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SELF-DESIGNED WASTEWATER TREATMENT SYSTEM FOR DOMESTIC WASTEWATER

Wastewater treatment in areas outside sewer networks in Kokkola

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ABSTRACT

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This thesis is related to the Finnish government decree on treating domestic wastewater in areas outside sewer networks (542/2003). The aim of this thesis was to design a simple, cheap and effective domestic wastewater treatment system and build its model.

The thesis includes not only the theoretical explanations of methods for removing nitrogen, phosphorus and BOD_7, engineering designed and building processes of model, but also the experimental processes of running the model and results of analyzed samples from the model. The analysis was done by the Maintpartner Laboratory.

The results prove the design is successful for treating domestic wastewater. However, the treatment methods still need to be adjusted if the design is going to be used in practice.

Key words

Domestic wastewater treatment, self-designed model, flocculation, sedimentation, denitrification, yeast, anaerobic biological treatment

TABLE OF CONTENTS

1 INTRODUCTION

Domestic wastewater treatment plays an important role in city management nowadays. It can influence the long term ecological circumstances in one large area. Wastewaters from houses and farms have huge amounts of nutrients, such as phosphorous and nitrogen. Excess of nutrients can cause many problems to water bodies: for example, the nutrients can increase the growth of algae and microorganisms and cause red tide, which leads to the death of other creatures in water (MPCA 2008, 1). These environmental influences are more obvious in the cities which are near the sea shores, having rivers, lakes and groundwater, such as Kokkola.

Finland has done a lot of measures to decrease the negative effects to the environment from domestic wastewater. Every city has its sewer networks and wastewater plants. But because of the economic and geographical limitations, sewer networks cannot cover all the land, especially in some rural areas. The wastewaters from areas which are outside of sewer networks are normally discharged to grounds or water bodies without effective treatment. According to the research, the discharge of phosphorous in wastewater in rural areas is 50% higher than in urban areas (Ruokojärvi 2007, 5). Because of this situation, environmental ministry of Finland published a decree in 2003. This decree requires that all domestic wastewater outside of sewer network needs to be treated before it discharges to the environment, and the decree also stipulates some details of domestic treatment system. Also, the environmental ministry of Kokkola has published a regulation based on its local situation. According to this regulation, the houses which are outside of sewer networks must achieve the requirements until 2014. But the domestic wastewater treatment systems in market are very expensive and difficult to install for individuals, especially for those who have their summer cottages in rural areas.

The aim of this thesis is to solve the mentioned problems by trying to build a simple, cheap and effective domestic wastewater treatment system model. The target is that this system can be inserted into the wastewater tanks of houses, and the outlet wastewater can be directly discharged to nature.

Therefore, this report has the following sections: first part is the design and construction of a domestic wastewater treatment system model; second part is the test and sampling of the treatment system model. In order to finish this project, the following questions need to be solved:

- What are the concrete requirements for outlet wastewater?
- What kind of treatments need to take place?
- How to separate the solid and liquid phase of wastewater?
- What are the best chemicals of the treatment and how to add them into the system?
- How to organize the system in order to put into the existed wastewater tank?
- What is the best for practical treatment system?

To solve all those problems, domestic wastewater samples are needed. The domestic wastewaters are taken from a Finnish family’s summer cottage in Kokkola, and the analysis of the samples is done by Maintpartner Laboratory. This thesis presents the basic requirements of the government decree, methods of the treatment system, the engineering design and simulations of the model, results of the simulations and existing problems.

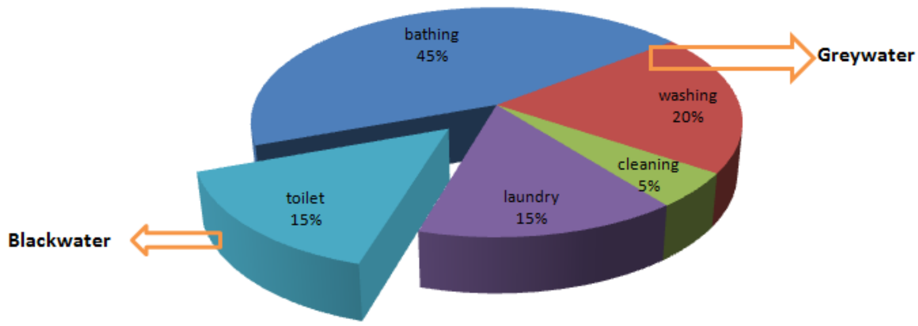
2 BACKGROUND OF ENVIRONMENTAL DECREE

In Finland, in order to decrease the diffuse pollution from domestic wastewater of houses in rural areas, environmental ministry of Finland has published a wastewater treatment decree since 2003. The decree indicates the released house holding wastewater must reach the requirements before 2014. The requirements are constituted by research, and they focus on three main contents: biochemical oxygen demand over 7 days (BOD_7), phosphorous (P) and nitrogen (N). (Finnish Ministry of the Environment 2003/542, 1-3.)

For the entire Finland, the decree specifies the discharging limits of these three contents in wastewater. Also, for a city such as Kokkola, there are also particular regulations according to the regional situation.

2.1 Decree requirements of Finland

According to the government decree 542/2003, domestic wastewater is defined as ‘wastewater originating from water closets of dwellings, offices, business premises and other facilities, and from kitchens, washing facilities and similar facilities and equipments, and wastewater with similar properties and composition originating from milk stores at dairy farms or resulting from other business operations’. It can be simplified as greywater and toilet water (blackwater), where greywater means domestic wastewater from bathing, washing, cleaning and laundry. Besides, greywater is different from blackwater which contains human wastes. (Finnish Ministry of the Environment 2003/542, 2; Marg & Pradesh 2007, 1.)



GRAPH 1. Ratio of Finnish domestic wastewater (Finnish Ministry of the Environment 2007)

Graph 1 shows the ratio of the domestic wastewater contents in Finnish society, where the greywater occupies 85% of domestic wastewater, and the rest is toilet water. Both of them have the contents of BOD_7, phosphorous and nitrogen. Finnish government requires that the person-equivalent load needs to reach the following values: BOD_7 amounts to 50 gram per day (g/d), total phosphorous amounts to 2.2 g/d and total nitrogen to 14 g/d. Also, for general wastewater treatment, there are two different situations: first, for municipal environmental protection regions, which are areas near underground water, coastlines and special environmental protection areas, the decree requires to remove at least 90% of BOD_7, 85% of total phosphorous and 40% of nitrogen from domestic wastewater before discharging; and then, for less sensitive areas, the requirements are lower, which needs to remove at least 80% of BOD_7, 70% of total phosphorous and 30% of nitrogen. (Finnish Ministry of the Environment 2007, 1.)

Based on the requirements, there are also regulations for the domestic wastewater treatment system (Finnish Ministry of the Environment 2003/542, 8):

1. The septic tank works as a container for the separated solid from

pre-treating wastewater.

2. The cesspool is also called holding tank, it is for holding the wastewater.
3. The soil infiltration system is connected to the ground and allowing ground to absorb the pre-treated water.
4. The sand filter system contains sands or other soil materials which works as a filter to purify the treated wastewater.
5. The Package plant is different from 1-4 and has function of treating wastewater, it can be physical, chemical or biological treatment systems.

This decree presents the primary regulations for the entire Finland, and on the basis of it, different regions can have their own detailed regulations according to different situations.

2.2 Regulations of Kokkola

Based on the local situation, the environmental ministry of Kokkola published a local regulation in 2011 (Valtioneuvoston asetus talousjätevesien käsittelystä viemäriverkostojen ulkopuolisilla alueilla). This regulation has the same basic information as decree 542/2003, but more detailed requirements for specific areas. It divides the city into four main parts: ground water areas, beach areas, buffer zones and basic treatment areas. Each area has its own required wastewater treatment system. For the first three areas, the systems are more limited because of their high sensitivity. Also, the basic treatment area covers most of Kokkola city, and the regulation of wastewater treatment system for this area is the same as in government decree 542/2003. More details for the area differences can be found in the Appendix 1, and this thesis only focuses on the basic treatment area.

As a standard comparison of the model treatment system, Table 1 shows the parameters of existed wastewater tanks for houses in Kokkola. The parameters are used to calculate the wastewater volume and compare it with the model. Also, the load of domestic water from one person is according to the data from environmental ministry of Kokkola.

TABLE 1. Parameters of wastewater tank and personal daily load in Kokkola

Wastewater tank parameters		**Loads (per person)**	
Height (m)	4	BOD_7 (g/d)	70
Diameter (m)	1	Phosphorous (g/d)	3
Volume (m^3)	3.14	Nitrogen (g/d)	14

The wastewater tank is also working as a holding tank, it is made of concrete, and its bottom is contacted to soil ground directly. On the tank, there are two pipes: one inlet pipe which is connecting to the house and domestic wastewater comes through this pipe; the other one outlet pipe is for discharging the after-treated water. The outlet pipe leads to a sand layer under the ground, which works as the sand filter system. On the other side, according to environmental ministry of Kokkola, the total average load of a person is 120 litres per day. Graph 2 shows the wastewater tank of Mr K's summer cottage.

GRAPH 2. Wastewater tank at Mr K's summer cottage

3 DESIGN OF DOMESTIC WASTEWATER TREATMENT SYSTEM

In Finland, domestic wastewater basically consists of greywater and blackwater. Because of the complicated contents in domestic wastewater, there are problems to separate the solid and liquid phases of it. Also, how to remove the BOD_7, phosphorous and nitrogen efficiently is also a crucial problem.

3.1 Methods of designed system

Various methods have been used to treat wastewater, such as sedimentation, flocculation, chemical precipitation, anaerobic and aerobic biological technologies and filtration. Because the aim of this thesis is to build a simple, effective and cheap treatment system for houses, the chosen methods must not be complicated, and the design needs to be convenient to assemble.

3.1.1 Primary treatment of designed treatment system

The first step of the domestic wastewater treatment system is to separate the solid and liquid phases of domestic wastewater. After separation, the solid stays in septic tank and can be taken away regularly by pump. And then the taken solid can be transferred by cars and used in farms as fertilizer. On the other hand, the liquid goes to future treatments in the system and can be discharged to nature. The primary separation can be done by gravity directly. In this step, solid phase is heavier than liquid phase so that the solid can stay at the bottom of septic tank and form sludge. This process is called sedimentation. Besides, there are floating particulates in the wastewater. The system needs to avoid these particulates go to the further treatment system as much as possible. For this purpose, a screen or filter can be helpful to filter most of the particulates and keep them in the septic tank. Also, flocculation is also a useful method in this case.

The basic principle of flocculation is to form groups of solid particulates by using flocculating agents. This method can speed up the sedimentation, take away part of nitrous and phosphoric contents and also decrease BOD_7. There are many kinds of chemicals which can be used as flocculating agents. The wastewater treatment plant normally uses aluminium salt and ferric salt. For instance, poly-aluminium chloride ($Al_2Cl(OH)_5$), aluminium sulphate ($Al_2(SO_4)_3*16H_2O$), ferric sulphate ($Fe_2(SO_4)_3*9H_2O$), ferric chloride ($FeCl_3*6H_2O$), and sodium aluminate ($NaAlO_2$). The model uses $Al_2(SO_4)_3*16H_2O$ and $FeCl_3*6H_2O$ as the final choices. There are series of chemical reactions taking place, and each of them has its effect for reaching the target. (FSC Architects and Engineers 2003; EPA 2000.)

The following equations show the chemical reactions in primary treatment (FSC Architects and Engineers 2003, 2-5):

- For flocculation:

$$Al^{3+}+H_2O = Al(OH)^{2+}+H^+ \quad (1)$$

$$Al\ (OH)^{2+}+H_2O = Al(OH)^{2+}+H^+ \quad (2)$$

$$Al(OH)^{2+}+H_2O = Al(OH)_3\downarrow+H^+ \quad (3)$$

$Al(OH)_3+H_2O = Al(OH)^{4-}+H^+$ (4)

$Fe^{3+}+H_2O = Fe(OH)^{2+}+H^+$ (5)

$Fe (OH)^{2+}+H_2O = Fe(OH)^{2+}+H^+$ (6)

$Fe(OH)^{2+}+H_2O = Fe(OH)_3\downarrow+H^+$ (7)

$Fe(OH)_3+H_2O = Fe(OH)^{4-}+H^+$ (8)

For taking away nitrous contents (EPA 2000):

$Fe^{3+}+3NH_3*H_2O = Fe(OH)_3\downarrow+3NH^{4+}$ (9)

$NH_3+H2O = NH^{4+}+OH^-$ (10)

For taking away phosphoric contents (FSC Architects and Engineers 2003, 2-6):

$Al^{3+}+PO_4^{3+} = AlPO_4\downarrow$ (11)

$Fe^{3+}+PO_4^{3+} = FePO_4\downarrow$ (12)

For decrease BOD_7 (Sharma 2001, 12):

$4Fe^{3+}+O_2+2H_2O = 4Fe^{3+}+4OH^-$ (13)

All the solid precipitations stay in the septic tank and form sludge, and then the liquid goes through the screen to next treatment.

3.1.2 Secondary treatment of designed treatment system

After the sedimentation and primary treatment, most of the solid particulates are separated from liquid, and the liquid goes to the secondary treatment tank. The secondary treatment mainly focuses on decreasing the amount of nitrous and phosphoric contents. In this stage, calcium carbonate ($CaCO_3$) and alcohol play the main roles. Consider the simulation period limit, the model treatment system uses chalkstone (also known as limestone) and methanol in the model system. The pre-treated wastewater first goes through layers of chalkstones, and there are hydroxide ions formed. This process can adjust the pH of wastewater for further treatment. Also, in order to remove the phosphoric contents, the added chalkstones must be sufficient to increase the pH to 10, and then the calcium ions can react with phosphate to form hydroxyapatite precipitate ($Ca_5(OH)(PO_4)_3$) (EPA 2000). After this process, the liquid goes to the next stage where contains methanol. In this stage, methanol works as a carbon source for growing bacteria and also causes denitrification, which can remove the nitrous contents by converting them to gas form and discharging to atmosphere (Methanol institute 2011). The following equations show the chemical reactions which are taken places in secondary treatment (Strom 2006, 9; The water plant company 2012):

- Chalkstone ($CaCO_3$):

  $$5Ca^{2+}+4OH^{-}+3HPO4^{2-} = Ca_5(OH)(PO_4)_3\downarrow+3H_2O \qquad (14)$$

- Methanol (CH_3OH):

  $$6NH_3+5CH_3OH+12O_2 = 3N_2\uparrow+5CO_2\uparrow+19H_2O \qquad (15)$$

During this process, most of the nitrous and phosphoric contents are taken away, and hopefully the ratios can reach the requirements in environmental decree. The treated wastewater can be discharged through the outlet pipe and goes to the sand layer underground, and it works as a natural sand filter. After the sand filter, the wastewater can discharge to nature directly.

3.1.3 Other methods for practical treatment system

Because the space and time limitations, there are many other methods can be useful in wastewater treatment but cannot be presented in the model. However, in the practical system, these methods can also be used. This chapter presents three most practical methods, and all of them can be add into this designed real wastewater treatment system without any difficulties.

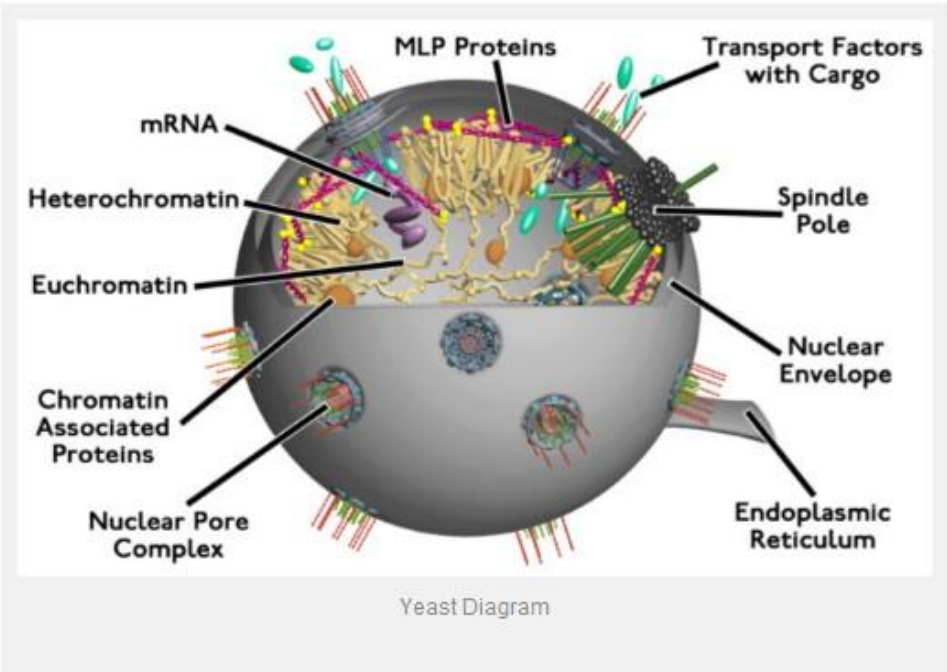
The first method is a kind of chemical treatment by using hypochlorous acid (HOCl), which can be used to remove the nitrous contents and lead to chlorination to purify the wastewater. Hypochlorous acid can react with ammonium ions (NH^{4+}) and forms nitrogen gas. About 7.5 milligrams of chloride can oxidize 1 milligram of ammonium ions. This chemical can be add to the secondary reaction tank with methanol, which is used to take more nitrous contents away. The following equations show the chemical reactions which are taken places in this case (EPA 1974, 17):

$$NH_4^+ + HOCl = NH_2Cl + H^+ + H_2O \qquad (16)$$

$$2NH_2Cl + HOCl = N_2\uparrow + 3Cl^- + H_2O + 3H^+ \qquad (17)$$

But the disadvantage of this method is that there are chloric contents, and too much chlorine can be toxic and cause problems to the environment. (EPA, 1974.)

The second method is a kind of biological treatment by adding yeast to the wastewater reaction tank. Yeasts are a kind of micro-organisms which are eukaryotic, heterotrophic and unicellular. They belong to kingdom fungi. Most types of yeasts have diameter from 3 to 4 micrometer and egg shape. (Dan 2001.)



GRAPH 3. Yeast diagram (Water treatment 2012)

Graph 3 shows the biological structure of yeasts. Under anaerobic circumstances, yeasts can cause fermentation and convert sugar to ethanol and carbon dioxide. In addition, under aerobic circumstances, yeasts can lead oxidation and convert organics and oxygen into water and carbon dioxide. According to these functions, yeasts can be used to produce ethanol, which can work as a substitute of methanol to take away nitrous contents in the secondary treatment system. Also, when there is enough oxygen, yeasts can also be used to decrease BOD_7 and purify other organic matters in wastewater. The following equations show the chemical reactions which are taken places in this case (Dan 2001, 22-24):

- Fermentation

$$C_6H_{12}O_6 \xrightarrow{\text{yeasts, nutrients}} C_2H_5OH + CO_2 + \text{new yeast cells} \quad (18)$$

- Oxidation

$$\text{Organics} + O_2 \xrightarrow{\text{yeasts, nutrients}} CO_2 + H_2O + \text{new yeast cells} + \text{end products} \quad (19)$$

The disadvantage of this method is that to breed yeasts and complete the transformations take longer period than chemical treatments. Also, yeasts are influenced by many factors: for instance, they require certain environment where pH of water needs to be lower than 7 and the temperature needs to be higher than 8 degrees Celsius, so the final results are difficult to predict and control. (Dan 2001.)

The third method is also biological, and it is called anaerobic biological treatment by breeding anaerobic bacteria in the treatment system. The anaerobic reaction can be divided to four steps (Dan 2001, 17; Mrowiec & Suschka 2008, 1-6):

1. Hydrolysis: Because polymeric organics have large molecular volumes, they cannot go through the cell wall of anaerobic bacteria. And the large molecules needs enzyme which is contained in the wastewater to decompose them to smaller ones. For instance, the cellulose in wastewater can be decomposed by cellulase enzyme into cellobiose and glucose, and starch can be decomposed into maltose and glucose, and protein into peptide and amino acid. After decomposition, these decomposed smaller molecules can go through the cell wall of bacteria and continue biological decomposition.

2. Acidification: in this step, all the decomposed organic molecules are converted by bacteria into other compounds. Most formed compounds are volatile fatty acid, and also small amount of alcohols, lactic acid, carbon dioxide, hydrogen, ammonia and hydrogen sulphide.

3. Acetogenic activity: during this process, the products from last step convert to acetic acid, carbonic acid, hydrogen and new cells.

4. Methanogenic activity: all the acetic acid, hydrogen, carbonic acid, formic acid and methanol are converted into methane, carbon dioxide and new cells. This process is the most important step in the anaerobic reaction and it takes long time.

The following equations show the chemical reactions which are happening in the last step of the anaerobic reaction (Mrowiec & Suschka 2008, 3):

$$CH_3COO^- + H2O = CH_4 + HCO_3^- \quad (20)$$

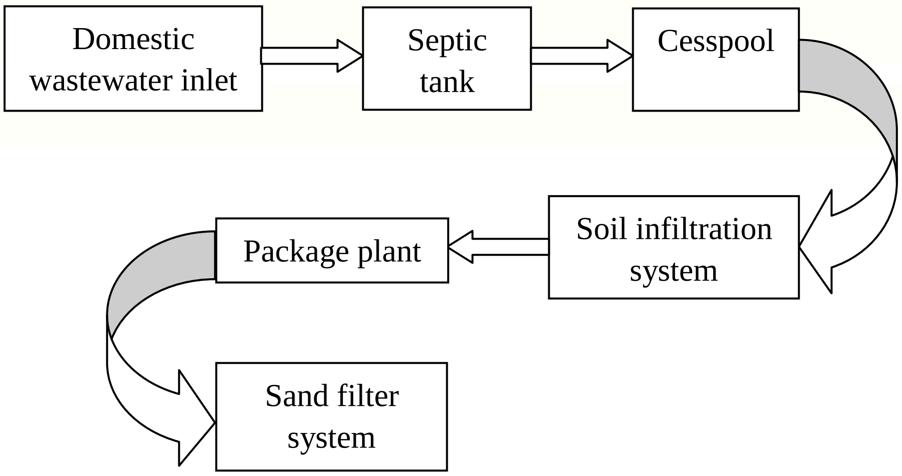
$$HCO_3^- + H^+ + 4H_2 = CH_4 + 3H_2O \quad (21)$$

$$4CH_3OH = 3CH_4+CO_2+2H_2O \quad (22)$$

$$4HCOO^-+2H^+ = CH_4+CO_2+2HCO_3^- \quad (23)$$

This method requires creating an environment for anaerobic bacteria to grow. In the designed treatment system, the anaerobic bacteria can be put in the secondary tank, and the anaerobic condition can be created by closing the secondary reaction tank.

All these three methods are widely used in wastewater treatment nowadays. The practical treatment system can add in these spare methods, because it has larger space and the treatment period is longer. In the model, the largest pipe works as the septic tank, cesspool and soli infiltration system which are required in the environmental decree. Graph 4 shows the basic process for the real treatment system.



GRAPH 4. General process of the practical wastewater treatment system

3.2 Self-designed domestic wastewater treatment system

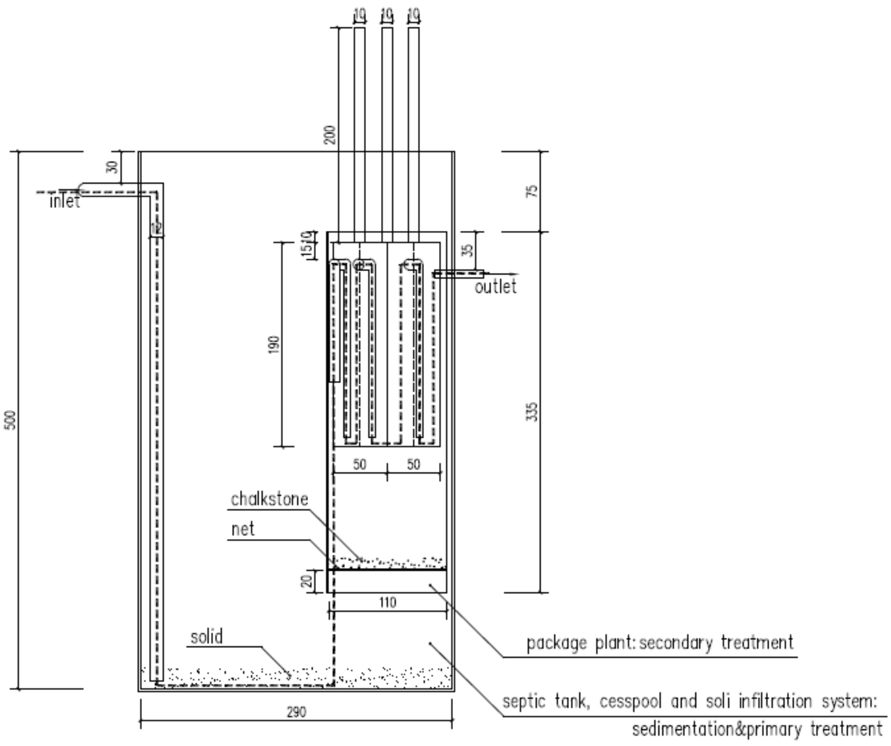
The self-design includes both practical system and model system. The model is built to represent the basic engineering structure and chemical treatment methods of the real treatment system. The methods which are used in the model are limited, and the real system can be more complicated and detailed. The model uses a large cylindrical plastic pipe to represent the real concrete wastewater tank, and the secondary treatment tank is consist of four smaller pipes which can be put into the largest one. The materials used in this model are ready-made pipes and tubes, so the size of these materials cannot be changed, but it can be adjusted and is good enough to represent the whole treatment system. The pipes are made of acrylic material and tubes are normal plastic water pipes which are typically used in boats.

3.2.1 Structure of system

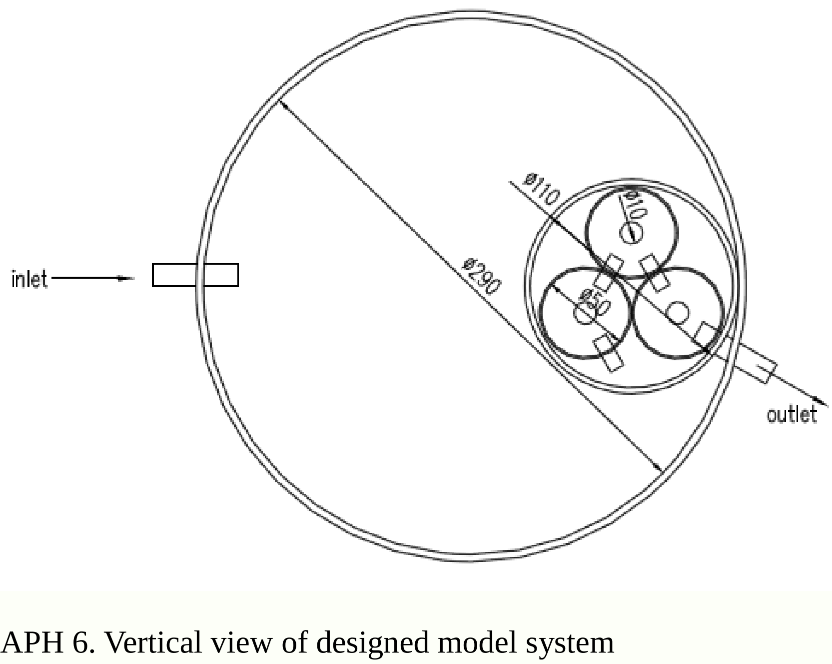
In the practical system, based on methods and requirements from the decree, the model has two main parts. The first part is an existed concrete wastewater tank which functions as the septic tank, cesspool and soil infiltration system. Domestic wastewater comes through the inlet tube and falls down to the bottom of it. The chemicals which are used for primary treatment are placed under the inlet tube, and the wastewater flow takes and mixes chemicals by itself. After this, the wastewater stays in the tank and begins to react with the chemicals. As time goes by, the water level in the tank is raised by adding more and more wastewater, and then the wastewater goes to the second part of the system. The second part of the system functions as a package plant, and it is in cylinder form and places on wall of the wastewater tank. This cylinder can be closed from the top which can create an anaerobic environment for anaerobic bacteria growth. At the lower part of this cylinder, there is a screen placed for preventing floating materials and other solid particulates from wastewater going into next treatment part. Moreover, on the screen are layers of chalkstone, and the wastewater goes through them and then to the upper part. Besides, in this cylinder, there are three smaller cylinders which are closed from both sides, and they are placed at the upper parts of the larger cylinder. While water level rises, the wastewater goes in to those three cylinders through small tubes. There are also three tubes connecting the cover of the three smaller cylinders with atmosphere. These three tubes are used for adding methanol or other chemicals. Also, in order to balance the pressure of this system, the three tubes can be used to release the produced gases.

In the model system, the first part is a largest pipe which represents the wastewater tank in the real system and works as a primary treatment tank. Inside of the largest pipe, four smaller pipes represent the secondary treatment system in the practical system. This part is made up of four pipes, where three smaller pipes are contained in one bigger pipe. The three smaller pipes are covered from both sides, and there are three plastic tubes connected on the top of each pipe.

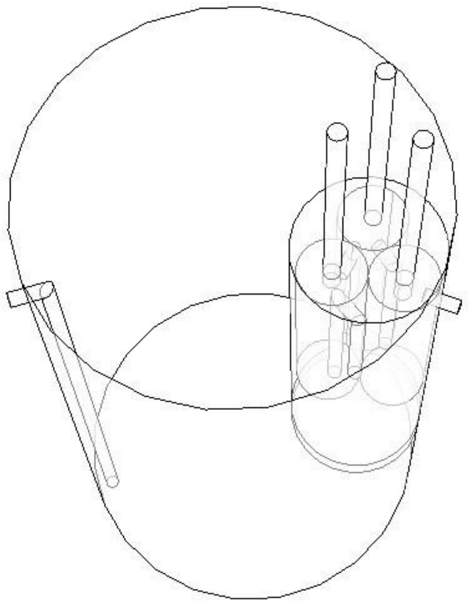
In order to explain the details of the system more clear, Graph 5 is the plan and Graph 6 is vertical view of the model system. Besides, Graph 7 shows the three-dimensional view of the whole designed system. All these graphs are drawn by using computer aided design (CAD) software.



GRAPH 5. Plan of designed model system



GRAPH 6. Vertical view of designed model system



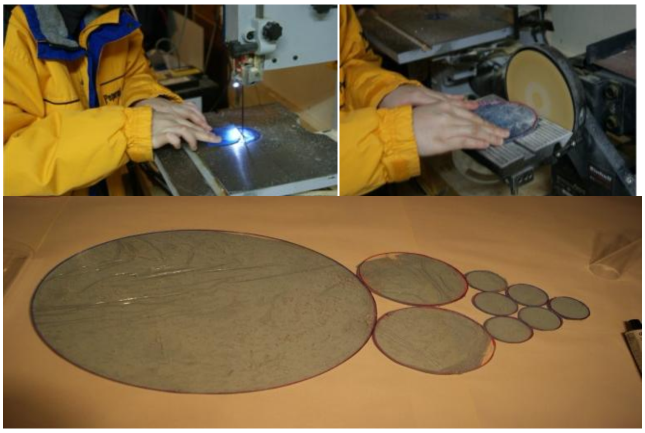
GRAPH 7. Three-dimensional view of designed system

3.2.2 Building procedure of designed model system

The model was built by hand, and the building tools were borrowed from Mr K, who also supervised the work during construction.

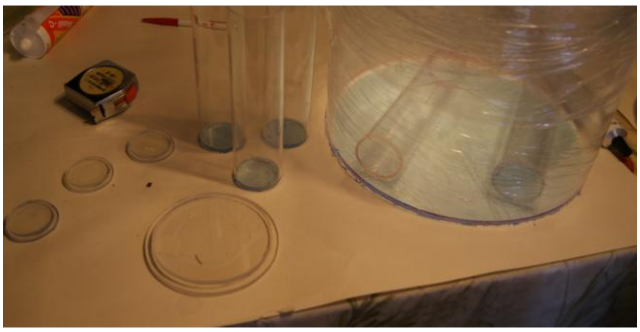
GRAPH 8. Materials for building model

Graph 8 shows the main materials for building the model. No.1 indicates the connecting tube for inlet and outlet, and it is also used to connect the three smaller pipes for secondary treatment system. No.2, 3 and 4 are acrylic pipes with three different sizes. No.5 indicates two materials which are used to glue the covers of pipes and fulfil the possible gap in order to prevent water or air leaking. No.6 has the same materials as 2, 3 and 4, and they are used to make the covers for pipes.



GRAPH 9. Cutting, grinding covers for pipes

Graph 9 shows the tools which are used to cut and grind the covers into different sizes for those pipes.



GRAPH 10. Glued pipes and covers

Graph 10 shows the pipes and covers after gluing. The largest pipe is covered and glued on one side, and the three smaller pipes are covered and glued on both sides. All the covers are first glued and then made water-tight by using silicone sealant.

GRAPH 11. Tools for making holes and connected pipes

Graph 11 shows the three smaller pipes and the assembled secondary treatment system with connected tubes. The model will be ready after putting all parts together.

GRAPH12. The assembled model system

Graph 12 shows the assembled model. The bottom of the largest pipe, the connecting tubes of secondary treatment and the outlet tubes are water-tight, so the wastewater path can go as planned and the model can work well without leaking. After assembling the model system, it can be taken to the laboratory to run simulation with domestic wastewater samples.

The principle for the model is as simple as possible, so the model has no electrical parts in its mechanism. But in the practical system, electrical mixing and pumping system can be added in, and they can make the whole system more effective. After mixing, the wastewater can react better with chemicals than in the model. Also, the more wastewater contact with air in the first holding tank, the more nitrous contents can be taken away. Besides, in the real treatment system, there is enough space for adding other kinds of chemicals, and the reaction time period is much longer than what is presented in the simulation of model. All in all, the simulation of model cannot totally represent the effects and results of the real treatment system, and it is limited by time, space and methods. The simulation can only show the working mechanism and basic methods of the real treatment system during short time period. Besides, the sand filter system is not presented in the simulation.

4 SIMULATIONS OF DESIGNED MODEL SYSTEM

There are two parts in this chapter: the first part is the simulation of the model. This part was made in the laboratory by myself, and my thesis teacher advised me during the simulation. The second part is sampling and analysis. The analysis was done in the Maintpartner Laboratory, which also does the water analysis for Kokkola City. This part presents the results and the discussion of appeared problems according to the results.

The simulations were done by repeating running the model for three times with domestic wastewater, and each time had the same procedures. Each run took several samples from the model, and the samples were sent to Maintpartner Laboratory for analysis. Before the three times simulations, there was a test to identify the needed amount of chemicals and reacting time for the simulation, in order to avoid wasting chemicals and also help to make the simulations more effective. Graph 13 shows the domestic wastewater sample which was taken from Mr. K’s house’s wastewater tank. Each bottle could store about 10 litres of domestic wastewater.

GRAPH 13. Domestic wastewater sample taken

4.1 Test run of designed model system

The test was to identify the best amount for flocculation by using $Al_2(SO_4)_3*16H_2O$ and $FeCl_3*6H_2O$ to react with domestic wastewater. According to research, the pH of wastewater and the concentration of flocculants could influence flocculation. For $Al_2(SO_4)_3*16H_2O$ and $FeCl_3*6H_2O$, the best pH value of wastewater is from 5.5 to 8, and the best ratio by weight of the flocculants and wastewater is 0.5-1.5:1000. Also, according to the properties of two chemicals, the used amount of $FeCl_3*6H_2O$ needed to be higher than $Al_2(SO_4)_3*16H_2O$. Therefore, in this test, the ratio between $Al_2(SO_4)_3*16H_2O$ and $FeCl_3*6H_2O$ is 2:5, the chemicals were dissolved in diluted water and had the concentration 0.02 grams per litre. Five different amounts of the solution were added respectively into 400 millilitres domestic wastewater to figure out the best flocculants' amount for flocculation. (Fasemore 2004.)

4.1.1 Equipment and chemicals

Measuring cylinders

Bakers

Balance

pH measuring equipment

Measuring pipes

Mixing plate

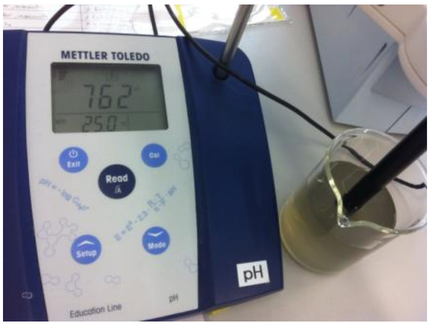
$Al_2(SO_4)_3*16H_2O$

$FeCl_3*6H_2O$

Domestic wastewater

4.1.2 Process of test run

The first step was taking 300 millilitres wastewater sample to measure its pH, and the measured pH value was about 7.6. Graph 14 shows the pH of wastewater sample.

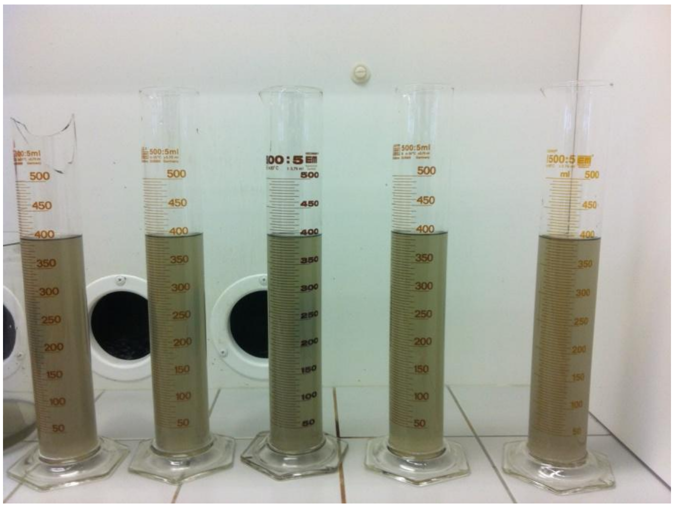


GRAPH 14. pH of wastewater sample.

And then, 2.0010 grams of $Al_2(SO_4)_3*16H_2O$ and 5.0052 grams of $FeCl_3*6H_2O$ were measured by the balance, and they were respectively mixed with 350 millilitres distilled water on a mixing plate. Graph 14 shows the chemicals which are measured.

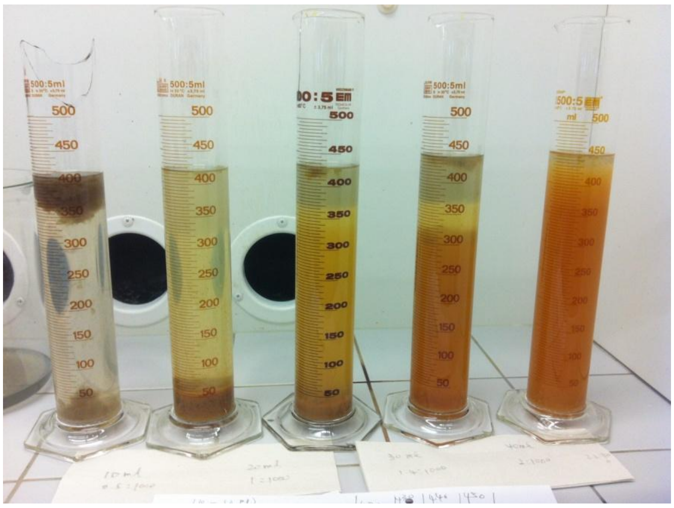
GRAPH 15. $FeCl_3*6H_2O$ and $Al_2(SO_4)_3*16H_2O$

During the mixing, 400 millilitres wastewater samples were respectively added into five 500 millilitres measuring cylinders. Graph 16 shows the wastewater samples in the five measuring cylinders.



GRAPH 16. Wastewater samples in measuring cylinders

After the chemicals were totally dissolved in the solution, five different amounts of solutions were added into each of those five measuring cylinders. Respectively, the amounts were 10 millilitres, 20 millilitres, 30 millilitres, 40 millilitres and 50 millilitres. Graph 17 shows liquid height changes during flocculation after one hour.



GRAPH 17. Flocculation results after one hour

4.1.3 Data and results of test run

In the experiment, the flocculants were $Al_2(SO_4)_3*16H_2O$ and $FeCl_3*6H_2O$, and the solution of flocculants has the concentration 0.02 grams per millilitre. For each of those five 400 millilitres wastewater samples, different amount of solution were added in.

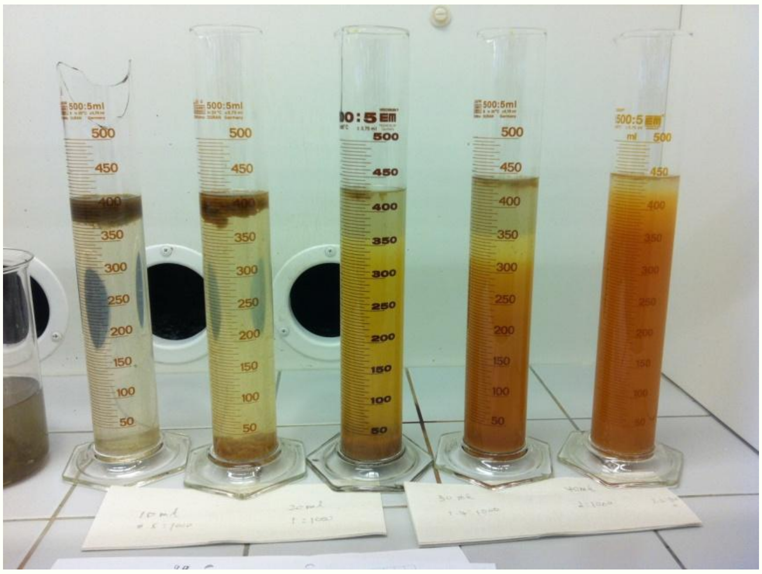
Table 2 shows the data and results during time. The beginning liquid heights with different amounts of flocculants solution were 410 millilitres, 420 millilitres, 430 millilitres, 440 millilitres and 450 millilitres. And after one and a half hour, the liquid heights changed to 380 millilitres, 370 millilitres, 380 millilitres, 400 millilitres and 430 millilitres. The appeared floats in the first two cylinders were separated from liquid and gathered together on the liquid surface, but the floats in the last three cylinders were scattering in the cylinders and not separated from the liquid.

TABLE 2. Records of liquid height during time

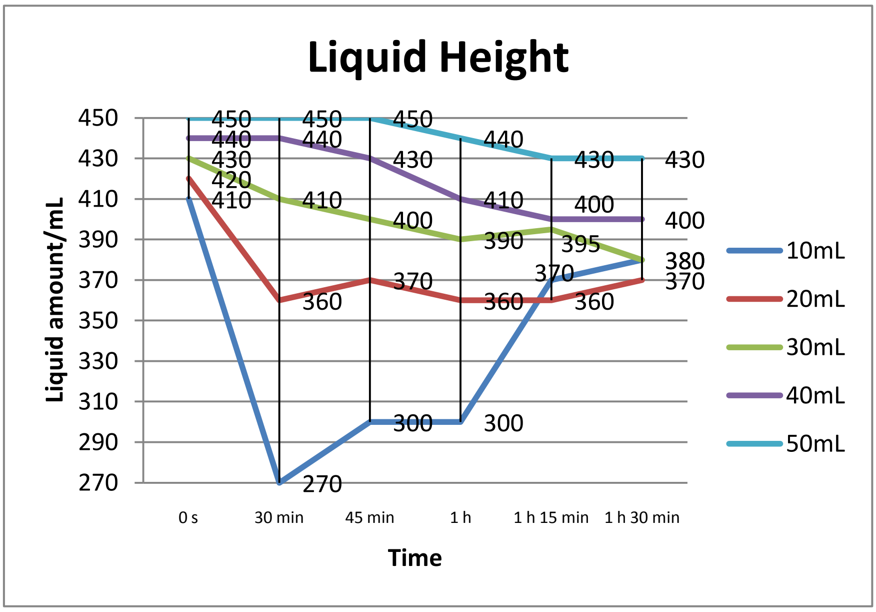
Flocculants / Time	**10mL**	**20mL**	**30mL**	**40mL**	**50mL**
0 s	410 ml	420 ml	430 ml	440 ml	450 ml
30 min	270 ml	360 ml	410 ml	440 ml	450 ml
45 min	300 ml	370 ml	400 ml	430 ml	450 ml
1 h	300 ml	360 ml	390 ml	410 ml	440 ml
1 h 15 min	370 ml	360 ml	395 ml	400 ml	430 ml
1 h 30 min	380 ml	370 ml	380 ml	400 ml	430 ml

4.1.4 Conclusion of test run

The flocculation time for this experiment is one and half an hour, the final results shows below.



GRAPH 18. Flocculation after one and a half hour



GRAPH 19. Liquid height changes during time

As shown in Graph 19, the 10 mL line has the most acute and evident changes. Therefore, as a conclusion with reference to Graph 18 and 19, in order to get the best flocculation results, every 400 millilitres wastewater needs 10 millilitres 0.02 grams per litre flocculants solution, and the flocculation takes about one and a half hour. The ratio of flocculants solution and wastewater by volume is 1:40, and the ratio of flocculants and wastewater by weight is 0.5:1000.

Based on the test run, after flocculation, the floats floated on the surface of liquid. While the liquid level rose, the floats could go into the secondary treatment system with liquid through the inlet pipe. In order to solve this problem, the length of inlet pipe for secondary treatment system was changed longer. Therefore, the floats could stay in the surface without going into the three small pipes in secondary treatment system. Also, during the model run, the amount of wastewater was larger than the test run, and the floats could gather together and have larger density than the liquid, so they can stay in the bottom of the primary treatment system.

4.2 Model run of designed model system

The test run helped to set up the plan of the model run. According to the results from test run, the amount of flocculants could be calculated, and the time period for each model run was about half a day. During each model run, there were five samples for analysis: one for raw wastewater, two for the first treatment liquid at different time, and two for secondary treatment at different time. In order to run the model appropriately, huge amount of domestic wastewater needed to be taken. Also, the Maintpartner Laboratory required 2 millilitres of each sample for analysis.

Before running the model, there were some calculations. Table 3 shows the parameters for model. The parameters were used to calculate the amount of needed domestic wastewater and flocculants.

TABLE 3. Parameters of model

	Height(cm)	**Diameter(cm)**	**Volume(L)**
Big tank	50	29	33.00925
Secondary tank	33.5	11	3.1819975
Three small pipes in secondary tank	9	5	0.176625

From Graph 5, the height of outlet tube was 39 centimetres, so the maximum volume of the whole model was about 26 litres, also there were five samples for each run and each sample needed 2 litres, so every run needed about 36 litres domestic wastewater. Based on the data from test run, 36 litres domestic wastewater needed about 900 millilitres 0.02 g/ml flocculants solution. Before the liquid went into the three small pipes in secondary treatment, the wastewater needed to stay in the primary treatment tank for flocculation and sedimentation. So at the beginning of the run, water level needed to be lower than the inlet tube of the three small pipes and the measured height was 35 centimetres, which leaded to 23 litres domestic wastewater.

Except the designed model system, the model run needed the same equipment and chemicals in the test run.

4.2.1 Process of model run

In order to get reliable results, the model run needed to be repeated for three times, each time had the same procedures. First step was taking 300 litres wastewater sample to measure the pH.

GRAPH 20. pH of three model runs

Graph 20 shows the pH for three runs were respectively 7.49, 7.57 and 7.55. All three pH values were in the range 5.5-8, which were suitable for flocculation.

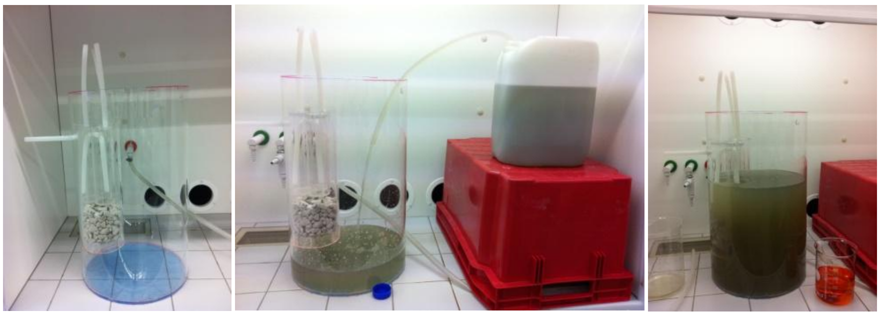
As time went by, 20 grams flocculants were dissolved into 1 litre flocculants solution, and there were 5.7 grams of $Al_2(SO_4)_3*16H_2O$ and 14.3 grams of $FeCl_3*6H_2O$. Table 4 and Graph 21 show the real values and solution for three runs.

TABLE 4. Real values of $Al_2(SO_4)_3*16H_2O$ and $FeCl_3*6H_2O$

	$Al_2(SO_4)_3*16H_2O$	**$FeCl_3*6H_2O$**
1st run (g)	5.702	14.3207
2nd run (g)	5.7017	14.3075
3rd run (g)	5.7082	14.3014

GRAPH 21. Flocculants solution

While the chemicals were mixing, the model was placed on the table and 23 litres wastewater was added in. The water level in the model was about 35 centimetres height. Graph 22 shows this process.

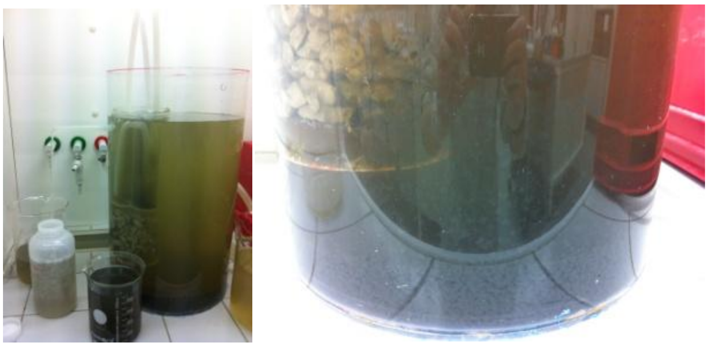


GRAPH 22. Adding wastewater into model

After adding wastewater into the model, 2 litres raw wastewater sample were added into the sampling bottles. Besides, by calculation, 23 litres wastewater needed 575 millilitres solution for flocculation. Also, 12 litres wastewater with 300 millilitres flocculants solution was prepared in several bakers. And this 12 litres wastewater was used to add into the model and got the outlet samples. Graph 23 shows the wastewater in model and beakers after adding flocculants solution.

GRAPH 23. Wastewater in model and beakers with flocculants solution

While waiting for flocculation, 10 millilitres methanol was taken in a beaker. After 45 minutes, 3 millilitres methanol were added into the small pipes in secondary treatment system. And then 6 litres wastewater from the prepared 12 litres beakers were added into the largest tank. After adding, 2 litres samples were taken from outlet tubes for secondary treatment systems. Also, 2 litres samples were taken fro the first treatment system. Graph 24 shows the model after 45 minutes.



GRAPH 24. Model after 45 minutes

After taking all the samples, the same processes need to be repeated after 1 hour and 45 minutes. According to the results, the solid particles gathered together and stayed in the bottom of primary treatment tank. Graph 25 shows the model after 2.5 hours.

GRAPH 25. Model after 2.5 hours

Graph 26 shows the samples which were taken. Each of the sampling bottles was one litre, so there were two bottles for each sample, and in total there were five samples with ten bottles.

GRAPH 26. Samples for one run

All three runs took two days. The first day had one run and second day had two. After each run, all the samples were taken to the Maintpartner Laboratory for analysis. The analysis for phosphorus and nitrogen took one day and the results come one day after the run, but the analysis for BOD_7 came after more than one week.

4.2.2 Results of model run

There were five samples for each run, and three runs had fifteen samples in total. The laboratory required for 2 litres of each sample, so they could make the analysis several times in order to get correct results. Table 5 shows the results of the model runs.

TABLE 5. Results of model run samples

		BOD_7 ±15%	**Phosphorus, total mg/l ±10%**	**Nitrogen mg/l ±9%**
First run	**Sample 1**	400	21	110
	Sample 2	280	2	110
	Sample 3	120	2.2	78
	Sample 4	260	1.1	96
	Sample 5	>500	0.75	78
	Removed	-25%	96%	29%
Second run	**Sample 1**	360	21	110
	Sample 2	250	1.8	99
	Sample 3	330	4	100
	Sample 4	250	207	100
	Sample 5	>500	1.5	94
	Removed	-39%	93%	15%
Third run	**Sample 1**	340	19	98
	Sample 2	210	1.9	99
	Sample 3	2400	4.9	100
	Sample 4	230	2	96
	Sample 5	>500	1.1	91
	Removed	-47%	94%	7%

The environmental decree requires removing at least 80% of BOD_7, 70% of total phosphorous and 30% of nitrogen (Finnish Ministry of the Environment 2007, 1). As shown in Table 5, the amount of phosphorous was successfully decreased, but the amount of nitrogen did not achieve the requirements. Based on the data, for phosphorous, the reactions were mainly happened in the primary treatment system. The primary treatment worked perfectly where the phosphorous was removed by more than 90%. But for nitrogen, the first run got the best result, where nitrogen was removed by 29%. There were some possible reasons to explain this result. First of all, during the first run, the liquid stayed in the secondary treatment system longer period than the last two runs, because the last two runs were finished in one day and the time was rush. In this case, methanol has enough time to react with NH_3 in the first run. Moreover, the secondary treatment tanks were not cleaned well enough after each run, so the amount of nitrogen in the second and third runs had only removed by 15% and 7%. Besides, the model system did not present the sand filter system, which could filter small solid particles away. On the other hand, the amount of BOD_7 was increasing according to Table 5. The data shows that BOD_7 amount was decreased well in the first treatment, but increased after secondary treatment. This result is because of that methanol reacts with the wastewater sample and forms more oxygen. In this case, in order to fix this problem, in the secondary treatment tanks, after adding methanol, there can be some ferric salt added in, which can remove the formed extra oxygen. Another option is that instead of using methanol, hypochlorous acid or other chemicals can be used to continue remove the nitrogen in the liquid. The original results of model runs are shown in Appendix 2.

5 CONCLUSIONS AND DISCUSSION

Domestic wastewater treatment is always important for a city, and the government decree proves that it is necessary to control the discharge of domestic wastewater outside sewer networks. This thesis follows the requirements of environmental decree to create a wastewater treatment system for family houses in Kokkola. The present methods are flocculation, sedimentation and chemical treatment. Besides, there are also other methods can be applied into the designed wastewater treatment system. As was shown in the simulation part and the practical experiences in wastewater treatment plants, the methods are proved effective for wastewater treatment purposes. The designed treatment system is presented by building a model, which can explain part of practical system. The design is easy to assemble in the real wastewater tank and the materials and methods of the system are cheap and easy to achieve. However, because of the limitations of time and chemicals, the present methods in the model treatment system was failed to remove enough nitrogen and BOD_7, the design for practical treatment system has enough space to apply more methods.

Compared the model system with practical system, the practical system has larger wastewater tank, which is represented as the primary treatment pipe in the model. Based on the data from Mr. K’s summer cottage, the wastewater tank is 3.14 cubic metres and can hold about 2500 litres domestic wastewater. Also, the daily load for per person in Kokkola is 120 litres. Also, on the average, there are 3 to 4 people living in one family house. By calculation, the daily load of wastewater for one family house is 360 to 480 litres, and the wastewater tank can hold the wastewater for 5 to 7 days. During this period, the chosen methods can work better in the practical system than in the model system. Moreover, other biological methods, such as yeast and anaerobic biological treatment can also be used in the practical system. In addition, the solution form of chemicals is not convenient for adding into the practical system. In order to solve this problem, the chemicals can be hold in a package which allows wastewater go through, and the chemicals can dissolve in the wastewater by themselves, so the residents can lift the package up and add the chemicals time after time.

In conclusion, the aim of this thesis, which is building a simple, cheap and effective domestic wastewater treatment system model, has basically reached. But for practical system, there are still many questions need to be solved. For instance, if the design is used in practice, how to adjust the flow rates, chemical kinds, chemical amounts and biological treatments to get the best results? This question still needs to be solved.

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Jätevesien käsittelyvaatimukset Kokkolassa. The local situation of Kokkola city shows below, graph is getting from Kokkla city hall.

Continuing graph shows blow.

The analyzed results for model run show below, the analysis is done by the Maintpartner Laboratory.

MAINTPARTNER OY
LABORATORY AND
ENVIRONMENT SERVICES

Examination report 2012-1230
WATER EXAMINATION

1(1)
03.05.2012

FINAS
Finnish Accreditation Service
T085 (EN ISO/IEC 17025)

Xiao Yao

Kokkola

Payer
Kokkolan ympäristöpalvelut

PL 43
67101 Kokkola

Sample data

Product	Waste water		
Sample taken	10.04.2012	Sample taken by	The client
Brought to laboratory	10.04.2012	Reason for analysis	Masters thesis
Examination commenced	10.04.2012		
Examination concluded	03.05.2012		

Small waste water treatment plant/Xiao/Hagström

Analysis / Unit / Method / Epävarm	BOD7 SFS-EN 1899-1:98 ±15%	Phosphorus, total mg/l Int.met.K29 ±10%	Nitrogen mg/l SFS 5508:88 mod. ±9%
Sample	*	*	*
1230-1, Waste water, 0 Raw	440	21	110
1230-2, Waste water, 1st treatment 45 min.	280	2,0	110
1230-3, Waste water, 2nd treatment 45min.	120	2,2	78
1230-4, Waste water 1st treatment 1h 30min.	260	1,1	96
1230-5, Waste water, 2nd treatment 1h 30min.	>500	0,75	78

*=Accredited.

Contact person Hanna Kauppila

Kirsi Vedenpää

Kirsi Vedenpää
Microbiologist

To be informed yao.xiao@cou.fi

The results of the analysis refer only to the samples analysed.
The examination report must only be copied in its entirety. Otherwise, written permission must be obtained.
Maintpartner Oy, Laboratory and Environment Services, Kemirantie 1, 67900 Kokkola, Finland.

Continuing analyzed results from the Maintpartner Laboratory shows below.

MAINTPARTNER OY
LABORATORY AND
ENVIRONMENT SERVICES

Examination report 2012-1245
WATER EXAMINATION

1(1)
16.05.2012

FINAS
Finnish Accreditation Service
T085 (EN ISO/IEC 17025)

Xiao Yao

Kokkola

Payer
Kokkolan ympäristöpalvelut

PL 43
67101 Kokkola

Sample data

Product	Waste water		
Sample taken	11.04.2012	Sample taken by	The client
Brought to laboratory	11.04.2012	Reason for analysis	Masters thesis
Examination commenced	11.04.2012		
Examination concluded	16.05.2012		

Analysis / Unit / Method / Epävarm	BOD7	Phosphorus, kok.	Nitrogen
Unit		mg/l	mg/l
Method	SFS-EN 1899-1:98	Int.met.K29	SFS 5508:88 mod.
Epävarm	±15%	±10%	±9%
Sample	*	*	*
1245-1, Waste water, 6, Raw	360	21	110
1245-2, Waste water, 7, 1st treatment 45 min.	250	1,8	99
1245-3, Waste water, 8, 2nd treatment 45min.	330	4,0	100
1245-4, Waste water, 9, 1st treatment 2h 30min.	250	2,7	100
1245-5, Waste water, 10, 2nd treatment 2h 30min.	840	1,5	94
1245-6, Waste water, 11, Raw	340	19	98
1245-7, Waste water, 12, 1st treatment 45 min.	210	1,9	99
1245-8, Waste water, 13, 2nd treatment 45min.	2 400	4,9	100
1245-9, Waste water, 14, 1st treatment 2h 30min.	230	2,0	96
1245-10, Waste water, 15, 2nd treatment 2h 30min.	1 500	1,1	91

*=Accredited.

Contact person Hanna Kauppila

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Microbiologist

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