TAMPERE UNIVERSITY
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Wastewater Treatment Pilot

Christos Alkiviadis Paraskevopoulos

Bachelor’s Thesis
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Environmental Engineering

ABSTRACT

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Christos Alkiviadis Paraskevopoulos
Wastewater Treatment Pilot

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The aim of this thesis was to investigate the functionality of the wastewater treatment pilot and produce a learning manual-handout, as well as to define the parameters of wastewater clarification by studying the nutrient removal and the effluent clarification level of the processed wastewater.

As part of the Environmental Engineering studies, Tampere University of Applied Sciences has invested on a Wastewater Treatment Pilot. The pilot simulates the basic wastewater treatment practices used in the wastewater treatment plants. This research was made to define the functions, parameters and capabilities of the Pilot, in order to incorporate the pilot as a learning tool in wastewater treatment courses for the degree students.

While considering some basic guidelines for the use of the pilot, for a four-month period different factors that affect wastewater treatment process were tried out to discover the capabilities of the pilot. Mechanical, chemical and biological means were used for water clarifications and for each change the efficiency of the pilot was tested with a vast variety of methods. MLSS, MLVSS, COD, nitrate, orthophosphate and microbial observation were used as methods of monitoring the concentrations of nutrients and cultivation of microorganisms in wastewater for the biological nutrient removal process.

The results of this study suggest that the WWTP can be used as a learning tool for students to become familiar with the biological wastewater treatment. The samples analyzed showed that the balance to maintain a thriving community of organisms is a demanding process. Phosphate removal was performed successfully in many cases and biomass increased was observed after using artificial influent with micronutrients.

Further study of the process of the WWTP is advised to widen the result data base while changing some of the observation methods and adding BOD measurements.

Key words: wastewater treatment, water purifications, aerobic, anaerobic, nutrient removal, biological wastewater treatment

Foreword

Family means the world to me. It has been my number one priority since I was a little boy, the first thing I think when I wake up every day and the last thing that crosses my mind before I fall asleep.

It feels right to say that most of the people I meet in my four-year journey in TAMK made me feel like family. I would like to mention everybody one by one, but since there is always the risk that I may forget someone, I will avoid it. The energy, the dedication, the enthusiasm that most of the teachers and staff have, gave the “family” character to the degree program.

I do not know yet, my next step in life, but I know that whenever I will think of Tampere and TAMK, I will have warmth in my heart and only good feeling and memories.

A big thank you for helping my try to be a better student, a better friend and a better person.

Tampere, May 2016

Χρήστος – Αλκιβιάδης Παρασκευόπουλος

Contents

GLOSSARY AND TERMS

$(COOH)_2 2H_2O$	Oxalic Acid
BOD	Biochemical Oxygen Demand
$C_2H_2O_4$	Oxalic Acid
CH_4	Methane
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
H_2SO_4	Sulfuric Acid
K	Potassium
$KMnO_4$	Potassium Permanganate
L	Litre
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
N	Nitrogen
$Na_4O_7P_2$	Sodium Pyrophosphate
NaOH	Sodium Hydroxide
NH_4^+	Ammonia
NO_2^-	Nitrite
NO_3^-	Nitrate
P	Phosphorus
PAO	Phosphorus Accumulating Organisms
pH	Acidity or Basicity index
PHB	Polyhydroxybutyrate
PIX-322	Ferric Coagulant
PO_4^{3-}	Phosphate
rpm	Rows per minute
S	Sulphur
SBR	Sequencing batch reactor
SVI	Sludge Volume Index
TAMK	Tampere University of Applied Sciences
TOC	Total Organic Carbon
VSS	Volatile Suspended Solids
WWTP	Wastewater Treatment Pilot

1 INTRODUCTION

One of the pressing challenges that mankind is facing is water shortage. Global population growth, urbanization, increase of life expectancy and quality of life, reveal a trend of increased water usage and along with drought and climate change make the demand for water greater. In a planet covered with water, only as small fraction of that water is potable and even smaller percentage of that is accessible, since icecaps and glaciers are storing most of the freshwater.

Water and especially drinkable water is essential for progress. According to the U.N.'s statement "Water is at the core of sustainable development and is critical for socio-economic development" (UN Water 2015). Thus we have to use all the available resources of water wisely. Our search for water resources has for many years been ignoring one of the most stable and increasing water resources; wastewater.

Wastewater is the result of domestic, industrial, agricultural, and any kind of human activity that alters the quality of water. In addition, we consider storm water also to be wastewater, since in most cases it ends up in the same sewage system and needs to be treated before returned to the environment. (Russell 2006) Discharging wastewater directly to the environment is called water pollution and has negative impacts on the aquatic ecosystem. Water pollution from wastewater can have many forms. Thermal pollution is one of the most obvious, since rarely, if ever, the wastewater has the same temperature as the water body it is discharged to. Biological pollution is another issue, while wastewater may contain pathogenic bacteria, parasites, viruses and disease carrying microorganisms that could threat public health. Organic pollution is the result of wastewater being discharged in a water body and contains excessive amounts of organic matter, the microorganisms in water will start degrading that organic matter by using the dissolved oxygen in the water. This means that the dissolved oxygen available for the aquatic life will be limited. Since the anthropogenic pollution increases the load of C, P, N, K, S and other micronutrients in the water, the excessive grand of nutrients will lead to cultural eutrophication. Eutrophication is the phenomenon where phytoplankton population is increased due to the increase of nutrients dissolved in the water and this once more will lead to oxygen depletion and light blockage from the algal bloom on the surface of the water body. (Radojevic and Bashkin 1999) Acidifications of water bodies. For almost a century lower pH levels have been observed in rivers and lakes in Nordic countries, US and Canada. The main reason is acid rain, especially from the air pollution in urban areas and drainage from sulphur-bearing deposits of coal, iron, lead, zinc and copper and surface and underground mines. (Radojevic and Bashkin 1999)

1.1 Objectives of this research

Tampere University of Applied Sciences has integrated courses concerning wastewater treatment and management for almost two decades in the Environmental Engineering Degree Program. A part of those studies, TAMK invested in purchasing a Wastewater Treatment Pilot developed by University of Eastern Finland. Though the pilot has many operations that are automated, many of its functions are manually handled and the WWTP cannot function without proper customization.

The task of finding the functioning and optimal range of parameters for the WWTP was assigned as a bachelor project/thesis to the author. The research could be divided in two sections. Firstly, the range of functioning parameters had to be defined clearly and secondly those parameters had to be optimized to achieve the best result. The definition of the conditions in which the pilot achieves the best results both qualitatively and quantitatively, is a long and demanding process that includes often chances of the operating conditions, daily sampling, chemical analysis of the samples and observation of the growth and diversity of the microorganisms in those samples. The efficiency of the process can be measured by comparing the amount of N and P removed in each stage, the amount of biomass produced and removed, and the visual clarity of the treated water. The WWTP combines mechanical, biological and chemical means for each stage of the treatment to increase its efficiency.

Additionally, a manual describing the use of the WWTP was produced to provide basic information on the functions and the operational parameters to the future users of the pilot. (Appendix 2.)

1.2 Wastewater treatment process

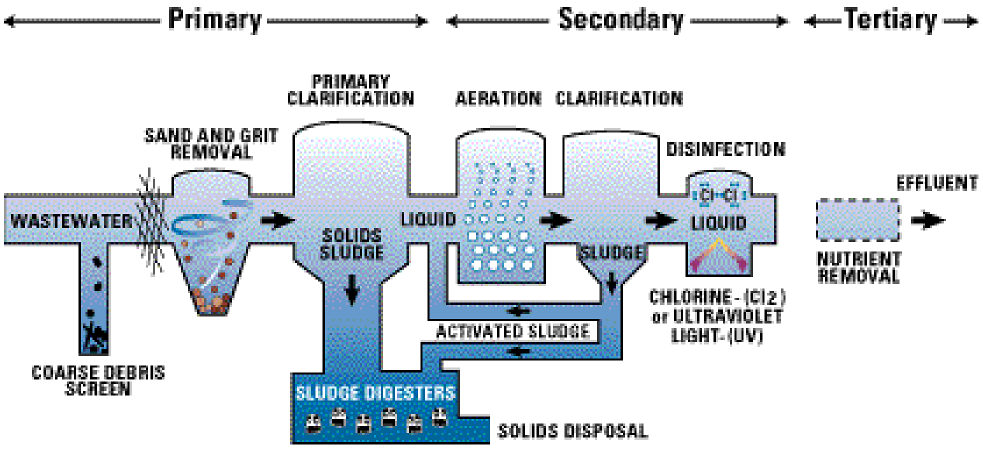
Wastewater can contain a vast variety of contaminants depending on its origin, but the main process by which we treat wastewater before returning it to the environment is standard. We can segment this process into three main stages. (Picture 1.)

1.2.1 Primary treatment

The first stage is the rough separation of solids, usually with the addition of coagulants that will speed up the process. During this stage, called preliminary treatment, most of the solids are removed via the mechanical method of sedimentation. The primary stage can reduce more than half of the suspended solids in wastewater and a significant percentage of the Biological Oxygen Demand (BOD) reaching up to 30%. (The World Bank 2016)

1.2.2 Secondary treatment

The second stage of wastewater treatment, called secondary or biological treatment, is when the organic matter discharged in wastewater is dissolved and consumed by microorganisms that are introduced in the wastewater. At this stage we want to make the conditions favourable for those microorganisms as much as possible to ensure that they will reproduce and grow. During this process most of the organic matter in the wastewater is broken down and used as food by the microorganisms with up to an impressive 85% of the suspended solids removed. This treatment step is widely known as “activated sludge process” due the use of active biological material. (The World Bank 2016)



Picture 1. Conventional Wastewater Treatment Process (Anderson and Sheffield 2006)

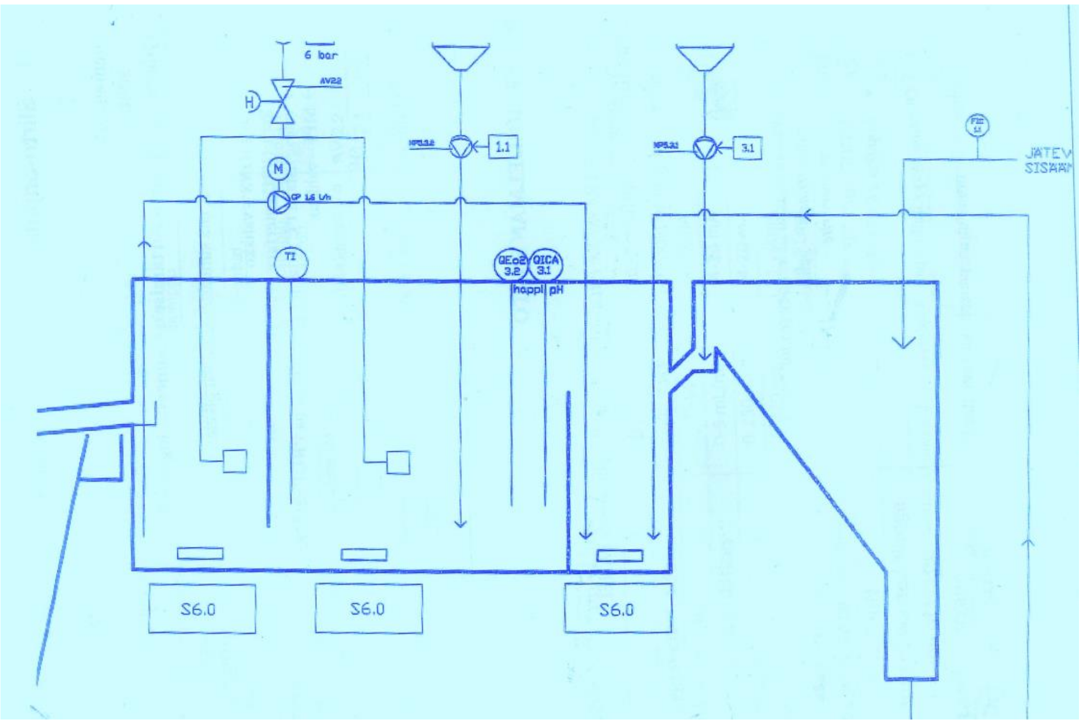
1.2.3 Tertiary Treatment

Tertiary or advanced stage is the last stage that usually removes most of the impurities of the wastewater before we return it to the environment. This stage can vary depending on the use of the treated wastewater. Different kind of treatments will be done to water that is intended for irrigation, for drinking or returned to the environment. (The World Bank 2016)

1.3 Wastewater treatment pilot

As mentioned our WWTP is based on the same principles as any wastewater treatment system. The device consists of the following parts:

a) Pre-sedimentation tank
b) Denitrification tank
c) Aeration compartment
d) Clarification / sedimentation tank



Picture 2. Blueprint of the WWTP (Christos Paraskevopoulos, 2015)

2 DESCRIPTION OF THE PROCESS

2.1 Wastewater

For the purpose of the research, artificial wastewater was generated frequently and inoculated with activated sludge from “Viinikanlahden jätevedenpuhdistamo” which is one of the Wastewater Treatment Plants of Tampere, situated in Viinikanlahti.

2.1.1 Artificial wastewater

In order to achieve biological treatment of wastewater, we have to create and sustain a colony of microorganisms that will be feeding on the nutrients from the wastewater. Every day each person in Finland produces an average of 150 L of wastewater. That wastewater, according to 2005 report of the Finnish Environment Institute (SYKE), has 50 g of organic matter, as carbon source, 2,2 g of phosphorus and 14 g of nitrogen. This means that the ratio between C:N:P should be 100:5:1 mg/L. For that purpose, during the project two different artificial wastewater recipes were followed to create nutritional conditions similar to the ones from municipal wastewater. (Table1.)

Table 1. Artificial Wastewater Recipes

	Ingredients	**Substance**	**Amount**
1st Recipe	Treacle	Carbon source Nitrogen source	216,67g
	Urea	Carbon and Nitrogen source	3,67g
	Fairy™ Dishwashing detergent	Phosphorus source	4,17g
	Water		60 L
2nd Recipe	Biobact ™ Fertilizer	Phosphorus, nitrogen and micronutrients	77,45g
	Urea	Carbon and nitrogen	2,86g
	Glucose	Carbon source	60g
	Sodium pyrophosphate	Phosphorus source	2,67g
	Water		60 L

The first recipe is used by the Environmental Engineering degree students of TAMK, to produce synthetic wastewater for the Wastewater Laboratory course and can be found in the corresponding course handout. (Viskari, et al. 2013)
The second recipe that was used is an alternative recipe with similar characteristics and nutrient ratio, and it was used by Mr. Alberto Freire Lopez on his “Leachate Treatment” project. (Lopez 2012) Both recipes that were used have the same C:N:P ratio but the second recipe due the liquid fertilizer BioBact ™ has 2,5% sulphur and 0,02% zinc of its mass fractions that contribute to the growth of microorganisms. (Lopez 2012)

2.1.2 Activated Sludge

For the biological treatment of wastewater microorganisms are needed. Microorganisms will break down the organic matter into CO_2 and water, use the nutrients to multiply and grow, and in the process remove most of the suspended solids that were not removed in the primary treatment. Initially since the medium we had in the WWTP did not contain any microorganisms, inoculation was needed. Thus 600 ml of activated sludge from the wastewater treatment plant in Viinikanlahti was introduced in the denitrifications/aeration tank. The wastewater treatment process in Viinikanlahti is ongoing and the activated sludge from the aeration pools has a thriving community of diverse microorganisms.

2.2 Primary Treatment

The first compartment of the WWTP is the sedimentations tank. Throughout this stage the suspended particles and dissolved matter will sediment by gravitational settling at the bottom of the tank, and can be removed and treated further as solid waste. Since the influent was synthetic, the organic load (BOD/COD) was zero and this step was bypassed.

2.3 Secondary Treatment

2.3.1 Coagulation/Flocculation

Sedimentation procedure can be accelerated by using chemicals called flocculants. Flocculants will increase the “Van der Waals” forces that attract the particles and this will accelerate the rate that particles sediment by creating flocs. Such chemicals can be anionic, like metallic hydroxides and salts, or cationic, like organic substances and silica. Following the addition of flocculants we have to gently stir the mixture for 20 to 40 minutes. (Howe, et al. 2012) The result of flocculation usually is quite visible, since the removal of the organic matter and suspended particles improves the clarity of the wastewater and reduces its turbidity.

Coagulants are chemicals that will treat the suspended colloids and dissolved matter, counteract their repulsive electrostatic forces and assist in this way in the creation of groups that are bigger and can settle faster. Such coagulants are ferric and aluminium sulphate. (Aemenante 2014) Thus we ensure increased sedimentation of solids in the final clarifier and more P is removed in the process. Coagulation in also performed in the denitrification tank with the addition of PIX 332 Ferric coagulant by KEMIRA™.

2.3.2 Denitrification (Tertiary treatment)

The second compartment of the WWTP is the denitrification chamber. In this compartment we create anoxic conditions. Those anoxic conditions will force the bacteria present in wastewater to use the oxygen that is bound in NO_3^- and NO_2^- and ideally the nitrogen would be released into the atmosphere.

For example, we can see the reduction of nitrate to dinitrogen in the following equations:

$$NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2 \qquad (1)$$

And step by step:

$$NO_3{}^- + 2e^- + 2H^+ \rightarrow NO_2{}^- + H_2O\ Nitrate\ reduction \qquad (2)$$

$$NO_2{}^- + e^- + 2H^+ \rightarrow NO + H_2O\ Nitrite\ reduction \qquad (3)$$

$$2NO + 2e^- + 2H^+ \rightarrow N_2O + H_2O\ Nitric\ Oxide\ reduction \qquad (4)$$

$$N_2O + 2e^- + 2H^+ \rightarrow N_2 + H_2O\ Nitrous\ Oxide\ reduction \qquad (5)$$

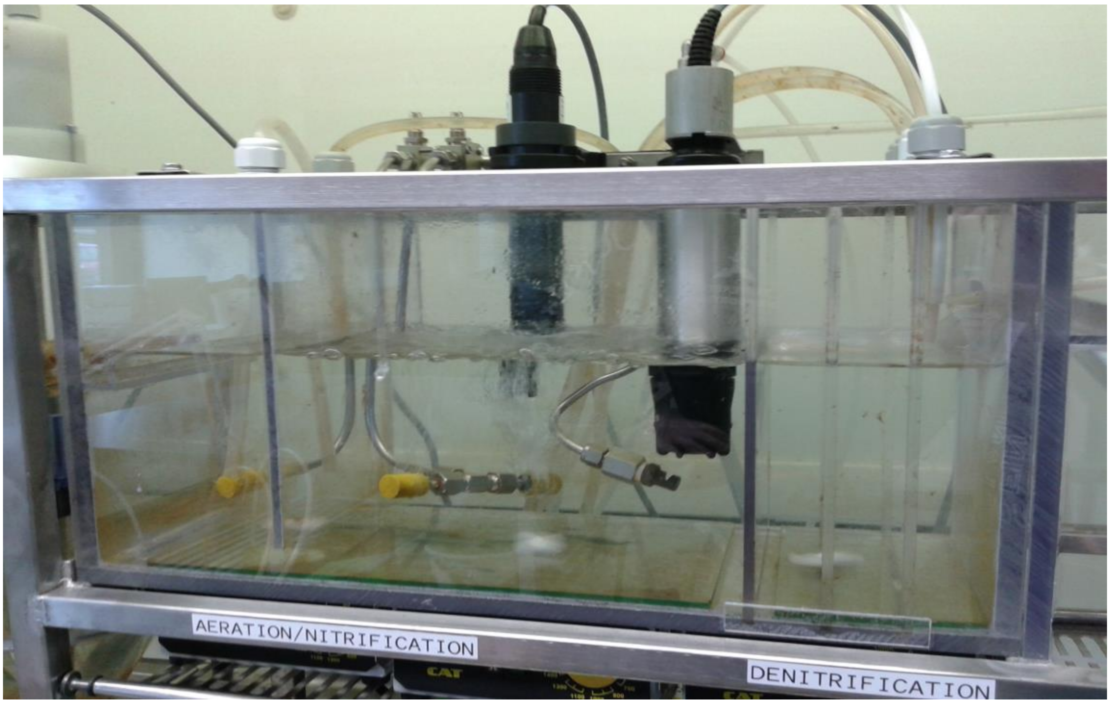
Bacteria that can perform denitrification are *Pseudomonas, Micrococci, Achromobater,* and *Bacillus.* (Russell 2006)

A visual indication of denitrification in the anaerobic compartments is the removal of gaseous Nitrogen from the tank in form of bubbles to the environment.

The conditions that favour the denitrification process in the anoxic compartments of the WWTP are pH close to 7,5 and dissolved oxygen under 0,4 mg/L. For the regulation of pH, a solution of 5% NaOH is introduced in that compartment and a constant monitoring of the pH is done to maintain the levels within the optimal range.

2.3.3 Aeration (Secondary treatment)

The central compartment in wastewater treatment is the aeration tank. By providing oxygen and maintaining the dissolved oxygen at a minimum of 2-3mg/L in that compartment we provide conditions for the microorganisms to dissolve organic matter and use it as energy for reproduction. The final result is the full oxidation of the carbon from the organic matter into CO_2. In the WWTP the oxygen is regulated from the control panel of the system and the flow of oxygen is maintained by the solenoid peristaltic pump installed in the tank. (Picture 3.)



Picture 3. Denitrifications and aeration chambers of the WWTP (Paraskevopoulos,2015)

In the aeration chamber the reverse process of denitrification occurs. As oxygen is provided for the microbial growth, the unionized ammonia and ammonium ion from the wastewater is oxidized into nitrite and nitrate. (Russell 2006) Unionized ammonia is highly toxic and can be extremely harmful for different species of aquatic life, but the ammonium ion is less harmful and toxic. By controlling pH to be less than 8,3 and the temperature less than 27 ˚C we can regulate the production of ammonia and especially the toxic unionized one. (Russell 2006)

2.3.4 Final Clarifier

The last compartment of the WWTP is the final clarifier. Treated wastewater overflows from the aeration/nitrification chamber to the Clarifier. At the lower part of a reversed conical tank is the sedimentation tank that recycles the activated sludge containing microorganisms to the denitrifications chamber and the upper chamber the clarified water is skimmed and lead into the container that holds the effluent. Extra sludge can also be removed at this point and taken away for further treatment.

Picture 4. Clarifications chamber (Paraskevopoulos, 2015)

2.4 Phosphorus Removal

Phosphorus and nitrogen are the limiting nutrients to plant growth, both aquatic and terrestrial. In the case of aquatic environment P is essential to algae growth. (Russell 2006) Usually water bodies have enough of these limiting nutrients to sustain the local aquatic life. When excess P is discharged in an aquatic environment from anthropogenic activities, usually this is mainly from agricultural and feedlot operations and secondly from phosphorus containing detergents. (EPA 2007) In the WWTP the removal of phosphorus is done both chemically and biologically. Chemically phosphorus is removed by using of the ferric coagulant at the secondary treatment stage in a rapid mixing tank with the formation of insoluble precipitate that can be removed from the sediment.

$$Fe^{3+} + H_nPO_4{}^{3-n} \leftrightarrow FePO_4 + nH^+ \text{ Ferric ions} \rightarrow \text{Ferric Phosphate} \quad (6)$$

Biologically phosphorus is removed under anoxic conditions by a very common bacterium that can be found everywhere, *Acinetobacter* that favourites anoxic conditions. This bacterium during the anaerobic stage of wastewater treatment will store additional phosphorus that it actually needs for future growth, along with the use of carbon sources. Bacteria store phosphate in the form of polyphosphates along with micronutrients such as magnesium, potassium and calcium cations, inside their cells. It must be noted that phosphorus removal is difficult while there are other oxygen donors present. Thus the removal of both phosphorus and nitrogen preferably do not happen in the same tank. To achieve that in the simultaneous precipitation, additional carbon resources must be provided, like sugars or alcohol. (Russell 2006)

In aerobic conditions, there is extensive energy production by oxidation of the stored elements, and polyphosphate bonds are increased within the cellular storage of the bacteria. Those can be removed along with the rest of the biomass at the next settling point of the wastewater pilot. (Lenntech BV 2016)

The efficiency of P removal can be the result of many variables, but most of the P is accumulated during anoxic and anaerobic conditions. This means that depending on the dissolved oxygen in the influent, achieving the optimal anaerobic conditions within the tank may take 2 to 5 hours. Of course, temperature, influent flow, presence of aiding chemicals such as flocculants and coagulants, and dissolved oxygen from the recycled sludge may all play a significant role. (Russell 2006)

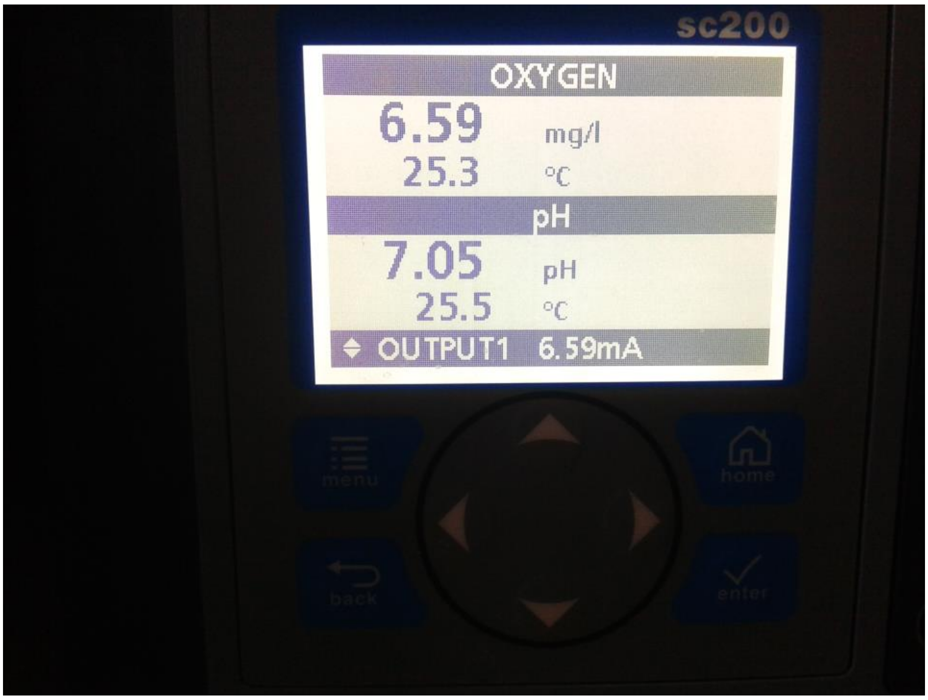
3 DESCRIPTION AND METHODS OF THE ANALYSIS

As mentioned, the system efficiency is dependent on a number of different variables. Thus for every change of the conditions that were made during this project, a thorough analysis of the results was needed.

Efficiency factors:

a) Temperature. The temperature was 22 to 26 ˚C (PICTURE 5)
b) pH
c) Coagulant feed
d) NaOH concentrations
e) Oxygen pressure and feed
f) Influent flow
g) Return sludge flow
h) Influent recipe

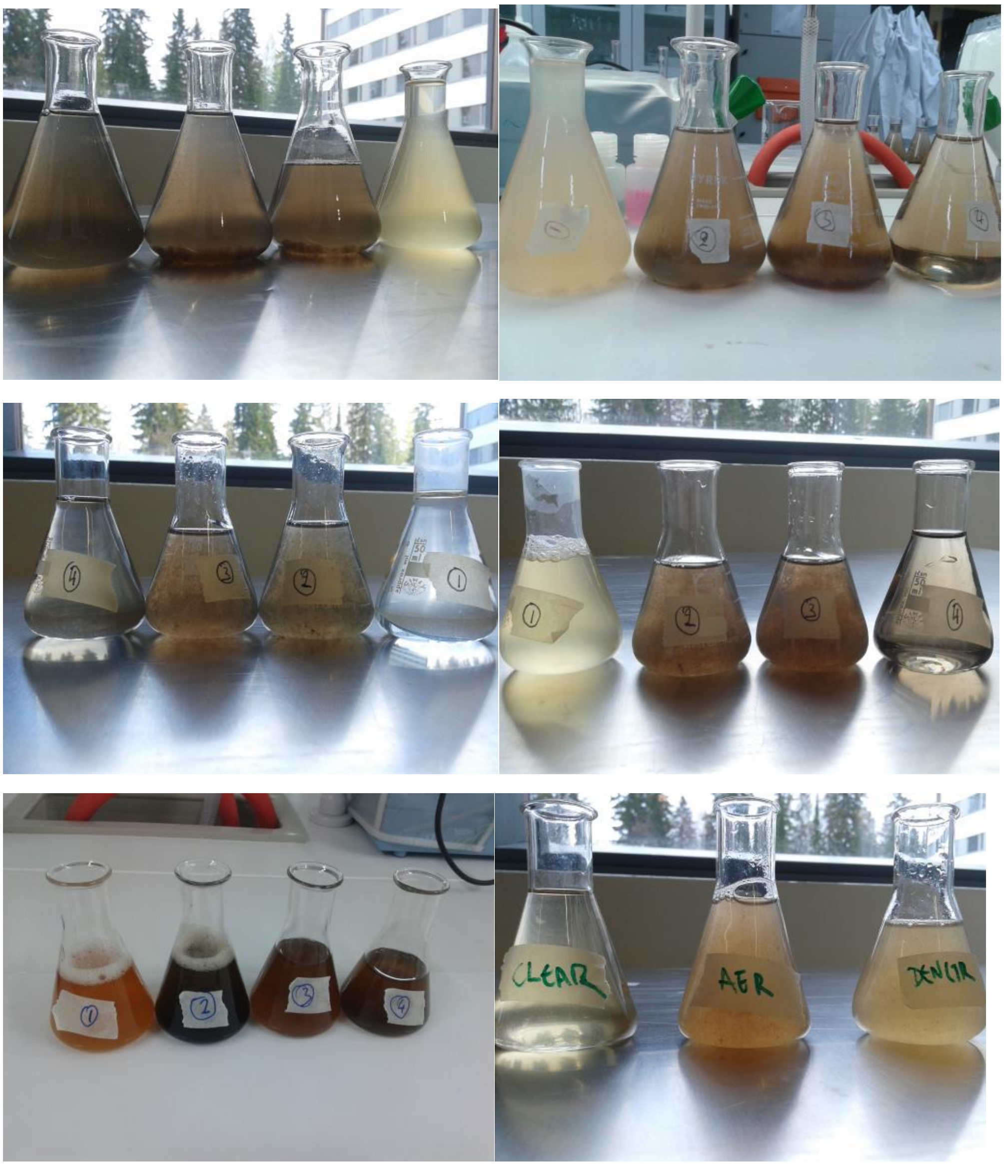
While changing one, and sometimes more, of those factors, maintaining as many as possible of the rest is crucial in order to be able to determine the effects of those changes.



Picture 5. Dissolved oxygen, pH and temperature (Paraskevopoulos, 2015)

3.1 Sampling process

For the daily analysis samples were collected from four different compartments of the WWTP. Those samples were numbered accordingly to correspond to the consecutive pilot chambers: influent (1), denitrification (2), aeration (3), effluent (4). (Picture 6.)
The samples then were taken into the faculty laboratory for analysis. The samples that were used for N and P removal analysis were centrifuged and diluted to meet the range of the analysis method.



Picture 6. Samples from different days (Paraskevopoulos, 2015)

3.1 Nitrate

The samples were analysed to determine the change in nitrate concentrations in each chamber. A HACH Lange DR 2800 Spectrophotometer was used with the corresponding Cadmium Reductions Method 8039 for 0,3 to 30,0 g/ L $NO_3{}^- - N$ (Appendix 3).
For each sample the procedure was repeated twice and the mean value of the successful measurement was calculated to minimize errors.

3.2 Orthophosphate

Each time four samples were analysed to determine the phosphorus concentration reduction in each chamber of the pilot. A HACH Lange DR 2800 Spectrophotometer was used with the corresponding Ascorbic Acid Method for 0,02 to 2,50 mg/L $PO_4{}^{3-}$range. For each sample the procedure was repeated twice and the mean value of the successful measurement was calculated to minimize errors (APPENDIX 3).

3.3 MLSS

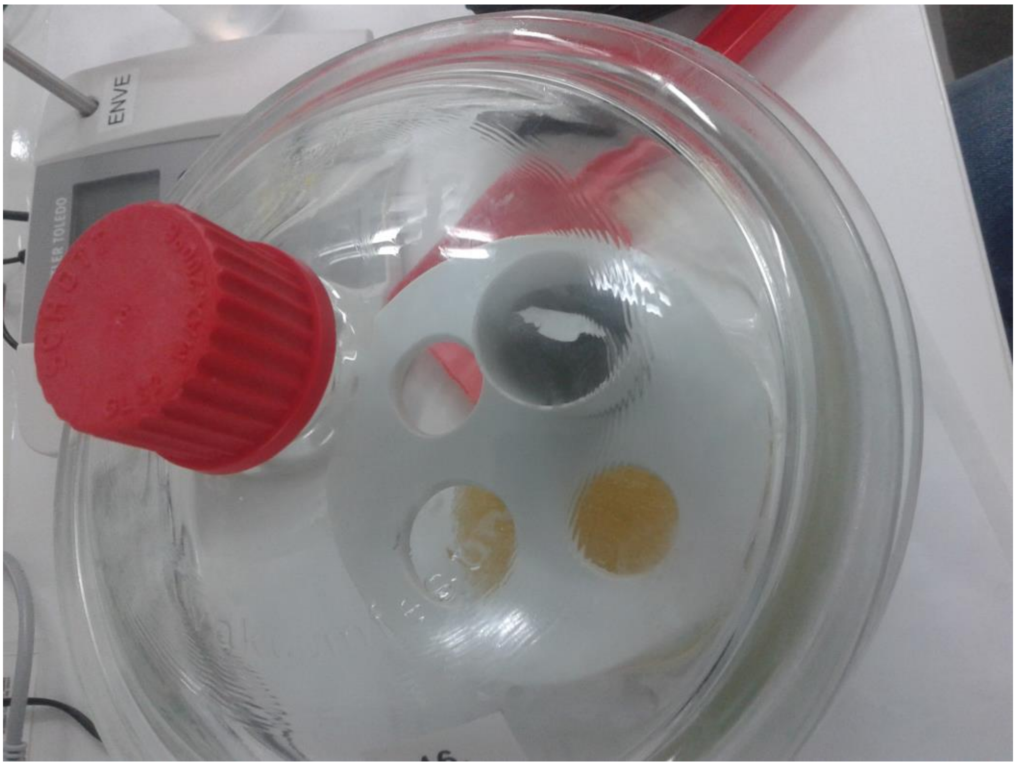
MLSS corresponds to the biomass in form of flocks or aggregates in wastewater. The range of MLSS is proportional to the recycling of the activated sludge from the clarifier to the denitrification chamber. Normal range for MLSS in activated sludge process should be 1500 - 3500 mg/L

$$MLSS = \frac{(a-b)}{c} \tag{7}$$

In the above equation a is the mass of the filter after filtration in mg, b is the mass of the filter before filtrations in mg, and c is the sample volume in L.
For each sample 10ml were filtered through a weighed pre-washed and dried filter. To ensure that all the suspended solids were captured in the filter, some 20ml of distilled water was used to rinse the funnel. The filters then were moved into an oven preheated at 105˚C and left to dry for 2 hours (PICTURE 7).
Desiccators were used to prevent the absorption of moisture from the air while the filters were cooling down (PICTURE 8). Each filter was weighed and the MLSS was calculated. The results of each chamber were compared to find out the suspended solid reduction or

increase from chamber to chamber. Though initially the influent was also sampled and MLSS was calculated, in every single case the result was zero, since the artificial wastewater did not have any suspended solids.

PICTURE 7. Filters before entering the oven (Paraskevopoulos, 2015)



PICTURE 8. Filter placed in desiccator during MLVSS/MLSS measurement (Paraskevopoulos, 2015)

3.4 MLVSS

Similar to MLSS, MLVSS measures the amount of volatile organic matter. In order to fully oxidize all the suspended solids, the filters were transferred into a furnace with temperature of 550˚C for 1h. The calculation of MLVSS is done using the following equation.

$$MLVSS = MLSS - \frac{d-b}{c} \tag{8}$$

Here *d* is the mass of the filter and residue in mg/L, *b* the mass of the filter before filtrations in mg and *c* the volume of the sample used in L.

3.5 SVI

Each time the WWTP was inoculated with new activated sludge from the wastewater treatment plant the sludge volume index was calculated. The SVI was compared to the SVI aeration tank from the reactor of the WWTP after at least one full day of operation to compare the results of the inoculant. SVI is an indicator of the characteristics of the wastewater used and its settling characteristics. After mixing the wastewater vigorously to create a homogenous mixture, 1 L of the sample was measured out and left to settle for 30 minutes . (PICTURE 9.) Then we measure the volume of the sludge that has settled on the bottom (SV_{30}). SVI can be calculated by using the following equation.

$$SVI(\frac{mL}{g}) = \frac{SV_{30}(\frac{mL}{L})1000(\frac{mg}{g})}{MLSS(\frac{mg}{L})} \tag{9}$$

PICTURE 9. Sludge settling after 30 minutes (Paraskevopoulos, 2015)

3.6 pH

pH values, as mentioned, are essential for the efficiency of the wastewater treatment process. pH was measured in all the chambers daily and a pH meter was installed in the aeration/ nitrification chamber for constant monitoring.

3.7 Microbial

The success of biological removal of the organic load in wastewater depends on the presence, or absence, of microorganisms that will decompose that load from the wastewater. Such an analysis was carried out in the microbiology laboratory of TAMK each day for each sample to define the microorganisms from the samples, such as aerobic bacteria, protozoa and rotifers.

3.8 COD

Chemical oxygen demand is water quality indicator being used in water and wastewater analysis to determine the amount of both organic and other materials that can be fully oxidized chemically. For this process potassium permanganate is used to fully oxidize the content of our water sample. The technique used was titration, where we can calculate accurately the amount of oxidized material by measuring the excess of potassium permanganate in our sample by the amount of oxalic acid needed to neutralize the remaining of permanganate ions (PICTURE 5). A typical organic compound has carbon, hydrogen, oxygen and nitrogen of in a ratio of $C_nH_aO_bN_c$. When that organic matter is fully oxidized the result will be CO_2, H_2O and NH_3.
This process as an equation would be mapped as followed

$$C_nH_aO_bN_c + \left(n + \frac{a}{4} - \frac{b}{2} - \frac{3}{4}c\right)O_2 \xrightarrow{acidic\ conditions} nCO_2 + \left(\frac{a}{2} - \frac{3}{2}c\right)H_2O + cNH_3 \quad (10)$$

Acidic conditions were ensured by the addition of sulphuric acid.

The results can be compared with the water quality classifications table (Table 2) but in our experiment the calculated COD values were used to check the effluent quality with respect to the organic matter content.

Table 2. Classification of water quality

$KMnO_4$ consumption ($\frac{mg}{l}$ $KMnO_4$)	COD $\frac{mg}{l}$ $(oxygen)$	
0-20 $\frac{mg}{l}$	0-5 $\frac{mg}{l}$	Good quality water / Drinkable
20-40 $\frac{mg}{l}$	5-10 $\frac{mg}{l}$	Not recommended for drinking
>40 $\frac{mg}{l}$	>10 $\frac{mg}{l}$	High organic content, not recommended for drinking

PICTURE 10. Stages of titration process (Paraskevopoulos, 2015)

4 RESULTS

4.1 Functioning parameters

Table 3. Function parameters of WWTP (Paraskevopoulos, 2015)

Equipment/ Sustains	Range of trials	Optimal
Ferric Coagulant PIX	5%-15%	12.5%
NaOH solution	5%-10%	10%
Influent flow	0-40 rpm (0-500mL/h)	4-6rpm (500-750mL/h)
Dissolved Oxygen	0.4mg/L- 5.0mg/L	3.5mg/L
pH anaerobic	3.0-5.0	3.5
pH aerobic	5.65-7.59	6.5
Denitrification stirrer	200-1200 rpm	500 rpm
Aeration stirrer 1	200-1100 rpm	700 rpm
Aeration stirrer 2	500-1000 rpm	600 rpm
Oxygen Gain	0-200%	50%
PIX Feed	0-60mL/h	30mL/h
NaOH Feed	0-250mL/h	20mL/h
Scraper	Lapse 0-60 min Duration 0-60 s	30 min 30 s
Sludge recycle	Laps 0-6 h Duration 0-60 s	6 h 30 s

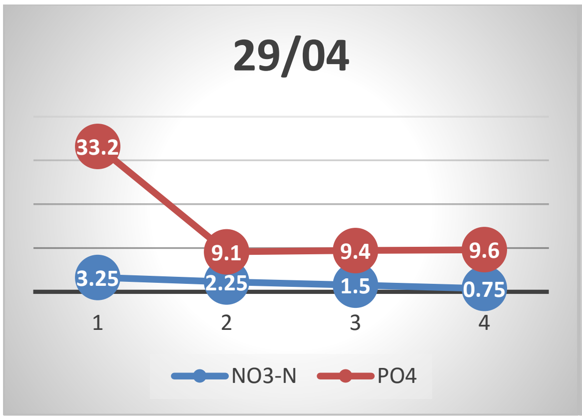
As mentioned earlier, in order to be able to compare the results between measurements while changing one or two factors, the rest had to stay the same. Some direct comparisons can be done between the results when the pilot was operating under similar conditions.

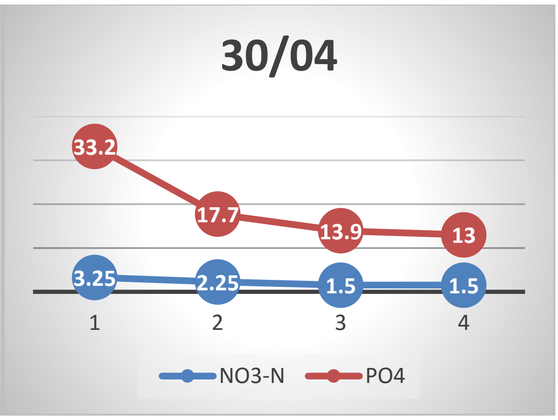
4.2 pH

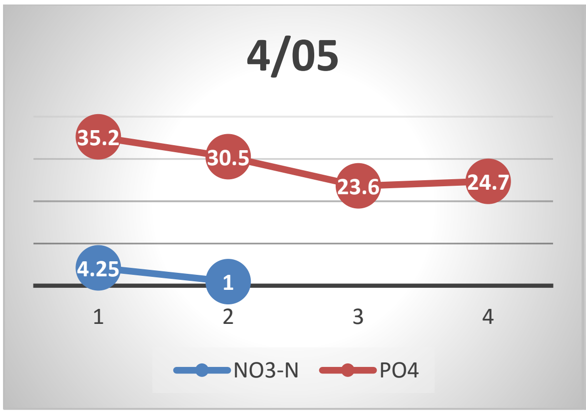
pH levels are low both in the influent, especially after a few days in the influent vessel, and in the denitrification chamber. Thus a constant feed of NaOH was needed to prevent acidification. This can be used to explain the gradual oxygen depletion of the synthetic wastewater. The microorganisms carrying out the biological treatment are not extremophiles. Bacteria and protozoa are neutrophils. (Sigee 2005)It was observed that during the lowest pH noted (5,65) the dissolved oxygen levels were at their lowest point (0,08 mg/L) and though the phosphorus removal was high, the amount of nitrogen was constant. The data were collected on 14 April, 2015 (Appendix 4.)

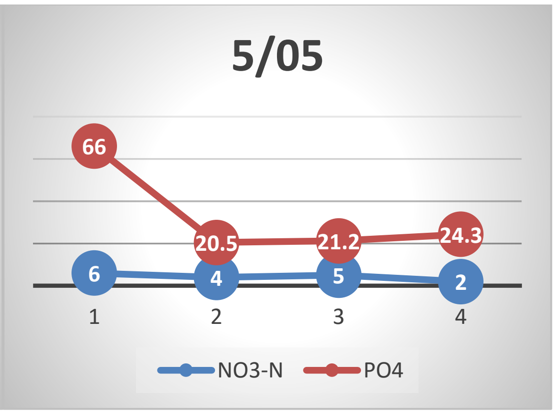
4.3 Phosphate and Nitrate concentrations

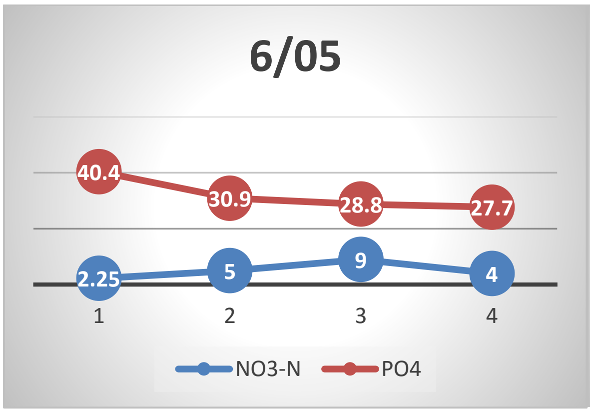
By using the data collected by the spectrophotometric analysis (Appendix 4.) we can compare the N and P removal depending on the major changes on the parameters of the WWTP on a day-to-day basis. The following charts demonstrate the concentrations of PO_4^{-3} and NO_3^- in (1) influent, (2) denitrification chamber, (3) aeration chamber, (4) effluent.

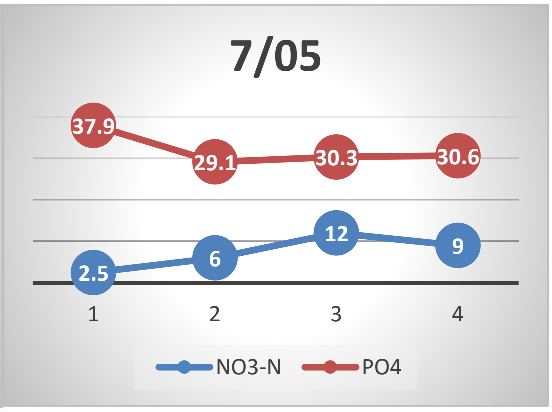


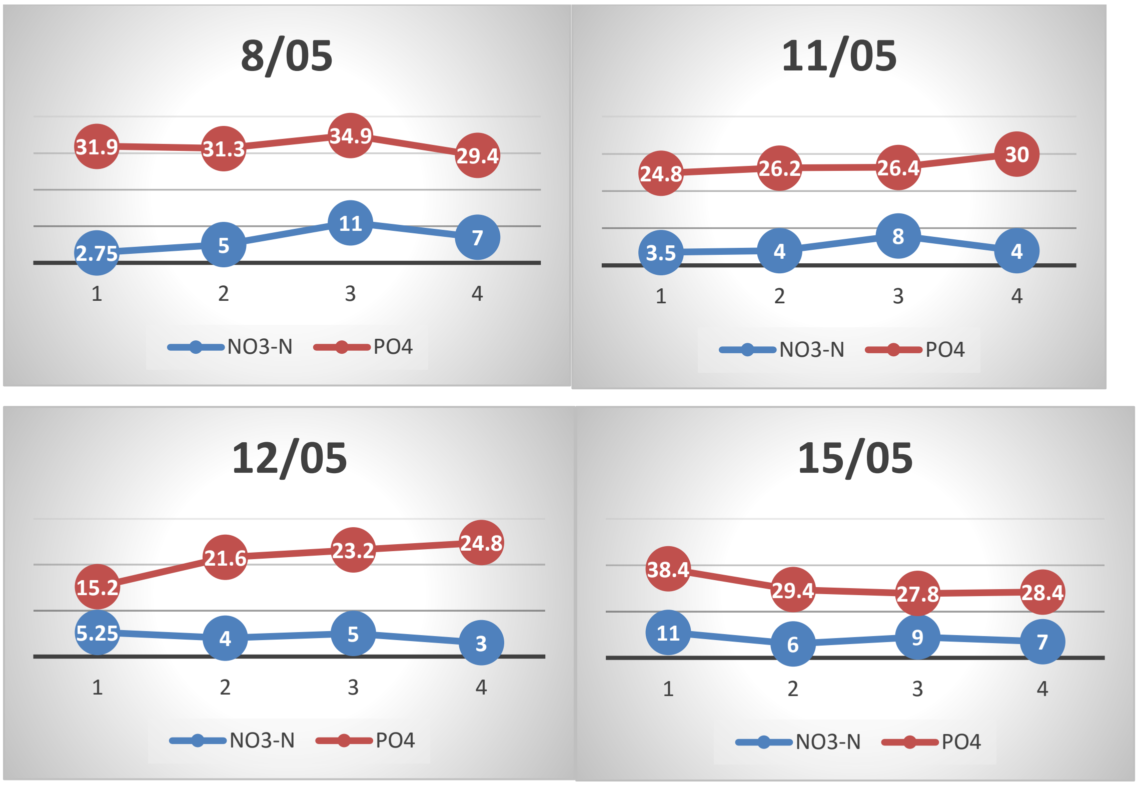












Figures 1-10. Phosphate and nitrate concentration results (Paraskevopoulos,2015)

Table 4. Percentage of change compared to factors

Date	Concentrations of Nitrate-N (%)	Concentrations of Phosphate-P (%)	Major changes
29/04	76.92	71.08	Coagulant 40 → 20mL/h, influent 600→750mL/h
30/04	55.85	60.84	Coagulant 30→40mL/h, influent flow 750→375 mL/h
4/05	-	29.83	concentrations 5%→10% of NaOH
5/05	66.67	63.18	Oxygen Gain 25% → 50%
6/05	-77.78	31.44	Dissolved Oxygen 3→5mg/L NaOH concentration 5%→10%
7/05	-260	19.26	Dissolved Oxygen 5→6 mg/L
8/05	-154.55	7.84	Coagulant 40→30mL/h
11/05	-14.29	-20.97	Influent flow 750→375 mL/h Coagulant 30→50mL/h
12/05	42.86	-63.16	Oxygen Gain 25%→50%
15/05	36.36	26.04	Influent flow 750→375mL/h Dissolved Oxygen 4→6.55mg/L

4.4 MLSS and MLVSS

Following the process described earlier the following results were extracted;

Table 5. MLSS and MLVSS results

		Denitrification				
Sample number	**Date**	**Filter Weight**	**MLSS weight**	**MLVSS weight**	**MLSS**	**MLVSS**
1	24/04/2015	0.1244	0.1283	0.1251	3900	3200
2	29/04/2015	0.1241	0.1255	0.1248	1400	700
3	30/04/2015	0.1243	0.1278	0.1255	3500	2300
4	04/05/2015	0.1244	0.1266	0.1253	2200	1300
5	05/05/2015	0.1247	0.1256	0.1249	900	700
6	06/05/2015	0.1239	0.1293	0.1252	5400	4100
7	07/05/2015	0.1241	0.1269	0.1258	2800	1100
8	08/05/2015	0.1244	0.1258	0.1249	1400	900
9	11/05/2015	0.1243	0.1275	0.1254	3200	2100
10	12/05/2015	0.1247	0.1286	0.126	3900	2600
11	15/05/2015	0.1247	0.1284	0.1259	3700	2500
		Aeration				
Sample number	**Date**	**Filter Weight**	**MLSS weight**	**MLVSS weight**	**MLSS**	**MLVSS**
1	24/04/2015	0.1241	0.1288	0.1258	4700	3000
2	29/04/2015	0.1244	0.1263	0.1253	1900	1000
3	30/04/2015	0.1243	0.1277	0.1258	3400	1900
4	04/05/2015	0.1244	0.1272	0.1251	2800	2100
5	05/05/2015	0.1241	0.1266	0.1255	2500	1100
6	06/05/2015	0.1244	0.1263	0.1249	1900	1400
7	07/05/2015	0.1248	0.1258	0.1244	1000	1400
8	08/05/2015	0.1244	0.1281	0.1259	3700	2200
9	11/05/2015	0.1241	0.1283	0.1246	4200	3700
10	12/05/2015	0.1247	0.1292	0.1253	4500	3900
11	15/05/2015	0.1243	0.1289	0.1263	4600	2600
		Effluent				
Sample number	**Date**	**Filter Weight**	**MLSS weight**	**MLVSS weight**	**MLSS**	**MLVSS**
1	24/04/2015	0.1244	0.1249	0.1246	500	300
2	29/04/2015	0.1243	0.1251	0.1247	800	400
3	30/04/2015	0.1244	0.1249	0.1246	500	300
4	04/05/2015	0.1241	0.1248	0.1244	700	400
5	05/05/2015	0.1244	0.1248	0.1245	400	300
6	06/05/2015	0.1239	0.1242	0.1241	300	100

7	07/05/2015	0.1241	0.1247	0.1242	600	500
8	08/05/2015	0.1244	0.1249	0.1246	500	300
9	11/05/2015	0.1243	0.1252	0.1247	900	500
10	12/05/2015	0.1244	0.1249	0.1246	500	300
11	15/05/2015	0.1247	0.1251	0.1249	400	200

4.5 SVI

Samples of the activated sludge were collected weekly to monitor the settling properties of the sludge in the reactor.

Table 6. SVI_{30} comparison between inoculant and WWTP reactor

Date of inoculation	SVI of inoculant (mL/g)	Date of sample	SVI of reactor (mL/g)
20/4/2015	78.45	24/4/2015	31.91
30/4/2015	81.03	4/5/2015	71.43
15/5/2015	76.79	15/05/2015	21.74

4.6 COD

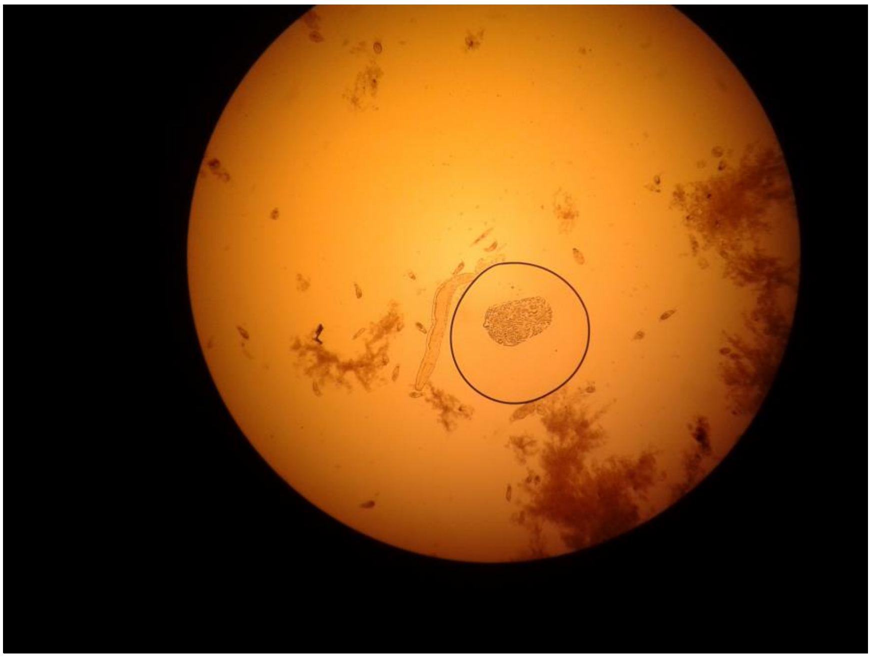
Following the process described earlier, the COD was calculated accordingly using two samples from the aeration tank each time, calculating the mean value on Potassium Permanganate needed for their full oxidation.

Table 7. Potassium Permanganate consumption and calculation of COD

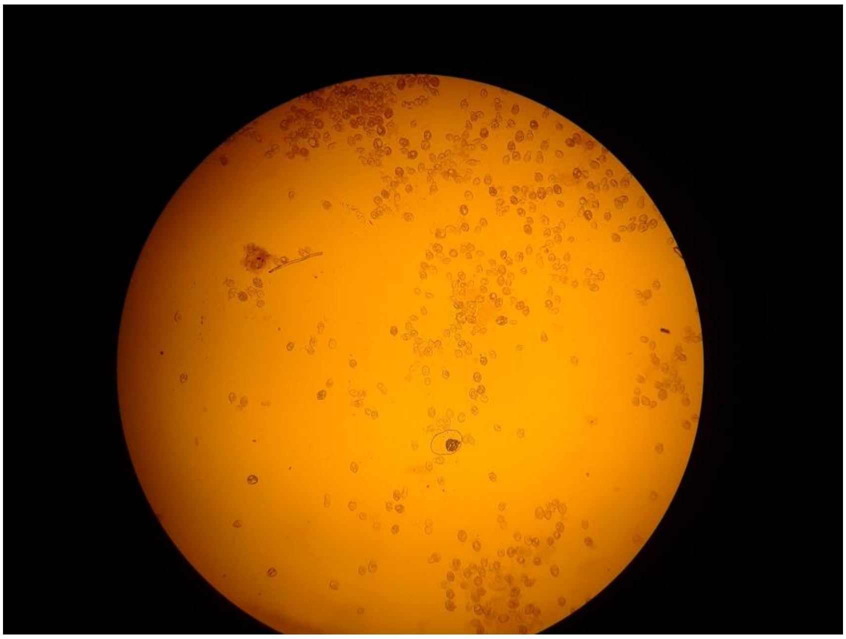
		Volume of $KMnO_4$ in mL	**Mean Volume of $KMnO_4$ in mL**	**Amount $KMnO_4$ in mol/L**	**Amount of $KMnO_4$ in g/L**	**Amount of $KMnO_4$ in mg/L**	**COD**
24-Apr	1st sample	4.7					
	2nd sample	5.1	4.9	0.0002	0.030968	30.968	7.84
04-May	1st sample	4.2					
	2nd sample	4.5	4.35	0.00017	0.027492	27.492	6.96
08-May	1st sample	5.2					
	2nd sample	5.4	5.3	0.00021	0.033496	33.496	8.48
15-May	1st sample	5.2					
	2nd sample	5.7	5.45	0.00022	0.034444	34.444	8.72

4.7 Microbial

Many different species of microorganisms were found in the samples collected from the different compartments of the WWTP. Some of the species identified were; rotifers, ciliates (*Climacostomum*) (PICTURE 12.), *Saprolegniales*, Oligochaeta worms (PICTURE 11.) from the *Aelosoma* family, shelled Ameoba, flowing bacteria, *Flagellates*, stalked ciliates from the *Vorticella* family along with algae and many more that could not be identified. (APPENDIX 6.)



Picture 11. A worm is grazing on phytoplankton (Paraskevopoulos, 2015)



Picture 12. A big colony of ciliates and other species (Paraskevopoulos, 2015)

5 DISCUSSION

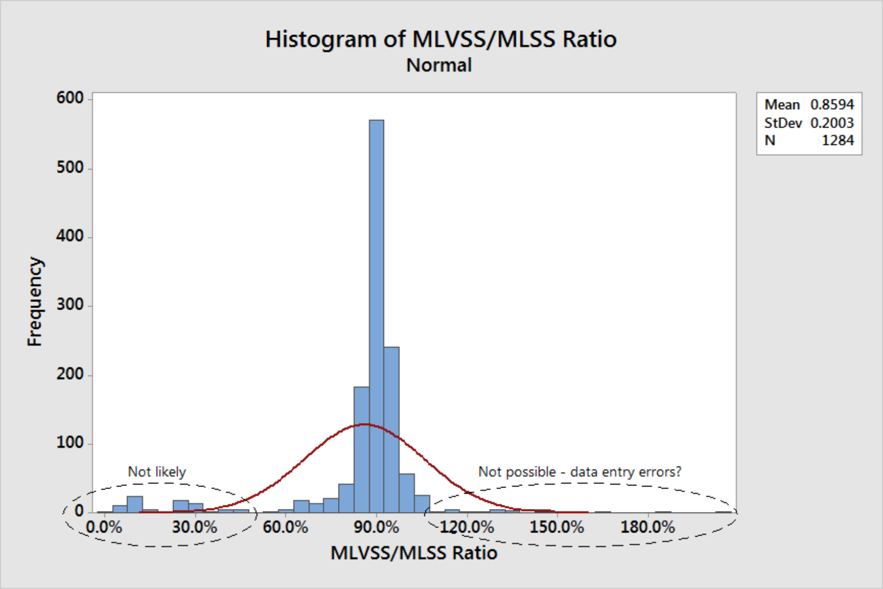
The principles that wastewater treatment is based on are simple and logical. However, in order, though, to achieve high efficiency and a low cost, and to avoid an excessive use of chemicals, a number of factors must be taken into account. During the four-month period that the WWTP was researched, it was made clear that the balance between those factors is sensitive and sometimes the results can be entirely unexpected. According to EPA's 2007 report, the cost of phosphorus removal in US by the use of ferric or aluminium coagulants both in secondary and tertiary treatment stages costs for residents depended on the municipal facilities is a small fraction from the 18$ to 46$ with an average of 25,5$ monthly fee (EPA 2007). Such a cost is relatively low and the removal of total phosphorus are as low as 0,01 mg/L. In the case of the WWTP we can assume that the concentration of total phosphorus and phosphate phosphorus are close to equal since the only source of P is the synthetic influent.

The measurement of Nitrate-N and Phosphate-P did not give us solid results on nutrient removal. Nitrate levels in some cases seemed to be increasing. This is possible because in the aeration tank oxidation of the nitrogen present in the wastewater is possible, but also because the aeration was done by the use of atmospheric air, of which dinitrogen makes up 78% (Table 4.) The increase of oxygen supply (oxygen gain, increase of atmospheric pressure, or increase of dissolved oxygen) favour the Phosphate-P reduction (Table 1. Dates 5/05, 7/05 and 8/05).

The coagulant added in the wastewater, in the denitrification chamber, increased significantly the removal of phosphate. (Table 1. Dates: 29/4, 30/4, 05/5) Phosphate due coagulations-flocculation precipitates and it can then be removed. The conditions in that chamber are unaerated rather than anoxic and denitrification is more efficient in anoxic conditions. Thus the suggestion is that the coagulant should be added in the aeration chamber. Aeration and the use of a coagulant should increase further the phosphate precipitation.

The change of synthetic wastewater recipe helped the growth of microorganisms. During the microscopy control before and after the new recipe the diversity and population of microorganisms grew.

On the MLVSS/MLSS research the results were encouraging since in almost all the cases the ratio 60-85% MLVSS/MLSS (Picture 13.) was met (Figure 11.). MLVSS/MLSS ratio is an empirical rule that gives the estimated ratio between organic and inorganic suspended solids in wastewater. Ratio values above 0,80 have a meaning of enough aeration in the tank to cover the needs of oxygen for microorganisms were values lower that 0,75 show lack of enough aeration. Roughly that means that 0,80 of MLSS is the fraction of the suspended solids have organic origin in the wastewater. (Fuller 2016)



Picture 13. Normality of MLVSS/ MLSS ratio (Fuller 2016)

The results extracted from the WWTP project can be compared to the results from a study published in “Water Science & Technology” magazine issued in February 2004. (Puig, et al. 2004). That pilot describes a lab scale sequencing batch reactor (SBR) with an initial volume capacity of 40L with similar functions and an identical setup to the WWTP. The common analytical methods used in that experiment and are comparable with the results from that publication were, TSS, VSS, and nitrates. TSS/VSS ratio has to be about 80%. The data extracted from WWTP were within the 60-80% range in most of the cases. COD of the effluent had a mean value of 53mg COD/L were in our case the COD measurement was done to the aeration sample and in any case it was less than 9mg COD/L. As far as nitrogen is concerned, both in the WWTP and in the publication’s pilot (Puig, et al. 2004), nitrate reduction could not be achieved successfully, due the absence of an organic electron donor in the anoxic chamber. (Puig, et al. 2004)

The SVI results indicate that the wastewater in the pilot needs a maturing time of at least 4 days before it reaches the density and settling characteristics of the inoculant from the wastewater treatment plant. (Table 6.) The results from SV index show that the WWTP was working towards the correct direction. SVI was compared between the inoculant provided from Viinikanlahti water treatment plant and wastewater from the aeration tank of the reactor. Though the results of the SVI were far from being the same, the longer the reactor was operating, the closest the values of SVI were converging.

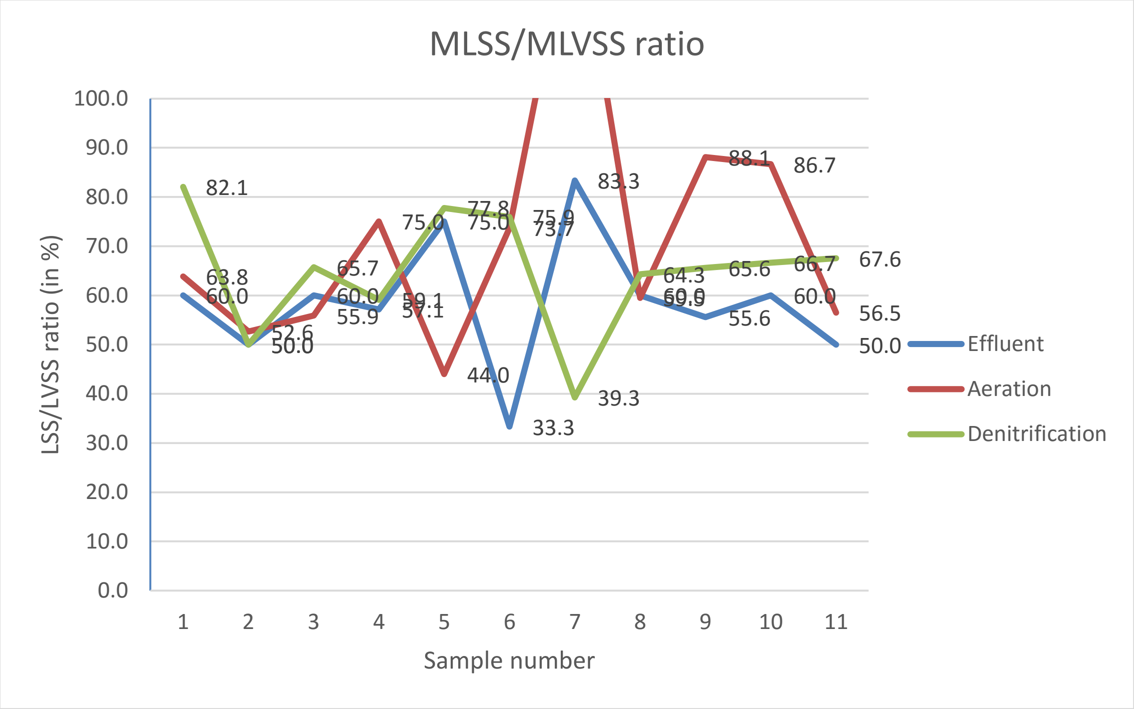


Figure 11. MLSS/MLVSS ratio

6 CONCLUSIONS

As a conclusion it must be stated that the WWTP project was a very interesting and challenging venture. Almost all the skills and knowledge gained during the Environmental Engineering degree studies from Environmental Chemistry, Aquatic Ecosystems, Wastewater Treatment were tested on an everyday basis, and due to the constant practice most of those skills are now routine.

Reguarding the methods used, for orthophosphate was a good choice of measurement for the concentration of P, since the difference in Total-P measurement should not be significant, but the choice of nitrate instead of Total-nitrogen was not successful. This is because nitrogen as an element is already present in many different forms in the air provided to the system for aeration and it may have conflicted with the results of the measurements. Additionally, BOD measurements could be implemented to widen the perspective of the pilot's efficiency.

One indicator that presented results that are optimal for the wellbeing of microorganisms in the wastewater was the MLSS/MLVSS ratio, since in most of the cases the results were within optimal range.

The project should be continued since the next users of the WWTP will have already a solid foundation and will be able to avoid repeating the mistakes that were done previously.

Furthermore, the pilot could be used as building module to handle different kinds of pollutions. Since the basic functions are already incorporated, other modules could be added, for example, a module that could counteract on industrial or agricultural pollution.

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APPENDICES

Appendix 1. Material Safety Data Sheets

Calcium Hydroxide	https://www.alfa.com/en/content/msds/english/A12650.pdf
Ferric Sulfate	https://www.alfa.com/en/content/msds/english/A15178.pdf
Oxalic Acid	https://www.alfa.com/en/content/msds/english/35619.pdf
Potassium permanganate	https://www.alfa.com/en/content/msds/english/14307.pdf
Sodium Hydroxide	https://www.alfa.com/en/content/msds/english/A18395.pdf
Sodium Pyrophosphate	https://www.alfa.com/en/content/msds/english/A17546.pdf
Sulfuric Acid	https://www.alfa.com/en/content/msds/english/35655.pdf

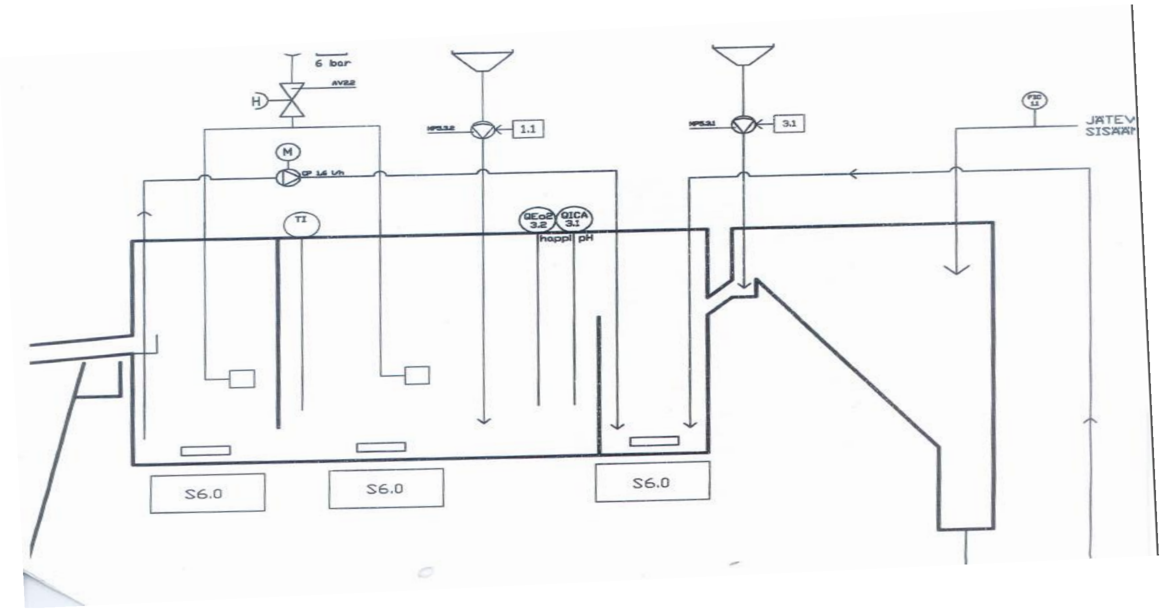
Appendix 2. WWTP Manual

Wastewater Treatment Pilot Manual

by Christos Paraskevopoulos

The following manual is a product of personal experience on using the **W**aste**W**ater **T**reatment **P**ilot, for the set period of time that we were working on it for our Bachelor thesis. Most of the results are a due the observation and via trial and error, since the Pilot in the Process laboratory of TAMK came with an outdated handbook, in many cases referring to so other similar device.

Schematics



Description of the Pilot

1) Influent source
2) Pre-sedimentation tank
3) Denitrification compartment
4) Aeration compartment
5) Clarification/Sedimentations tank
6) Effluent pipe
7) Solenoid metric pump
8) Peristaltic pump
9) Controller
10) Dissolved oxygen sensor
11) pH sensor
12) Effluent tank

1. **Influent source**

For influent we are using a two basic recipes that result in a mixture with nutrients needed for the microorganisms and resamples of wastewater.

In a 20 litre bucket of distilled water we add:

Recipe no1:

25.816g of Biobact fertilizer

0.954g of Urea

20g of Glucose

0.888g of Sodium pyrophosphate

Recipe no2:

43,33g of treacle

0.733g of urea

0.833g of dishwasher powder (containing phosphorus)

In our experience the influent must be kept for as little time as possible, since even with regular stirring eventually there will be a depletion of dissolved oxygen in the bottom layers of the bucket and the artificial wastewater fed into the system will be anoxic. The amount of influent needed is dependent on the pace of feeding we choose for our pilot.

2. Pre-sedimentation tank

Though for the synthetic wastewater a pre-sedimentation tank is not needed, in the wastewater treatment process this is a vital stage in order to discard the suspended solids via mechanical means, i.e. gravity.

3. Denitrification compartment

Denitrification is taking place in the first part of the second compartment of the tank. The conditions there are anoxic and we create optimal conditions for anaerobic bacteria to produce N_2 that will be released in the air. In this compartment we have to monitor the pH in order to avoid extreme conditions that could kill the microorganisms.

4. Aeration compartment

In the aeration compartment we increase the dissolved oxygen to ensure the removal of dissolved gases (for example decarbonation) and oxidize dissolved metals (magnesium, iron, hydrogen sulfide etc.) that may be present in our wastewater.

5. Clarification/Sedimentations tank

This part of the pilot can be divided into two functions. At the top of this reversed conical tank the clarified water is being skimmed and lead into the container that holds the clean water. The rest of the tank is the sedimentation tank that mixes the sediment and returns the microorganisms that are needed into the denitrification chamber.

6. Effluent Pipe

The effluent pipe is abducting pipe for the treated wastewater that comes out from the upper part of the clarification tank.

7. Solenoid metric pump/Air Pump

The solenoid pump system is responsible for transferring chemicals to the denitrification chamber; a ferric sulphate based coagulant and sodium hydroxide for regulation of pH, as well as a simple air pump that cleans the oxygen sensor in the tank.

8. Peristaltic pump

The peristaltic pumps are used to regulate the pace of recycling and feeding from the different tanks of chemicals and activated sludge.

9. Controller

The controller is the “heart” of the pilot since there you can see and adjust most of the variables in the process. The flow of the chemicals, pH and dissolved oxygen values, temperature and more can be monitored and modified according to the situation.

10. Dissolved oxygen sensor

The oxygen sensor is one of the monitoring devices that we used for everyday observations. It is important to keep maintaining and calibrating the sensor regularly according to the manufacturer’s instructions.

11. pH sensor

pH values in the denitrification chamber are very vital maintaining the living organisms in our pilot tank. Naturally without any interference stillwater tends to be acidic. The tolerance of microorganisms for acidity is limited. The pH sensor has to be also calibrated at least once per week, but for more accurate results once every 3 to 4 days.

12. Effluent tank

This is the tank where we can store treated water for analysis or disposal.

Key values

Chemicals

Pix concentrations 12.5%
NaOH solution 10%

Influent flow

Range 0-40 rpm (optimal 4-10)

Dissolved Oxygen

Optimal value 3.5 mg/L (±0.5 mg/L)

pH

Optimal value 7 (±1)

Magnetic Stirrers

In order to ensure a homogenous mixture in the denitrification (1) and the aeration (2) tanks there are magnets installed and underneath the tank there are three CAT scientific magnetic stirrers. The specific stirrers have a range of 0-1600 rpm. The range for each tank in practice is different.

Denitrification chamber 200-1200 rpm optimal 500 rpm,

Aeration chamber

- stirrer #1: 200-1100 rpm, optimal 700 rpm,
- stirrer#2: 500-1000 rpm optimal 600 rpm

Appendix 3. Procedure Manual

HACH DR 2800 Nitrate http://www.hach.com/asset-get.download.jsa?id=7639983736

HACH DR 2800 Orthophosphate http://www.hach.com/asset-get.download.jsa?id=7639983836

Appendix 4. Day by day factors data

Date	Coagulant (ml/h)	NaOH (%)	Pressure (atm)	Oxygen (mg/l)	Gain (%)	rpm Flow	pH
20/03/2015	20	2.5	6	8.34	25	6	6.64
	20	2.5	6	8.12	25	6	6.88
	20	2.5	6	7.93	25	6	7.34
	20	2.5	6	7.17	25	6	6.97
	20	2.5	6	5.64	25	6	6.63
	20	2.5	6	4.45	25	6	6.58
	20	2.5	6	3.25	25	6	6.52
	20	2.5	6	1.18	25	6	6.5
27/03/2015	20	2.5					
07/04/2015	20	2.5	5	8.95	25	3	7.07
	20	2.5	5	9.08	25	3	7.13
	20	2.5	5	9.01	25	3	7.19
08/04/2015	20	2.5	5	7.82	25	3	7.12
	20	2.5	5	7.01	25	3	6.96
	20	2.5	5	6.99	25	3	6.93
	20	2.5	5	6.92	25	3	6.92
	20	2.5	5	9.75	25	3	6.9
	20	2.5	5	6.77	25	3	6.88
	20	2.5	5	6.7	25	3	6.88
09/04/2015	20	2.5	2	3.56	25	3	6.67
	20	2.5	2	3.58	25	3	6.63
	20	2.5	2	2.3	25	3	6.7
10/04/2015	20	2.5	6	7.35	25	3	6.3
	20	2.5	3	5.36	25	3	7.1
	20	2.5	3	7.31	25	3	7.34
	20	2.5	3	6.28	25	3	7.11
	20	2.5	4	2.03	25	3	6.65
	20	2.5	3	3.5	25	3	6.76
13/04/2015	20	2.5	3	3.7	0	3	6.76
14/04/2015	20	2.5	4	0.08	0	3	5.65
	20	2.5	5	1.18	25	3	6.1
	20	2.5	4	1.82	75	3	6.09
	20	2.5	4	4.34	75	3	6.35
	20	2.5	4	3.45	75	3	6.26
	20	2.5	4	3.17	75	3	6.18
15/04/2015	20	2.5	4	2.96	25	3	6.94
	20	2.5	4	2.7	50	3	7.18
16/04/2015	20	2.5	5	1.65	75	3	7.18
	20	2.5	6	2.4	50	3	7.24
	20	2.5	6	3.04	50	3	7.21
	20	2.5	6	3.1	50	4	7.22
	20	2.5	6	3.68	50	4	7.25
	20	2.5	6	3.88	50	4	7.28

	20	2.5	6	3.99	50	4	7.28
	20	2.5	6	3.9	25	4	7.28
	30	2.5	6	4.76	25	4	7.28
	30	2.5	6	4.77	25	4	7.24
	30	2.5	6	5.68	0	4	7.16
	30	2.5	6	5.05	0	4	7.09
	30	2.5	6	4.8	0	4	7.08
17/04/2015	30	2.5	6	4.41	0	3	7.02
20/04/2015	30	2.5	5	5.95	0	3	7.05
	30	2.5	4	3.91	0	3	6.9
	30	2.5	5	2.44	0	6	6.72
	30	2.5	5	3.83	0	6	6.88
	30	2.5	5	4.09	0	6	6.78
23/04/2015	40	2.5	5	4.68	0	4	6.48
	40	2.5	5	4.35	0	5	6.46
	40	2.5	5	4.18	0	5	6.46
	40	2.5	5	4.13	0	5	6.43
24/04/2015	20	2.5	4	3	25	6	6.5
30/04/2015	30	2.5	6	3.18	25	6	7.59
	40	2.5	5	2.05	25	3	7.51
	40	2.5	5	3.15	25	3	7.5
	40	2.5	5	3.75	25	3	7.57
	40	2.5	5	3.34	25	1.5	7.5
	40	2.5	5	3.72	25	6	7.5
05/05/2015	40	5	5	5.44	25	6	6.95
08/05/2015	30	5	5	3.77	50	6	6.82
11/05/2015	50	5	5	3.72	50	6	7.33
15/05/2015	30	5	5	4.55	25	3	7.06
18/05/2015	40	5	5	5.8	75	3	6.85

Appendix 5. Removal of nitrates and phosphates

(Egido 2015)

Date	Removal NO_3-N (%)	Removal PO_4-P (%)
15/05/2015	36.36	26.04
12/05/2015	42.86	-63.16
11/05/2015	-14.29	-20.97
08/05/2015	-154.55	7.84
07/05/2015	-260.00	19.26
06/05/2015	-77.78	31.44
05/05/2015	66.67	63.18
04/05/2015	-	29.83
30/04/2015	53.85	60.84
29/04/2015	76.92	71.08

Date	SAMPLE		NO3-N	PO4
15/05/2015	Influent	1	11	38.4
	Denitrification	2	6	29.4
	Aeration	3	9	27.8
	Effluent	4	7	28.4
12/05/2015	Influent	1	5.25	15.2
	Denitrification	2	4	21.6
	Aeration	3	5	23.2
	Effluent	4	3	24.8
11/05/2015	Influent	1	3.5	24.8
	Denitrification	2	4	26.2
	Aeration	3	8	26.4
	Effluent	4	4	30
08/05/2015	Influent	1	2.75	31.9
	Denitrification	2	5	31.3
	Aeration	3	11	34.9
	Effluent	4	7	29.4
07/05/2015	Influent	1	2.5	37.9
	Denitrification	2	6	29.1
	Aeration	3	12	30.3
	Effluent	4	9	30.6
06/05/2015	Influent	1	2.25	40.4
	Denitrification	2	5	30.9
	Aeration	3	9	28.8
	Effluent	4	4	27.7
05/05/2015	Influent	1	6	66
	Denitrification	2	4	20.5

	Aeration	3	5	21.2
	Effluent	4	2	24.3
04/05/2015	Influent	1	4.25	35.2
	Denitrification	2	1	30.5
	Aeration	3		23.6
	Effluent	4		24.7
30/04/2015	Influent	1	3.25	33.2
	Denitrification	2	2.25	17.7
	Aeration	3	1.5	13.9
	Effluent	4	1.5	13
29/04/2015	Influent	1	3.25	33.2
	Denitrification	2	2.25	9.1
	Aeration	3	1.5	9.4
	Effluent	4	0.75	9.6
24/04/2015	Influent	1		6.725
	Denitrification	2		14.5
	Aeration	3		8.3
	Effluent	4		9.25

Appendix 6. Microorganisms present in the WWTP samples