slightly high, given that the rest of the treatment was outstanding. This could be due to the combination of high free oxygen levels, high retention time of solids (SRT) and complete nitrification (Morling, Personal communication, May 2012) (see 2.2.5).

The monthly energy consumption of the JE-WWTP during continuous operation was found to be around 42 000 kWh.

4.3 TREATMENT RESULTS AND ENERGY CONSUMPTION WITH INTERMITTENT AERATION

In May 2012, the plant was operated in intermittent aeration mode and samples were taken during the whole commissioning period. The statistical figures were calculated from the test results (see Appendix 6) and are presented in Table 5. The composition of the incoming wastewater was similar during the periods continuous and intermittent aeration.

Table 5. Statistical data of pollutants in outgoing water during intermittent aeration

	No of observ. (nos)	**Mean value (mg/l)**	**Median value (mg/l)**	**Max value (mg/l)**	**Min value (mg/l)**	**Standard deviation (mg/l)**	**Standard error (mg/l)**
COD	15	35	36.0	43.0	28.4	4.1	1.05
BOD_5	8	2.1	2.0	4.0	1.0	0.7	0.25
Tot-N	15	7.2	6.9	11.8	5.1	1.7	0.43
NH_4-N	13	1.7	1.6	3.5	0.1	1.0	0.28
Tot-P	15	1.2	0.95	3.51	0.6	0.31	0.08
SS	14	10.7	11.0	18.0	4.0	4.2	1.12

In the intermittent operation of the aeration system, the run/pause time of the blowers was controlled by fixed run/pause time values together with limitations in DO concentration, i.e. if the DO concentration exceeds/falls below given maximum/minimum values before run/pause time has elapsed the blowers will be switched off/on.

The maximum and minimum DO concentrations were set to 5 and 0 mg/l. A record of the operation of the blowers during the intermittent control is presented in Table 6.

The curve in Figure 10 illustrates the variation of DO concentration in the aerated basin during intermittent aeration. As shown in this time interval of about 11 h, the DO level never reach minimum (0 mg/l) or maximum (5 mg/l), hence the intermittent mode is time controlled.

Figure 10. Variation of DO in the aerobic basin

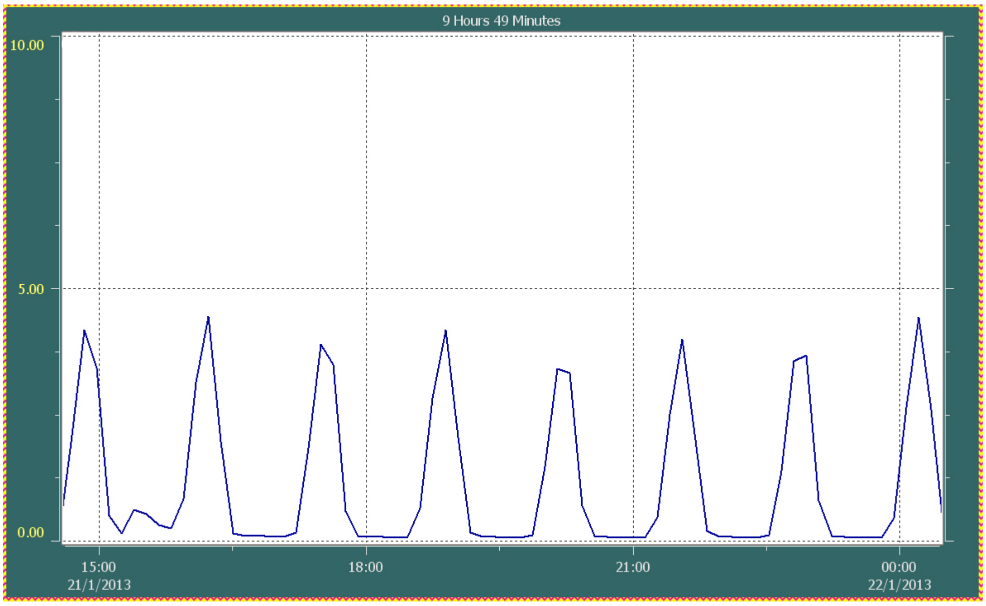


Table 6. Aeration/non-aeration in the nitrification basin at JE-WWTP

Date	Run-Time min	Pause-Time min	Cycle time hours	Cycles per day nos/d	Oxygen time per day hours/d	Anoxic time per day hours/d
4-30-2012	10	90	1.67	14.4	2.4	21.6
5-1-2012	10	90	1.67	14.4	2.4	21.6
5-2-2012	10	90	1.67	14.4	2.4	21.6
5-3-2012	8	90	1.63	14.7	2	22.0
5-4-2012	17	90	1.78	13.5	3.8	20.2
5-5-2012	16	90	1.77	13.6	3.6	20.4
5-6-2012	17	90	1.78	13.5	3.8	20.2
5-7-2012	17	90	1.8	13.5	3.8	20.2
5-8-2012	18	90	1.8	13.3	4	20
5-9-2012	18	90	1.8	13.3	4	20
5-10-2012	20	90	1.8	13.1	4.4	19.6
5-11-2012	17	75	1.5	15.7	4.4	19.6
5-12-2012	22	90	1.9	12.9	4.7	19.3
5-13-2012	22	90	1.9	12.9	4.7	19.3
5-14-2012	20	90	1.8	13.1	4.4	19.6
5-15-2012	19	90	1.8	13.2	4.2	19.8
5-16-2012	25	90	1.9	12.5	5.2	18.8
5-17-2012	17	90	1.8	13.5	3.8	20.2
5-18-2012	19	90	1.8	13.2	4.2	19.8
5-19-2012	20	90	1.8	13.1	4.4	19.6
5-20-2012	20	90	1.8	13.1	4.4	19.6
5-21-2012	19	90	1.8	13.2	4.2	19.8
5-22-2012	18	99	2.0	12.3	3.7	20.3
5-23-2012	18	99	2.0	12.3	3.7	20.3
5-24-2012	17	99	1.9	12.4	3.5	20.5
5-25-2012	15	99	1.9	12,6	3.2	20,8
5-26-2012	17	99	1.9	12.4	3.5	20.5
5-27-2012	17	99	1.9	12.4	3.5	20.5
5-28-2012	17	99	1.9	12.4	3.5	20.5
5-29-2012	19	99	2.0	12.2	3.9	20.1
5-30-2012	18	99	2.0	12.3	3.7	20.3
5-31-2012	17	99	1.9	12.4	3.5	20.5
6-1-2012	17	99	1.9	12.4	3.5	20.5

The monthly energy consumption of the JE-WWTP during intermittent operation was found to be around 8000 kWh, i.e. 20 % of the consumption during continuous operation. The energy consumption of the aeration system was reduced by 80-90 %, going from 24 hrs/day operation to 2-5hrs/day.

According to gathered sample results together with recorded running time of blowers, the performance of the JE-WWTP during intermittent aeration was improved with respect to both energy consumption and discharge concentrations of important pollutants. The diagram in Figure 11 illustrates the improved effluent quality after intermittent mode was introduced. The diagram is based on mean values of each parameter under continuous and intermittent mode. The diagram, giving a reduction of total phosphorous during the intermittent aeration, shows clearly that phosporous removal is sensitive to oxygen concentration.

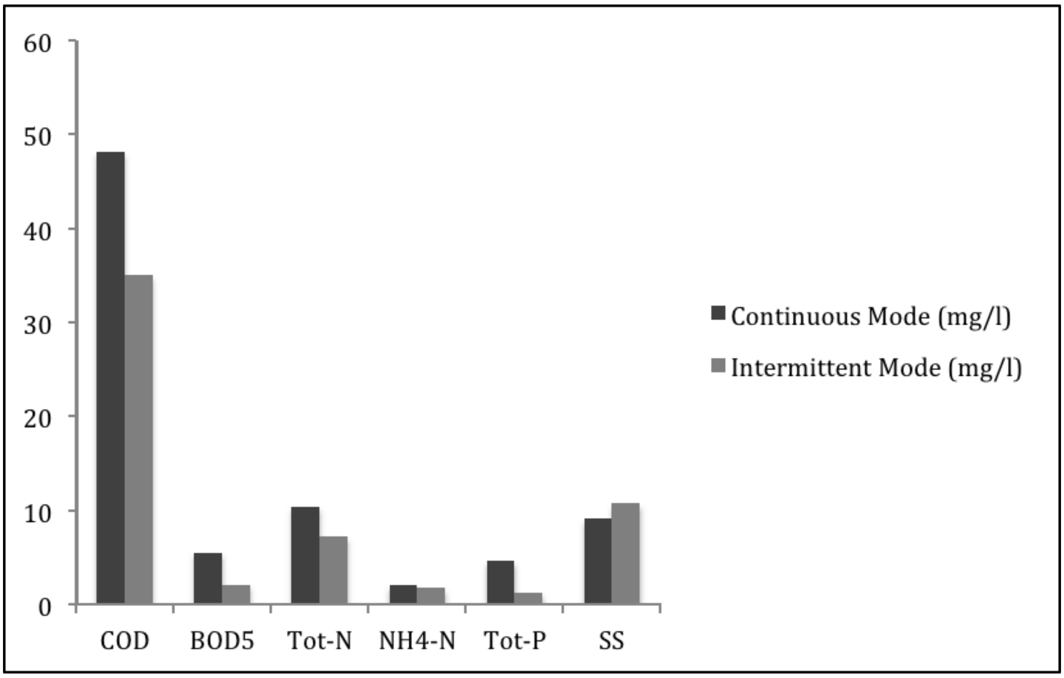


Figure 11. A comparison of mean effluent concentrations during continuous and intermittent operation mode

5. DISCUSSION AND CONCLUSIONS

That intermittent aeration will save energy (due to less operation time of the aeration system), compared to continuous, is a fact in all plants where it is applied. However, the amount of energy that can be saved and how the biological process will be affected is individual for each plant, depending on restrictions from machinery, load and flow into the plant together with pH, temperature and other factors which directly affects the biological growth, sludge stabilization and nutrient removal.

Environmental Technology has published a review paper that critically assesses positive and negative implications of interrupting aeration in nitrifying activated sludge plants designed for continuous aeration (Dotro, 2011). The conclusion drawn regarding treatment and energy efficiency is however positive, suggesting potential savings in terms of aeration to 33-45%.

The complications that have aroused at the JE-WWTP are mostly due to the fact that the biological reactors in the plant were not designed to run in intermittent mode. For example, since the plant has been in intermittent operation, the aeration basin has acted as a sludge storage, with SS concentrations around 7000 mg/l. This due to the fact that the basin is not equipped with mixers, hence when blowers are turned off, mixed liquor suspended solids settle within a short time. This same negative impact has been met in other similar plants (Dotro, 2011). A solution that could be attended to in JE-WWTP, if not installing mixers, is to pump sludge directly from the aeration basin to the sludge storage. The absence of mixers, resulting in less frequent contact between the biomass and water, also slows the nitrification rate. However, due to the high retention time kept in the basins, JE-WWTP still has been able to keep good results.

In general, the change of operation mode from continuous to intermittent has been successful with regards to both treatment and energy efficiency. The plant will continue to run with intermittent control until there is a major increase of the load and flow into the plant.

5.1 EVALUATION OF THE INTRODUCTION OF INTERMITTENT AERATION AT JE-WWTP

Optimization of the intermittent control was done under consideration of energy consumption, effluent quality and restrictions from SCADA and the machinery. Out of security reasons the SCADA limits the maximum pause time to 99 minutes. In late 2012 the plant was running with a pause time of 99 minutes and runtime of 20 minutes. Initially, the run time of the blowers was mostly controlled by the pre-set maximum oxygen level and usually reached maximum value (5 mg O_2/l) before the programmed run time of 20 min. However, as the SS in the aeration basin has increased during the months of intermittent operation, the aeration is now completely time controlled.

Since there are many factors affecting the process, it is not possible to evaluate small changes in run/pause time of the blowers with regard to treatment results. To be able to make a fair evaluation, one should run the plant for (minimum) one sludge age between every change.The reason for this is that the whole biomass should be exchanged at least once, so that the new biomass can adjust to the new living conditions. One sludge age is therefore used as a rule of thumb before evaluating a new operation mode.

Theoretically, in a total-mixed system like at JE-WWTP, the complete biomass will not be exchanged in one sludge age. Still, this approximation can be made since a majority of the bacteria will grow under the new conditions.

For example, there is an hourly and diurnal variation in the incoming load (including pH and temperature) and flow due to factory working hours and variations in processes, daily household routines, heavy rains and load variations due to low flow and anaerobic circumstances in the lines. If these variations have a substantial impact on the biological process, even if it is recorded, the variations in the incoming flow together with the process adjustments made on the plant, create too many variables to conclude a relationship between incoming load, flow and treatment result. However, the whole period of intermittent aeration mode has demonstrated improved treatment results compared to the previous continuous operation mode.

Why does the intermittent mode favour the treatment performance? With continuous airflow into the system in combination with the low load and relatively high return sludge flow, there is an excess of oxygen in the whole system, including the anoxic and anaerobic basins, inhibiting the biological processes which the basins are designed for. Introducing intermittent airflow, with carefully chosen on/off intervals, reduces the oxygen level in the anoxic and anaerobic basins. Still this operation mode allows nitrification to occur in the aerobic basin.

With respect to the mechanical parts of the plant and to the biology, implementing intermittent control does require some additional understanding of the treatment process and surveillance by plant operators.

Energy consumption through the aeration system when the plant is run in intermittent aeration mode, can be decreased by 80-90 %, going from a 24 h/d operation time during continuous mode to 2-5 h/d operation time in the intermittent mode. In late 2012 the energy consumption of the whole plant was around 8000 kWh per month.

5.2 MANAGING ADVANCED WASTEWATER TREATMENT PLANTS IN DEVOLOPING COUNTRIES

The wastewater treatment plant in Ja-Ela is the first high-tech plant in operation in Sri Lanka. Even though it is operated by local staff after the formal take-over procedure, the management must have good understanding of the process, the automatic control system and the machinery. The main parts of the plant have been imported from Europe and for the majority of the management, this is the first acquaintance. In order to have a smooth handover of the plant from contractors to employers, the commissioning and trial period was overlapped by on-site training of future personnel and management. During 6 months, the staff (with different educational background) from the employer has followed on-site training together with personnel from the contractor and representatives from the suppliers of equipment and technology. The training has covered the everyday procedures of the plant, repairs and adjustments in machinery, laboratorial work and monitoring of the automatic control system. Over all, on maintenance basis, the hand-over of the plant has been smooth. The complications found in the treatment process due to low incoming flow, can even be seen as positive side-factor with respect to the improved knowledge it has brought to the future personnel.

The Ja-Ela/Ekala sewerage system is distributed around the big industrial area in Ekala and the treatment plant is situated next to Nivasipura, a housing scheme accommodating approximately 3600 people. The industrial area includes a mix of factories, small to large scale, more or less spread out over a large area also including small households. The choice of location has had its complications. Complaints and protests from Nivasipura, from the smaller households and business enterprises neighbouring the pump stations and from fishermen residing in the disposal area have been received since the start of the project. Some have been formal and somehow easier to respond to. Others have been directly violent, reflecting the lack of environmental understanding among the people. However, in my opinion, the complaints, appropriate or not, have been rightfully placed. During the planning of the project, the government has not taken enough consideration of the residents and their exposure to odour coming from the sewerage system. Respecting the complaints, finding solutions and going through lawful procedures in order to appease the plaintiffs and continue with the project has been time (=money) consuming and could have been avoided with better planning and more understanding from both the government and the people.

After agreement with the employer, the JE-WWTP was designed in 2007 for 36 000 p.e. Having the plant ready to receive water in September 2011, there was approximately 4 500 p.e connected to the network, due to incorrect information about flows from individual clients and bad approximation. Also many of the clients had in an early stage expressed interest in connecting to the network, but no agreement was formalised and up to October 5, 2012 the employer is still having problems to get more connections to the network.

As a summary, building a high-tech wastewater treatment plant in a developing country like Sri Lanka requires precise planning and time scheduling, including the period during and after commissioning and a non-optimistic time span left for the unexpected.

6. REFERENCES

ATV-DVWK Specialist Committees KA 5 and KA6, 2000, *Standard ATV-DVWK 131E Dimensioning of Single-Stage Activated Sludge Plants*, GFA Publishing Company of ATV-DVWK Water, May 2000, Wastewater and Waste, Germany CBD NEWS, 2009,The history of Sri Lanka,http://www.cbc.ca/news/world/story/2009/02/04/f-sri-lanka.html, accessed 2012-12-23

Doan, H. and A. Lohi, 2009, *Intermittent Aeration in Biological Treatment of Wastewater, V*ol. 01 No. 02 American Journal of Engineering and Applied Sciences, USA

Dotro, D., Jefferson, B., Jones, M., Vale, P., Cartmell, E. and Stephenson, T., 2011, *A review of the impact and potential of intermittent aeration on continuous flow nitrifying activated sludge*, Vol. 33 No. 15 Environmental Technology

Driscoll,T.P., Barber, J.B. And Chandran, K., 2008, *Industrial Wastewater Management*, Treatment and Disposal, Water Environment Federation Press, McGraw-Hill, USA

Habermeyer, P. and Sanchez, A., 2005, *Optimization of the Intermittent Aeration in a Full-Scale Wastewater Treatment Plant Biological Reactor for Nitrogen Removal*, Vol. 77 No. 3 Water Environment Research, Water Environment Federation, USA

Indebetou, 2007, *Operation Instruction JE-WWTP*, Purac, Sweden

Jörgensen, D., Onnerth, T. and Verkuijlen, J., 2011, *Advanced Process Control by STAR Control Reduces Effluent Quality to the Safe Side of Limit Values,* Kruger A/S, Denmark

Kruger, 2009, STAR Control, http://www.kruger.dk/krugeras/ressources/files/1/8176,STAR_control-UK.pdf, accessed 2012-12-27

Metcalf & Eddy, 2004, *Wastewater Engineering – Treatment and Reuse,* The McGraw-Hill Series in Civil and Environmental Engineering, McGraw-Hill, Singapore

Ministry of urban development and water supply, 2005, *Supplementary environmental impact assessment report,* Democratic socialist republic of Sri Lanka, Sri Lanka

National Water Sanitary and Drainage Board, 2007, *Terms of Reference for Supervisory Services of Ratmalana/Moratuwa and Ja-Ela/Ekala Wastewater Disposal Project In Sri Lanka*, Sri Lanka

National Water Sanitary and Drainage Board, 2007, *Tender Notice*, Sri Lanka

Skövde Kommun, 2009, Planprogram för Stadskvarn – Aspelund, http://www.skovde.se/upload/ByggaBo/BilderPBLK/Planutstallningar/Stadskvarn_Aspelund/Programbeskrivning%20Stadskvarn%20Aspelund%20godkännande.pdf, accessed 2012-12-25

Svenskt Vatten, 2010, *Avloppsteknik 2- Reningsprocessen,* Sweden

Tekniska Verken, 2012, Nykvarnsverket, http://www.tekniskaverken.se/om-oss/anlaggningar/nykvarnsverket/index.xml, accessed 2012-12-25

Todar’s online textbook of bacteriology, 2009, Nutrition and growth of bacteria, http://textbookofbacteriology.net/themicrobialworld/nutgro.html, accessed 2012-12-23

US Environmental Protection Agency, 2010, Wastewater Technology Fact Sheet, www.epa.gov, accessed 2010-05-20

University of Missouri Extension, 2012, Nitrogen Cycle, http://extension.missouri.edu, accessed 2012-05-26

VA-Ingenjörerna, 2009, Nyhetsbrev Nr 1, http://www.vaing.se/vaengineers/ressources/documents/1/4252,STAR_2009_lite.pdf, accessed 2012-12-27

Xia, S., Gao, TY. And Zhou, ZY., 2002, *Nitrogen and phosphorous removal under intermittent aeration conditions,* Vol. 14 No. 4 Journal of environmental sciences

Österlund, R., Vogel, K. and Fjallstrom, M., 2004, *Växters kvävefixering och kvävemetabolism,* BMC, Sweden

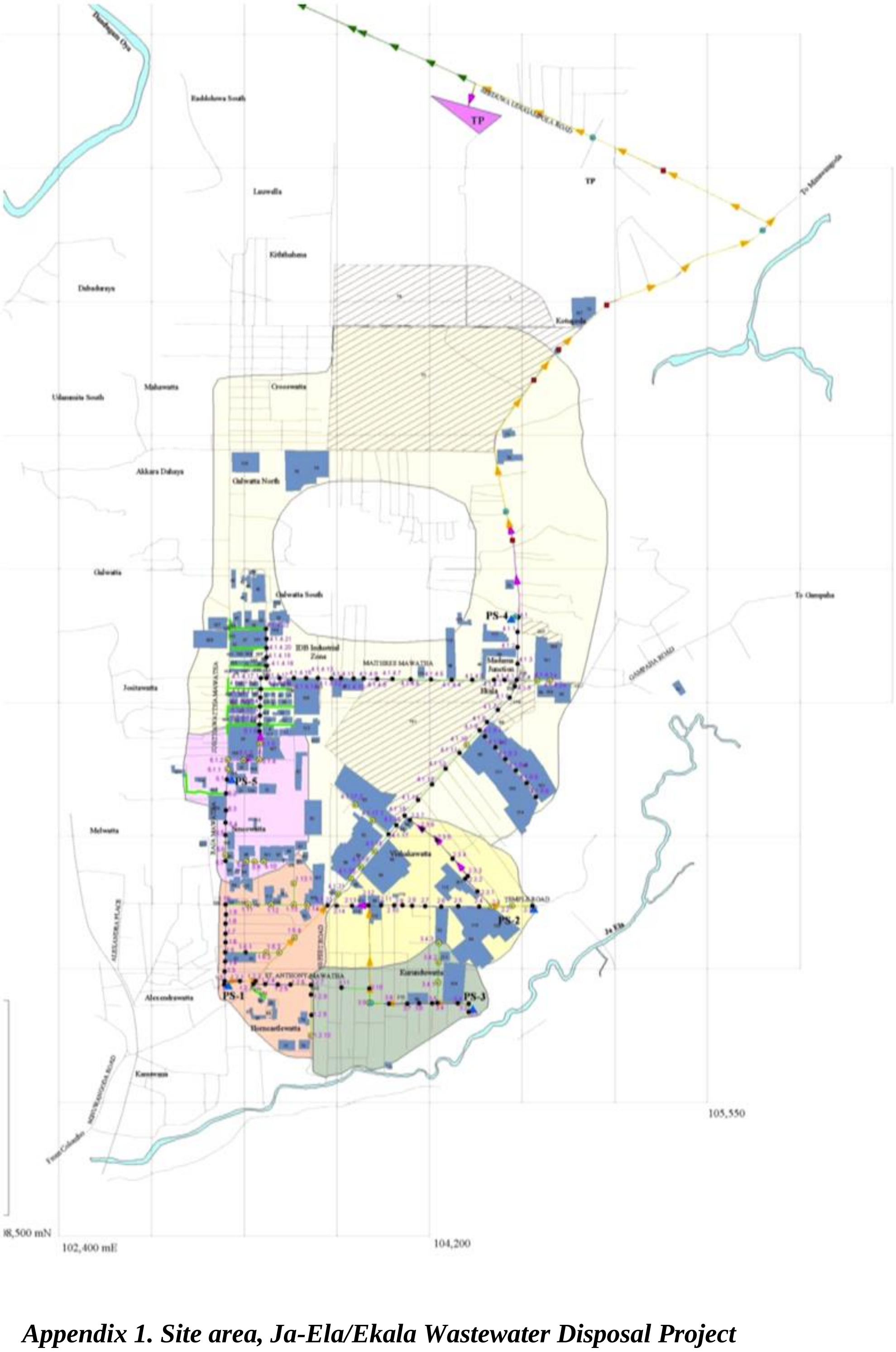
PERSONAL COMMUNICATIONS

Staffan Indebetou, Purac AB, May 2012

Stefan Sehlén, Tekniska Verken, February 2013

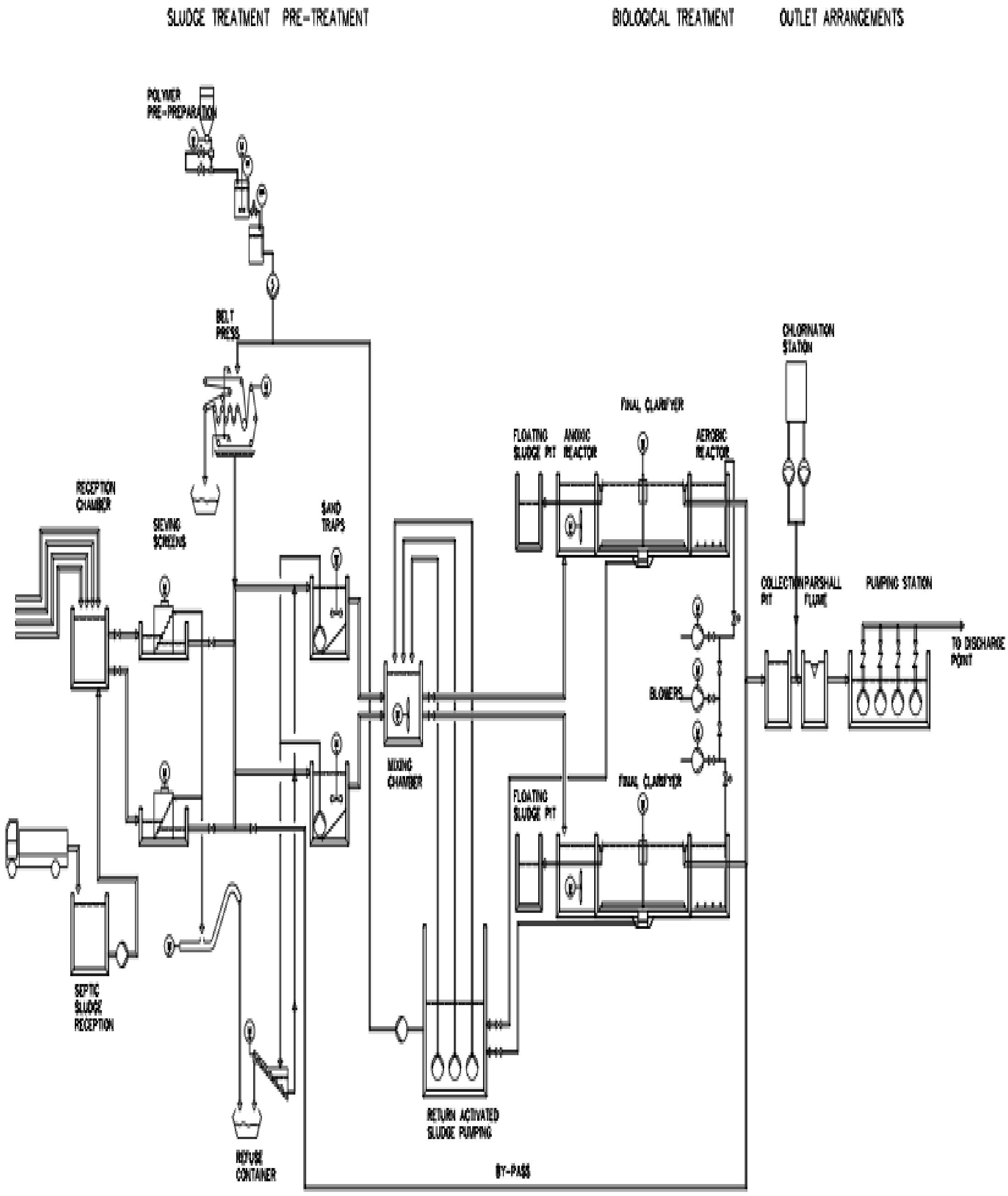
Stig Morling, Sweco, May 2012

7. APPENDIX



Appendix 1. Site area, Ja-Ela/Ekala Wastewater Disposal Project

Appendix 2 Process Design, JE-WWTP



Appendix 3. Influent during continuous aeration

Date	BOD_5 mg/l	COD mg/l	Tot-P mg/l	PO_4 mg/l	Tot-N mg/l	NH_4-N mg/l	SS mg/l
9-9-2011		323	2.42		22.3		85
9-12-2011		321	3.31		38.6		46
9-13-2011		535	3				128
9-14-2011		438	2.67		29.1		74
9-15-2011		244	2.39	1.74	40.4	21.2	22
9-16-2011		237	3.78	1.83			38
9-19-2011		355	3.1	2.61	32.3	19.1	46
9-20-2011		385	4.28	3.51	36.8	24.8	74
9-21-2011		365	3.45	2.74	33.3	25.5	38
9-26-2011		349	3.62	2.53	34.1	21.1	58
9-27-2011		353			35.1		52
9-28-2011		341			50.6		62
9-29-2011		366			47.8		60
9-30-2011	125	359			45.9		62
10-3-2011		374	4.02	3.22	46.2	23.1	58
10-4-2011		369			48		66
10-5-2011		372			47.6		66
10-6-2011		355			39.3		60
10-10-2011		388			43.4		55
10-11-2011		287	3.54	2.93	41.4	29.4	56
10-12-2011		299			40.2		56
10-13-2011	266	401			45.7		62
10-14-2011		309			44.1		59
10-17-2011		342	3.47	3.01	45.2	30.2	59
10-18-2011		355			43.7		65
10-19-2011		299			35		86
10-20-2011	151	341			47		94
10-21-2011		502			33.8		104
10-24-2011		490	3.35	2.98	38.9	30	92
10-25-2011		297			26.6		18
11-3-2011		236	1.7	1.44	38.8		35
11-4-2011		275		5.67	23.3	0.58	114
11-7-2011		244	11.5		22.1		94
11-9-2011		314	3.15		22.8		166
11-10-2011		309	6.36		22.8		190
11-11-2011		251			26.7		99
11-12-2011		258			25.2		56
11-14-2011		267	3.54	5.7	24.9	<5	56
11-15-2011		321			32.9		86
11-16-2011	117	357			39.7		96
11-17-2011		319			32.1		64
11-18-2011		315			32.7		42
11-21-2011		377			28.3		144
11-22-2011		392			28.7		138
11-23-2011	60	315	3.71	2.52	74.3	0.54	70
11-24-2011		278			79.9		88
11-25-2011		286			68		32
11-28-2011		299			73.2		44
11-29-2011		331			68.5		62
11-30-2011		399	9.44	4.43	72	72	148

12-1-2011	214	399			33.8		118
12-2-2011	249	278			46.8		59
12-5-2011		295			59.5		110
12-6-2011		390			61.9		186
12-7-2011	151	353			61.3		108
12-8-2011	238	408	6.19	4.06	65.5	25.3	102
12-9-2011	198	320			110		96
12-12-2011		397			69.1		230
12-13-2011		398	3.93	3.44	64.8	14.6	364
12-14-2011		330			35.8		290
12-15-2011	291	280			27.9		100
12-16-2011	288	289			30.2		84
12-19-2011		290			27.2		56
12-20-2011		377			44		114
12-21-2011		388			42		105
12-22-2011	142	356			29		93
12-23-2011	279	361			44		98
12-26-2011		418			53.1		126
12-27-2011		351			82.4		126
12-28-2011	81	392			72.3		133
12-29-2011	103	332			45.4		92
12-30-2011		354			62.2		
1-2-2012		551			39.8		286
1-3-2012		272			41.5		68
1-4-2012		285			65.2		96
1-5-2012	211	331			68.2		96
1-6-2012	179	339			46.7		84
1-9-2012		348			38.2		120
1-10-2012		331			44.4		142
1-11-2012		295			40.9		114
1-12-2012	144	358			100	27.4	108
1-13-2012	111	293			49.6		86
1-16-2012		382			51.3		116
1-17-2012		403			69.6		82
1-23-2012		475			57.3		
2-8-2012		450	5.85	4.33	52.4	31	138
2-20-2012		1292	11.1	6.84	114	40	
2-21-2012		518	8.57	7.26	43	36.5	185
2-22-2012	183						
2-27-2012		404	7.4	6.15	47	25.9	244
2-28-2012		451	8.68		48.9		
3-1-2012	208						
3-14-2012		441	6.42	3.82	52.9	16	228
3-20-2012	181	797	12.2	4.92	57.9	21.8	200
3-25-2012		293	3.93	3.28	30.3	14.5	92
4-4-2012	299	1203	8.82	5.19	88.1	31.3	1280
4-10-2012		819	7.29	5.12	69.9	32.2	1189

Appendix 4. Effluent during continuous aeration

	BOD5	**COD**	**tot-P**	**PO4-P**	**tot-N**	**NH4-N**	**NO3-N**	**SS**
Date	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
9-9-2011		186		1.71				
9-12-2011		174	2					4
9-13-2011		227	2.03					12
9-14-2011		195	1.9		16.8			13.5
9-15-2011		200	2.04	1.71	7.53	15.5		21
9-16-2011		189	2.01	1.63				6
9-19-2011		241	2.8	1.93	15.1	9.13		14
9-20-2011		188	2.83	2.02	10.2	8.42		13
9-21-2011		174	2.36	2.03	13.1	12.5		3
9-26-2011		164	2.66	2.33	9.6	9.34		15
9-27-2011		170			10.2			12
9-28-2011		165			10			2
9-29-2011		167			11			6
9-30-2011		168			10.5			10
10-3-2011		166	2.62	2.23	13.2	11.9		7
10-4-2011		170			13			12
10-5-2011		172			9			2
10-6-2011		158			9.8			6
10-10-2011		169			11.3			4
10-11-2011		181	2.09	<0.5	13	11.8	<5	4
10-12-2011		176			13.1			6
10-13-2011		194			13.2			10
10-14-2011		168			12.9			12
10-17-2011		175	2.15	<0.5	11.8	10.9	<5	10
10-18-2011		177			12.3			14
10-19-2011		175			16.7			8
10-20-2011	6	204			18			15
10-21-2011		172			14.4			12
10-24-2011		180	2.12	<0.5	12.8	11.2	<5	10
10-25-2011		163			12.7		5.8	8
11-3-2011		166	2.62	1.53			4.74	8
11-4-2011		123	1.83	1.61	8.01	0.57	4.61	6
11-7-2011		182	9.57		12.2			32
11-8-2011		252	2.92		10.5			15
11-9-2011		130	4.53		6.84			7
11-10-2011		144			8.3			15
11-11-2011		118			5.86			4
11-14-2011		134	2.69	2.55	8.39	<5	<5	10
11-15-2011		119			7.81			12
11-16-2011	0	118			9.69			5
11-17-2011	0	128			9.19			7
11-18-2011		172			8.86			8
11-21-2011		116			10.8			7
11-22-2011		118			11			5
11-23-2011	36	120	2.99	2.84	24.7	0.58	3.47	11
11-24-2011		72			23.7			6
11-25-2011		63.3			23.8			6
11-28-2011		78			21.1			7
11-29-2011		100			23.3			13
11-30-2011		91.2	4.52	2.11	8.06	1.99	3.45	7

12-1-2011		75.2			6.98			6
12-2-2011		80.2			13.6			5
12-5-2011		77.2			4.01			7
12-6-2011		87.3			9.3			7
12-7-2011	8	86.1			7.98			7
12-8-2011	20	77.9	3.94	3.53	10.3	0.14	3.76	6
12-9-2011	17	83.1			12.6			5
12-12-2011		99.2			6.49			5
12-13-2011		103	3.2	3.11	6.92	0.15	3.55	4
12-14-2011		69.5			6.61			14
12-15-2011	24	65.9			8.2			8
12-16-2011	<4	62.8			6.22			4
12-19-2011		69.7			4.04			4
12-20-2011		71.6			10.7			6
12-21-2011		89.8			11.3			5
12-22-2011	<4	87.3			10.1			6
12-23-2011	11	39.3			8.27			6
12-26-2011		61.4			9.35			5
12-27-2011		51			12.2			13
12-28-2011	<4	55			9.88			7
12-29-2011	<4	47			9.65			3
12-30-2011		47			9.6			
1-2-2012		39.9	3.35	5.03	8.16	0.43	3.83	3
1-3-2012		41.1			7.79			6
1-4-2012		45.2			9.49			5
1-5-2012	10	46			13.9			16
1-6-2012	11	49.1			9.79			6
1-9-2012		67.9			5.49			10
1-10-2012		39.5			7.46			4
1-11-2012	7	43.2			7.15			2
1-12-2012	4	53.9			11.1			5
1-13-2012	2	40.1			27.8			3
1-16-2012		44.3			7.88			5
1-17-2012		45			9.06			
1-23-2012		40.3			11.8			
1-24-2012		50.5						
1-27-2012		48.2						
2-6-2012		54.4						14
2-8-2012		46.2	7.79	4.1	17.8	1.237	5.13	6
2-16-2012		40.1						
2-20-2012		73.1	5.03	4.92	10.6	4.53	3.96	9
2-21-2012		46.2	5.59	5.35	8.28	3.9	4.18	8
2-22-2012	6							
2-27-2012		66.6	4.97	4.35	7.97	0.56	4.85	4
2-28-2012		42.5	4.09		6.35			
3-1-2012	9							
3-14-2012	2	45	3.65	3.61	8.68	4.14		18
3-20-2012	3	47.1	8.04	1.03	6.36	1.99	2.86	14
4-4-2012	4	55.4	3.46	2.51	10.7	1.1	6.47	28
4-10-2012		52.6	3.41	2.5	9.8	1.2	5.8	30

Appendix 5. Influent during intermittent aeration

	BOD5	COD	tot-P	PO4-P	tot-N	NH4-N	SS
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
4-18-2012	148	359	5.99	5.96	33.9	15.8	330
4-25-2012	168	393	3.93	3.28	30.3	14.5	292
5-4-2012	128	820	8.89	5.29	99	48.5	1285
5-9-2012	188	346	4.81	2.66	32.6	13	320
5-10-2012	114	332	6.54	4.76	31.6	20.3	365
5-11-2012		466	5.21	4.4	35.4	20	212
5-16-2012	168	899	8.44	3.81	64.9	40.1	686
5-17-2012	195	636	6.23	3.59	46.8	30.4	314
5-22-2012		961	8.69	5.76	84.6	57	892
5-23-2012		501	6.7	3.9	48.1	42.6	688
5-24-2012		478	6.21	4.31	42.8	39.3	728
5-25-2012		674	6.24	3.21	66.8	38.2	398
5-28-2012		443	6.01	4.24	64	28.6	356
5-29-2012		331	5.08	3.54	68.5	29.2	262
5-30-2012	421	2248	13.7		191		1328
5-31-2012	198	675	7.85	3.29	95.4	20.9	654
6-1-2012	184	551	8.01	4.69	49.8	22.6	286
6-6-2012	298	1889	6.81	3.49	86	22	1634
6-7-2012	346	2116	8.81	4.76	94.3	21	2554
6-14-2012		439	5.21	3.13	50	22.2	690
6-21-2012	481	529	7.98	6.2	49	19	280
6-28-2012	249	491	6.71	6.59	53.1	35.7	420
7-4-2012	160	383	4.42	2.25	46	13.4	670

Appendix 6. Effluent during intermittent aeration

Date	BOD5 mg/l	COD mg/l	tot-P mg/l	PO4-P mg/l	tot-N mg/l	NH4-N mg/l	NO3-N mg/l	SS mg/l
4-25-2012		34.5	3.92	2.52	8.47	0.78	4.14	16
5-4-2012	2	34.8	1.81	1.63	5.93	2.46	1.91	8
5-9-2012	2	32.7	0.942	0.784	11.8	1.63	3.4	16
5-10-2012	1	38.5	0.901	0.823	6.94	1.2	3.3	8
5-11-2012		36.9	0.709	0.622	6.25	2.9	2.47	8
5-16-2012	3	43	0.595	0.59	8.34	0.13	2.55	6
5-17-2012	2	39.4	0.95	0.586	5.13	1.2	1.78	18
5-22-2012		34.4	0.872	0.85	6.74	3.52	1.08	12
5-23-2012		31	0.83	0.8	6.9	0.989	1.4	12
5-24-2012		28.4	0.95	0.864	7.9	1.13	1.64	10
5-25-2012		32.15	1.08	0.899	7.98	1.68	2.13	8
5-28-2012		36.5	0.98	0.89	7.64			
5-29-2012		38	1.28	1.13	7.97	0.56	2.85	4
5-30-2012	2	42.2	3.51		6.55			12
5-31-2012	1	34.3	1.25	0.835	6.25	2.1	1.43	16
6-1-2012	4	36	1.48	0.92	6.4	1.98	1.2	12
6-6-2012	1	39.3	1.57	1.07	6.97	0.67	5.21	14
6-7-2012	2	35.1	1.13	1.1	5.86	0.67	2.89	14
6-14-2012		35.6	0.86	0.8	8.42	0.34	1.38	12
6-21-2012	1	38.2	0.83	0.58	11.5	4.78	3.1	20
6-28-2012	1	36.3	0.605	0.41	11.2	4.05	2.32	28
7-4-2012	1	33.8	0.86	0.604	5.55	0.858	1.62	30
7-12-2012		34.7	0.544	0.472	12	6.87	2.17	9