WILLOW STACK TOWER IN LEACHATE TREATMENT

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TIIVISTELMÄ

Tämän työn tarkoituksena oli arvioida pajukerpputornin tehokkuus valumavesien käsittelyssä osana valumavesien käsittelyjärjestelmää. Tämä opinnäytetyö tehtiin Tampereen ammattikorkeakoululle osana PAJUKÄSITTELY - pajukerpputorni erilaisten jätevesien käsittelyssä projektia. Kaksi tapausta tutkittiin tässä osassa projektista; ensimmäinen oli suljettu kaatopaikka Vaasan kaupungissa, Suvilahdessa, ja toinen oli Aukeasuon lietteenkäsittelykenttä Pälkäneen kunnassa Ruokolan kylässä. Pajukerpputornin tehokkuus määriteltiin tarkkailemalla valumaveden fysikaalisia, kemiallisia ja biologisia tekijöitä ennen ja jälkeen pajukäsittelyn. Tämä tehtiin näytteiden otolla ja kenttä sekä laboratorio mittausten suorittamisella. Tekijät kuten pajun aktiivinen pinta-ala, lämpötila, haihtumissuhde, tuulen nopeus ja suhteellinen ilmankosteus otettiin myös huomioon, jotta niiden vaikutuksia tornin toimintaan voitaisiin tarkkailla. Pajukerpputorni käsittely oli menestyksellinen ravinteiden, taudinaiheuttajien ja kiintoaineiden poistamisessa sekä biokemiallisen hapenkulutuksen ja kemiallisen hapenkulutuksen vähentämisessä. Tämän tutkimuksen tulokset edustavat vain pajukerpputornia käsittelyjärjestelmässä, ja että Suvilahden kaatopaikalla sekä Aukeasuon lietteenkäsittelykentällä valumavedet jatkokäsiteltiin pajukerpputornin jälkeen ennen vesistöön päästöä. Tapauksien tulokset käsiteltiin erillään toisistaan.

Avainsanat; Valumavesien käsittely, kaatopaikka, paju, ravinteet, fosfaatti fosfori, kokonaisfosfori, Kok. P, nitraatti, nitriitti, kokonaistyppi, kiintoaine, suolistoperäiset enterokokit, koliformiset bakteerit, biokemiallinen hapenkulutus, BHK_7, kemiallinen hapenkulutus, raskasmetallit, atomiabsorptio spektrometri.

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ABSTRACT

The aim of this work was to evaluate the efficiency of the willow stack tower as a component of leachate treatment system. This final thesis was done for the Tampere University of Applied Sciences as a part of the PAJUKÄSITTELY- willow stack tower in various wastewater treatments project. Two cases were studied in this part of the project; the first one was the closed landfill in Vaasa City, in Suvilahti and the second one the sludge treatment field of Aukeasuo, in Pälkäne region, in Ruokola village. The efficiency of the willow stack tower was determined by monitoring the physical, chemical and biological parameters of the leachate before and after the willow treatment. This was done by taking leachate samples and conducting field and laboratory analyses. Factors such as the active surface area of the willow, temperature, the evaporation ratio, wind speed and relative humidity were also taken into consideration in order to observe their effects on the functioning of the tower. The willow stack tower treatment was successful in removal of nutrients, pathogens, suspended solids and in reduction of biochemical and chemical oxygen demand. The results of this study represent only the willow stack tower in the treatment system and that in both landfill of Suvilahti and sludge treatment field of Aukeasuo, leachate was processed further before being released into the water bodies. The results of the cases were handled separately.

Keywords; Leachate treatment, landfill, willow, nutrients, phosphate phosphorus, total phosphorus, TP, nitrate, nitrite, total nitrogen, TN,total suspended solids, TSS, Fecal *Streptococci*, *Coliforms*, biochemical oxygen demand, $BOD_{7\ ATU}$,chemical oxygen demand, COD_{Cr}, heavy metals, atomic absorption spectrometry, AAS.

ABBREVIATIONS USED IN THIS FINAL THESIS

AAS	Atomic absorption spectrometry (Atomiabsorptio-spektrometria)
dB	Colour: dark brown (Väri: tummanruskea)
B1	Odor: dirt (Tuoksu: multa)
B3	Odor: natural- unpleasant (Tuoksu: luonnollinen-epämiellyttävä)
$BOD_{7\ ATU}$	Biochemical oxygen demand with allyl-2-thiourea to prevent oxidation of ammonium (Biologinen hapenkulutus jossa käytetään allyylitiourealisäystä ($C_4H_8N_2S$), joka estää ammoniumin hapettumisesta johtuvan hapen kulumisen)
BY	Colour: brownish yellow (Väri: ruskehtavan keltainen)
C5	Odor: rotten- foul (Tuoksu: mädäntynyt- inhottava)
Circumference	Distance around a closed curve (Kehä, ympärysmitta)
COD_{Cr}	Chemical oxygen demand with dichromate ion which is usually specified oxidant in majority of cases (Kemiallinen hapenkulutus, dikromaatti ioni hapettajana)
Correlation	Statistical relationships involving dependence (Riippuvuussuhde)
D1	Odor: soil (Tuoksu: maa)
D14	Odor: sulphide sulphur (SO_4^-S) (Tuoksu: sulfidirikki)
Drizzle	Light rain (Tihkusade)
E	East (Itä)
Effluent	Out flow
ELVs	Emission limit values (Päästörajat)
hG	Colour: hint of green (Väri: hienoisen vihertävä)
Inc.	Increased (only used in the conclusions and discussion section)
Influent	In flow
Ltd	Limited-liability Company (Osakeyhtiö)
lY	Colour: light yellow (Väri: haalea keltainen)
N	North (Pohjoinen)
NE	North East (Koillinen)
NW	North West (Luode)
pmy/ 100 ml	Colony forming units/ 100 ml, same as piece/ 100 ml (Pesäkkeen muodostavia yksiköitä/ 100 ml, sama kuin kpl/ 100 ml)
S	South (Etelä)
SE	South East (Kaakko)
SW	South West (Lounas)
TKN	Total Kjeldahl nitrogen, sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+). TKN includes protein nitrogen as well as nonprotein nitrogen (Kjeldahl-typpi, orgaanisen typen, ammoniakin ja ammoniumin summa)
TN	Total nitrogen, sum of dissolved inorganic (nitrites, nitrates and ammonia) and organic nitrogen (Kokonaistyppi, liuenneen epäorgaanisen (nitriitti, nitraatti ja ammoniakki) ja orgaanisen typen summa)
TP	Total phosphorus, sum of $(PO4)^{-3}$ and acid-hydrolysable phosphate (Kokonaisfosfori, fosfaattifosforin ja happo hydralisoituvan fosforin summa)
UHP	Ultra high purified water

W	West (Itä)

Sample code

E	Effluent (Lähtövesi)
I	Influent (Sisäänvirtaus)

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1 INTRODUCTION

Finnish legislation requires treatment of leachate from all dischargers considered to be hazardous for the environment, by setting emission limit values (ELVs) with regulations such as government decision on landfills 861/1997 and Government Decree on Substances Dangerous and Harmful to the Aquatic Environment 1022/2006. Facilities which are not part of the public wastewater treatment network are given the ELVs in the environmental permits which are specifically tailored regarding to the type of activity. For landfills emission limit values are mostly based on the characteristics of the waste and the location of the landfill. The environmental permits are licensed by environmental administration. (Government decision on landfills 861/1997; Government Decree on Urban Waste Water Treatment 888/2006; Government Decree on Substances Dangerous and Harmful to the Aquatic Environment 1022/2006)

The sampling and measurements presented here were made during the practical training, which took place from May 2010 to February 2011 in the PAJUKÄSITTELY, a research and development project of Tampere University of Applied Sciences. The aim of the project was to determine the efficiency of the willow stack tower in the treatment of leachate. Two different cases were studied, the closed landfill of Suvilahti in Vaasa municipality and the sludge treatment field of Aukeasuo owned by Humuspehtoori Ltd in the village of Ruokola in Pälkäne region. In both cases samples were taken from influent and effluent of the willow stack treatment. Since the function of the treatment systems of the two towers in Vaasa and Pälkäne differed from each other significantly, no comparison was done between them in this study. The most significant difference between the towers were that in Vaasa the cycling of leachate was controlled with flow rate while in Pälkäne leachate was treated according to duration of the treatment. Also very important factor was that in Pälkäne the tower could be isolated from the other treatment units but in Vaasa the tower was directly connected with underground pipes which could not be closed during the test runs. In the closed landfill of Suvilahti two different test runs based on the flow rate of leachate (10 l/s and 5 l/s) were conducted with two replicas while in Pälkäne it was three test runs based on the duration of the treatment (6, 16 and 22 hours) with three replicas for each test run. In order to monitor the influence of the willow tower in leachate treatment, a series of physical, chemical

and biological parameters were selected to be analysed such as pH, oxygen, total suspended solids, biochemical oxygen demand, chemical oxygen demand, nutrients, heavy metals, *Coliforms* and Fecal *Streptococci*. Other parameters susceptible to affect the functioning of the willow stack tower were taken into consideration and recorded such as air temperature, wind speed and direction, relative humidity, rainfall and evaporation. The samples were divided into four categories for both Vaasa and Pälkäne regarding to the parameter to be analysed, the available material and location; pH and temperature were measured onsite during sampling, samples to be used for determining phosphate phosphorus, nitrite, nitrate, oxygen and total suspended solids were taken to the laboratory to be filtered and then analysed immediately, samples to be used for *Coliforms*, Fecal *Streptococci*, biochemical and chemical oxygen demand analyses were given to commercial laboratories, and samples for total nitrogen, total phosphorus and heavy metals were preserved and analysed later on in the laboratories of Tampere University of Applied Sciences.

The willow stack towers of Vaasa and Pälkäne consisted of a wooden frame with three floors filled with willow stacks and of a pool located underneath the willow stack tower. In regular use leachate was pumped from the storage pond to the top of the tower and it went through once in the case of Vaasa before continuing into the sedimentation pool from where it was mostly directed back to the storage pond and a part was pumped to the gravel and sand filter from where it continued to the wetlands and finally to the water body. In regular use during summer 2009 in Pälkäne, leachate was treated in the tower until it was satisfactory in reduction of unwanted substances and was then transferred to the septic tanks for sedimentation from where it continued to the soil filtration and finally to the water bodies. (Pajukerpputorni kaatopaikkavesien käsittelyssä, 24-25 & 31-33)

The landfill of Suvilahti in Vaasa was in use from 1966 to 1999. The willow stack tower has been used in Suvilahti since 2001. Previous studies done by the environmental laboratory of Vaasa City (Vaasan kaupungin ympäristölaboratorio) on the closed landfill of Suvilahti have confirmed that as a whole, the treatment system in use including the willow stack tower, sedimentation pool, gravel and sand filtration and the wetland is efficient, but no research has been conducted on the willow stack tower as a

separate unit. (Pajukerpputorni kaatopaikkavesien käsittelyssä, 24; Suvilahden lakkautettu kaatopaikka. Vedenlaadun tarkkailu vuonna 2009)

FIGURE 1. Willow stack tower in Vaasa

Humuspehtoori Ltd was established in 1984, and is specialized in composing organic fertilizers and soil conditioners by mixing animal manure and side products from forestry, wood and paper industry. (Pajukerpputorni kaatopaikkavesien käsittelyssä, 31; Humuspehtoori Ltd, http://www.humuspehtoori.fi/)

FIGURE 2. Willow stack tower in Pälkäne

2 METHODS

2.1 Experiment design and sampling of leachate

The sampling of leachate was done according to the international standard ISO 5667-3:2003. In both case studies the sampling of influent and effluent was done according to a sampling plan given on 18th of June 2010, in which were taken into consideration various factors such as the suitable sampling points, available means and safety measures, the availability of collaborating staff and managers of the sites concerning the field work, the co-operation with the environmental laboratory of Vaasa City (Vaasan kaupungin ympäristölaboratorio), and the Water Protection Association of The River Kokemäenjoki (Kokemäenjoen vesistön vesiensuojeluyhdistys ry, KVVY) in Tampere.

2.1.1 Vaasa, Suvilahti: Closed landfill (City of Vaasa)

The sampling method in Suvilahti landfill was designed according to leachate treatment system in use (Figure 3).

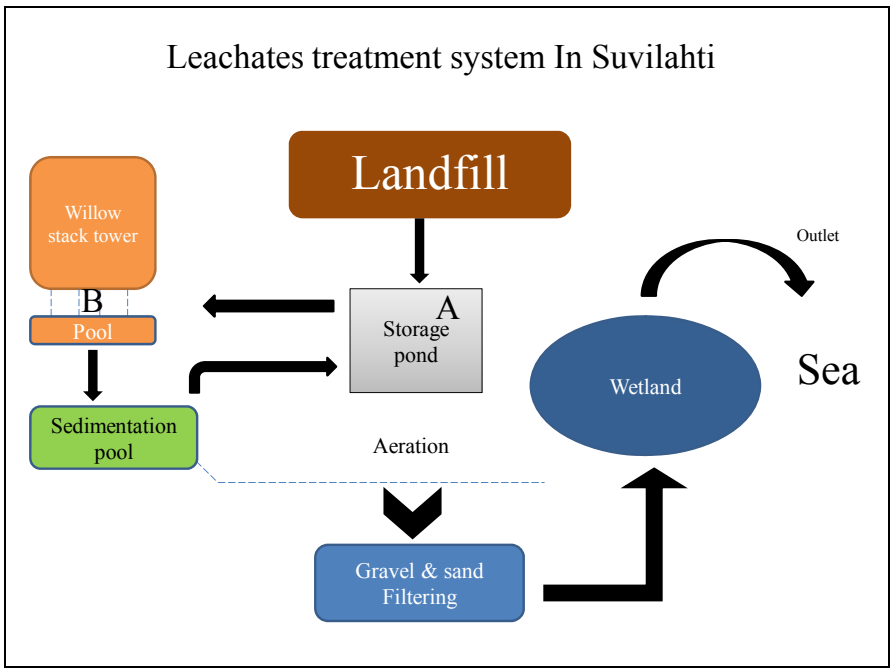

FIGURE 3. Layout of the leachate treatment system in the landfill of Suvilahti

The system consisted of recovering leachate from underneath the landfill by a set of wells which gathered the leaching water, and by the mean of water pumps was pumped back to the surface through pipes and discharged into the storage pond, from which the water was pumped to the top of the willow tower. From the willow tower leachate streamed through the willow stacks at a flow rate of 10 l/s, then transferred to the sedimentation pool from where most of it was directed back to the storage pond and a part was collected in a well in order to be passed later through the gravel and sand filtration and finally was taken through a pipe to the wetlands where it was gradually mixed with sea water.

The locations of sampling points of influent and effluent are presented in the figure 3 as A being influent and B effluent. The flow rate was changed from original 10 l/s to a slower flow rate of 5 l/s in order to observe the effects of the flow rate on the treatment efficiency. Two test run replicas were taken from each one of the used flow rates, at a time interval of 12h or 24h between. The following table 1 simplifies the parameters taken into consideration for the sampling.

TABLE 1. Sampling parameters in Vaasa

Flow rate	Time between replicas	Samples taken	Number of Replicas
10 l/s	12h	Inf. & eff.	2
5 l/s	24h	Inf. & eff.	2

2.1.2 Pälkäne, Ruokola: Sludge treatment field of Aukeasuo (Humuspehtoori Ltd)

For the Pälkäne case study, similar sampling procedure and material was used as in Vaasa, however leachate treatment system in use is different due to the origin and consistence of leachate.

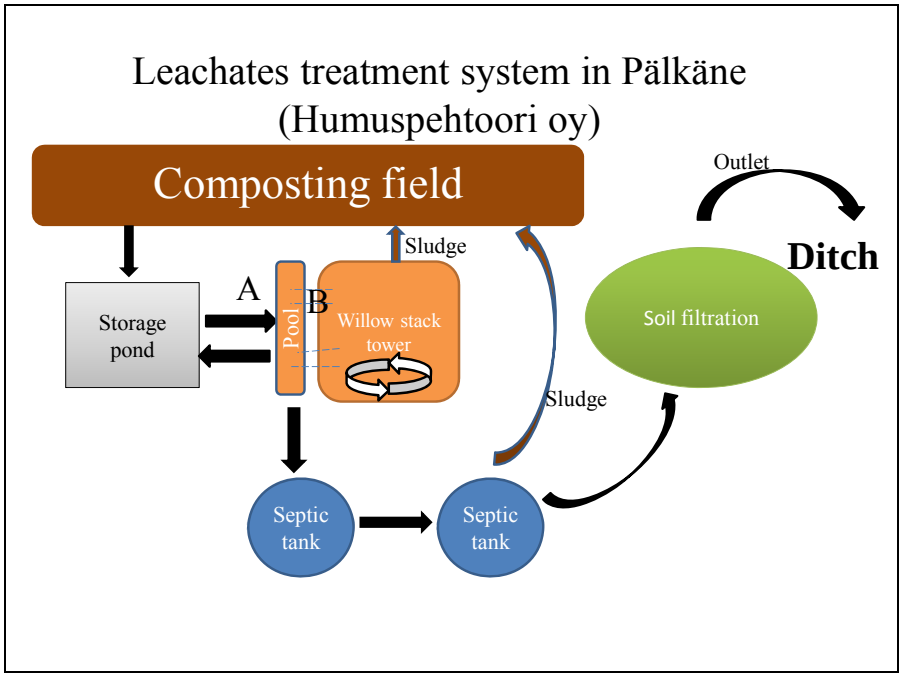

FIGURE 4. Layout of the leachate treatment system in sludge treatment field of Aukeasuo

The sampling method was designed around the treatment time of leachate in the willow stack tower as a comparison parameter. The duration of leachate cycling in the tower was set to three different test runs - 6, 16 and 22 hours. The influent samples were taken from the inlet of the willow tower at the beginning of each test run; Location A (figure 4). The effluent samples were collected from underneath the willow tower in point B.

TABLE 2. Sampling parameters in Pälkäne

Leachate cycling time in willow stack tower (h)	Samples taken	Replicas
6	Inf./ eff.	3
16	Inf./ eff.	3
22	Inf./ eff.	3

2.2 Material

During the sampling the following equipments were used:

- Protective clothing
- A telescopic rod with a sampler attached at the end
- Containers
- labelled plastic bottles
- Cool boxes and ice packs

FIGURE 5. Sampling method of effluent

2.3 Pre-treatment and preservation of the samples

After each sampling the samples were bottled, marked and transported to the laboratory immediately in a cool box. In the laboratory the samples were filtered with a vacuum

flask, preserved according to the international standard ISO 5667-3:2003 and put in the refrigerator until further analyses. The table 3 shows the type of preservatives used according to the type of analyse.

TABLE 3. Type of preservative used

Parameter to be analysed:	Type and volume of preservative:
Total nitrogen	10 ml/l of concentrated H_2SO_4, 4M
Total phosphorus:	10 ml/l of concentrated H_2SO_4, 4M
Heavy metals	10 ml/l of concentrated HNO_3, 5M

2.4 Analysing methods

The analyses were divided into four categories for both case studies regarding to the timing, the available material and location; Field measurements done together with sampling, commercial laboratory analyses done immediately after sampling, laboratory analyses done immediately after sampling and laboratory analyses done later with preserved samples. pH and samples temperature were measured during sampling. Phosphate phosphorus, nitrite, nitrate, oxygen and total suspended solids were done in the immediate laboratory analyses. $BOD_{7\ ATU}$, COD_{Cr}, Fecal *Streptococci* and *Coliforms* were done by the commercial laboratories. Total nitrogen, total phosphorus and heavy metals (cadmium, chromium, lead, iron, nickel, copper and zinc) were done from the preserved samples.

2.4.1 Field measurements done together with sampling

Temperature and pH

The sample temperature and pH were measured onsite immediately after collecting the samples (influent and effluent) with model Q150 handheld pH/mV/Temperature meter manufactured by IQ Scientific Instruments, Inc.

FIGURE 6. model Q150 handheld pH/mV/Temperature meter manufactured by IQ Scientific Instruments, Inc

2.4.2 Laboratory analyses done from unpreserved samples

Appearance and odor

Before filtering the samples and adding the preservatives the odor and the colour were estimated by observing the samples with senses and using the Odor Circle (appendix 1) provided by the environmental laboratory of Vaasa City as a guide.

Determination of the total suspended solids (TSS)

Determination of the total suspended solids (TSS) was done with filtration through glass microfiber filters according to Finnish standard SFS-EN 872.

Material

- Whatman's glass microfiber filter grade GF/A, circles 110mm
- Glass beaker 1000 ml
- Three glass dishes
- Tweezers
- Vacuum flask 1000 ml and vacuum tubing
- Graduate cylinder 50 ml
- Glass filter holder (funnel) with rubber adapter
- Drying oven for operation at 105 °C
- Glass desiccators
- Analytical scale
- Distilled water
- Leachate sample

Procedure of TSS

The glass microfiber filter GF/A was dried in the oven in order to minimize errors generated by humidity, then weighed before vacuum filtering 50 ml of the sample and dried it in the oven at 105°C for 2 hours, and then weighed again after cooling in the desiccators. The results in mg/l were calculated according to the following equation:

$$TSS = \frac{(a-b)}{c} \quad (1)$$

Where

a= the mass of the filter after the filtration (mg)

b= the mass of the filter before filtration (mg)

c= sample volume, (l)

Determination of the nitrate (NO_3)

In order to determine the Nitrate content of leachate samples the DR 2800 Spectrophotometer (HACH) manufactured by Hach company was used with Cadmium Reduction Method MR (0,1 to 10,0 mg/l NO_3^-), a method used for monitoring water, wastewater and seawater described in the HACH manual. (HACH manual)

Material

- DR 2800 Spectrophotometer (HACH)
- Two sample cells of 10 ml
- Dustless paper
- Stopper
- Distilled water
- NitraVer5 reagent powder pillow
- Beakers
- Automatic pipette
- Filtered leachate sample

Procedure

The procedure is available in the HACH manual provided by Hach Company but main steps can be summarized as follows:

- The test 353 N, Nitrate MR PP was selected from the STORED PROGRAMS list by pressing on the digital keys displayed on the HACH interface
- Two sample cells were filled with 10 ml of leachate sample each
- One cell was used as a blank for zeroing the machine (HACH), and in the other content of a NitraVer5 reagent powder pillow was added and a stopper was inserted

- From the TIMER option a one minute time period was selected, then the sample cell containing the reagent was shaked vigorously during that time period, and left to rest for a five minutes reaction time during which an amber colour was developed when Nitrate was present
- When the timer expired after the 5 min reaction time, the blank was inserted into the cell holder and by pressing the ZERO key, the display showed: 0,0 mg/l NO_3^-N which marked the end of the zeroing step
- Within two minutes after the 5 minutes reaction time the blank sample was removed from the cell holder and replaced by the reagent containing cell, and after pressing on the READ key the results were shown in mg/l NO_3^-N.

Note: In some cases the samples had to be diluted to meet the concentration range of the selected method. (HACH user's manual)

Determination of the nitrite (NO_2)

The Nitrite content of leachate samples was determined by using the DR 2800 Spectrophotometer (HACH) with Diazotization Method LR (0,002 to 0,300 mg/l NO_2^-N) a method used for monitoring water, wastewater and seawater, USEPA approved for wastewater analysis under federal register ,44(85), 25505 (May 1, 1979), described in the HACH manual.

Material

- DR 2800 Spectrophotometer (HACH)
- Two sample cells of 10 ml
- Dustless paper
- Stopper
- Distilled water
- NitriVer3 reagent powder pillow
- Beakers
- Automatic pipette
- Filtered leachate sample

Procedure

The procedure is available in the HACH manual provided by Hach Company but main steps can be summarized as follows:

- The test 371 N. Nitrite LR PP was selected from the STORED PROGRAMS list by pressing on the digital keys displayed on the HACH interface
- Two sample cells were filled with 10 ml of leachate sample each
- One cell was used as a blank for zeroing the machine (HACH), and in the other the content of a NitriVer3 powder pillow was added and a stopper was inserted to the cell
- The sample was swirled in order to dissolve the reagent
- From the TIMER option a twenty minutes time period was selected, and the sample was left to rest for a twenty minutes time reaction during which a pink colour developed when Nitrite was present
- When the timer expired after the twenty minutes reaction period, the blank was inserted into the cell holder and by pressing the ZERO key, the display showed: 0,0 mg/l NO_2^-N which marked the end of the zeroing step
- Within two minutes after the twenty minutes reaction period, the blank sample was removed from the cell holder and replaced by the reagent containing cell, and after pressing on the READ key the results were shown in mg/l NO_2^-N

Note: In some cases the samples had to be diluted in order to meet the concentration range of the selected method. (HACH user's manual)

Determination of the phosphate phosphorus, reactive (Orthophosphate, PO_4^-P)

The Phosphorus content of leachate samples was determined by using the DR 2800 Spectrophotometer (HACH) with PhosVer 3 (Ascorbic Acid) Method (0,02 to2,50 mg/l PO_4^{3-}) as described in the HACH manual.

Material

- DR 2800 Spectrophotometer (HACH)
- Two sample cells of 10 ml

- Dustless paper
- Stopper
- Distilled water
- PhosVer3 reagent powder pillow
- Beakers
- Automatic pipette
- Filtered leachate sample

Procedure

The procedure is available in the HACH manual provided by Hach Company and can be summarized as follows:

- The test 490 P React.PV was selected from the STORED PROGRAMS list by pressing on the digital keys displayed on the HACH interface
- Two sample cells were filled with 10 ml of leachate sample each
- One cell was used as a blank for zeroing the machine (HACH), and in the other the content of a PhosVer3 reagent powder pillow was added and a stopper was inserted to the cell
- The sample was shaken vigorously for thirty seconds
- From the TIMER option a two minutes time period was selected, during which the reaction took place
- When the timer expired after the two minutes reaction period, the blank was inserted into the cell holder and by pressing the ZERO key, the display showed: 0,0 mg/l PO_4^{3-} which marked the end of the zeroing step
- The blank sample was removed from the cell holder and replaced by the reagent containing cell, and after pressing on the Read key the results were shown in mg/l PO_4^{3-}

Note: In some cases the samples had to be diluted in order to meet the concentration range of the selected method. (HACH user's manual)

Determination of the dissolved oxygen content (O_2)

The dissolved oxygen content was determined by using the YSI Pro ODO™ Handheld Optical DO Meter manufactured by YSI Incorporated, and was measured according to the device manufacturer's instructions.

FIGURE 7. YSI Pro ODO™ Handheld Optical DO Meter manufactured by YSI Incorporated

2.4.3 Laboratory analyses with preserved samples

Determination of the total nitrogen with modified Kjeldahl method (TN)

Total Kjeldahl nitrogen contains organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+), total nitrogen contains both organic and inorganic nitrogen. The inorganic nitrogen is a combination of nitrate, nitrite and ammonium. In ELVs TN is more commonly used.

Total nitrogen was determined by using the modified Kjeldahl method **Range** [1-30]mg/l according to the Finnish standard SFS 5505, the method consisted of reducing the Nitrite and Nitrate with devarda alloy, and digesting organic matter with sulphuric acid in presence of copper catalyst which will form Ammonium sulphate from which Ammonia is released by adding NaOH and then distilled in boric acid solution containing indicator, and finally determining the Ammonium from the distilled sample by titrating it with sulphuric acid (H_2SO_4).

Material

- Digest system K-437 manufactured by Büchi
- A scrubber
- Tubing
- Distillation unit K-314 manufactured by Büchi
- Metrohm 775 Dosimat Automatic Burette for Titrator manufactured by Metrohm AG
- UHP water
- Concentrated H_2SO_4 (density 1,84g/ml)
- Kjeldahl tablets
- NaOH solution
- Boric acid solution (0,3mol/l)
- Share indicator
- H_2SO_4 (0,005mol/l)
- Glycine 5,362g/l
- Filtered leachate sample

Procedure:

Wet digestion

- 50ml of filtrate sample were put into the digestion tubes
- 2ml of concentrated H_2SO_4 98% and 2 Kjeldahl tablets were added into each tube

- Blank samples containing 50ml of UHP were treated as regular samples for rest of the procedure
- Büchi scrubber B-414 was put on
- The Wet digestion machine was put on and the samples heated up to 370°C
- The machine was operating until one hour

FIGURE 8. Digest system K-437 manufactured by Büchi

Distillation

- After digestion the samples were left to cool down
- The tubes were put onto the distiller holder one by one and 2ml of UHP were added to them
- For distillation of each tube an Erlenmeyer was put in the other end as a receiver containing 20 ml of boric acid and a share indicator
- 20ml of NaOH solution was added to the sample
- After 4 minutes of distillation the receivers were taken from the distillation unit

FIGURE 9. Distillation unit K-314 manufactured by Büchi

Titration

After taking them from the distillation unit the distilled samples were titrated one by one with diluted H_2SO_4 by using Metrohm 775 Dosimat titrator. The equivalent point was identified when the colour turned from blue to grey-brown or the pH changed to 4,56.

FIGURE 10. Metrohm 775 Dosimat Automatic Burette for Titrator manufactured by Metrohm AG

Calculating the results

The results were calculated by using the following formula:

$$X = V_3 - V_4 * c * 14 * 2 * 1000 * V \quad (2)$$

Where:

X= Nitrogen content of the sample (mg/l)

V_3= The volume of 0,005M H_2SO_4 used in sample titration (ml)

V_4= The Volume of H_2SO_4 used for titration of blank sample (ml)

c= The concentration of H_2SO_4 (mol/l)

14= The molar mass of Nitrogen (g/mol)

1000= The multiplication factor (mg/g)

2= The multiplication factor of the H_2SO_4 acid (N=2)

V= The sample volume digested (ml)

Determination of the total phosphorus (TP)

Total phosphorus was determined by using the Acid Persulfate Digestion Method with the ascorbic acid (Phosver3) method according to the Standard Methods for the examination of water and wastewater 4500-P B & E, which consists of first converting the phosphate present in the sample as organic and condensed inorganic forms to reactive orthophosphate by the digestion of the samples, then determining the phosphorus content of the samples by using the reactive phosphorus (orthophosphate) analysis method.

Material:

In addition to the material described in the section of phosphate phosphorus, the following items were collected:

- Hot plate
- Graduated cylinder (25 ml)
- Erlenmeyer flasks (125 ml)
- UHP water
- Potassium persulphate powder pillows
- Sodium hydroxide solution (5,0N)
- Sulphuric acid solution (5,25N)

Procedure

- The content of one potassium persulphate powder pillow was added to a 125 ml Erlenmeyer flask containing 25 ml of filtered leachate sample and swirled for few seconds
- 2 ml of 5,25 N sulphuric acid solution was added to the flask
- The mixture was heated for 30 mn under a hood while maintaining the volume with UHP water around 20ml in order to avoid boiling the sample dry
- After cooling the sample to the room temperature, 2ml of 5,0 N sodium hydroxide solution was added and the mixture swirled

- By mean of a graduated cylinder the volume was adjusted to 25ml with UHP water
- Total phosphorus was then determined by using PhosVer 3 (Ascorbic Acid) Method (0,02 to2,50 mg/l PO_4^{3-})

Determination of the heavy metals (Cd, Cr, Fe, Pb, Zn, Cu and Ni)

Determination of cadmium (Cd), chromium (Cr), iron (Fe) , lead (Pb), zinc (Zn), copper (Cu) and nickel (Ni) was done by using the atomic absorption spectroscopy method according to the Finnish standard SFS 3047 and SFS-EN 1233, with the SOLAAR AA Series Spectrometer (AAS) which was manufactured by Thermo Scientific. Air-acetylene mixture was used in the measurements. For each one of the analysed elements standard solutions were prepared from a 1000 mg/l stock solution of the corresponding metal after identifying its primary wavelength, flame type, atomizing temperature and measuring range. The necessary calibration solutions for determining the heavy metals were prepared according to the standard.
(Atomiabsorptio-spektometria)

FIGURE 11. SOLAAR M Series AA Spectrometer manufactured by Thermo Scientific

2.4.4 Commercial laboratory analyses

Biochemical oxygen demand ($BOD_{7\ ATU}$), chemical oxygen demand (COD_{Cr}), *Coliforms* and Fecal *Streptococci* were analysed by accredited commercial laboratories. Each sample was taken to the laboratory immediately after the sampling in a cool box in order to minimize possibility of errors due to improper preservation. The samples from The Suvilahti landfill of Vaasa were analysed by the environmental laboratory of Vaasa City (Vaasan kaupungin ympäristölaboratorio), and the ones from the sludge treatment field of Aukeasuo were analysed by the Water Protection Association of The River Kokemäenjoki (Kokemäenjoen vesistön vesiensuojeluyhdistys ry, KVVY) in Tampere. The table 4 shows the standards used by the accredited commercial laboratories.

TABLE 4. Used standards

Parameters	Vaasan kaupungin ympäristölaboratorio	Kokemäenjoen vesistön vesiensuojeluyhdistys ry
$BOD_{7\ ATU}$	SFS 1899-1/98	SFS 1899-1/98
COD_{Cr}	SFS 5504/88	ISO 15705, 2002 (TL25)
Coliforms	SFS 4088/2001	SFS 4088/2001
Fecal *Streptococci*	SFS 7899-2/2000	SFS EN ISO 7899-2, 2000 (TL 25)

2.5 The estimated active surface area of the willow stack towers

In order to estimate the active surface area of the willow stack tower the dimensions of the tower were measured and then the active surface area was calculated for one branch, and then for one floor given that there are three floors in the tower and finally for the whole tower. This was based in the measurements taken during the sampling stage of the research. In the towers the branches are in stacks but in the calculations the branches are presented as maximum surface the branches can cover from the floors because the diameter of the stacks varied and could not be measured.

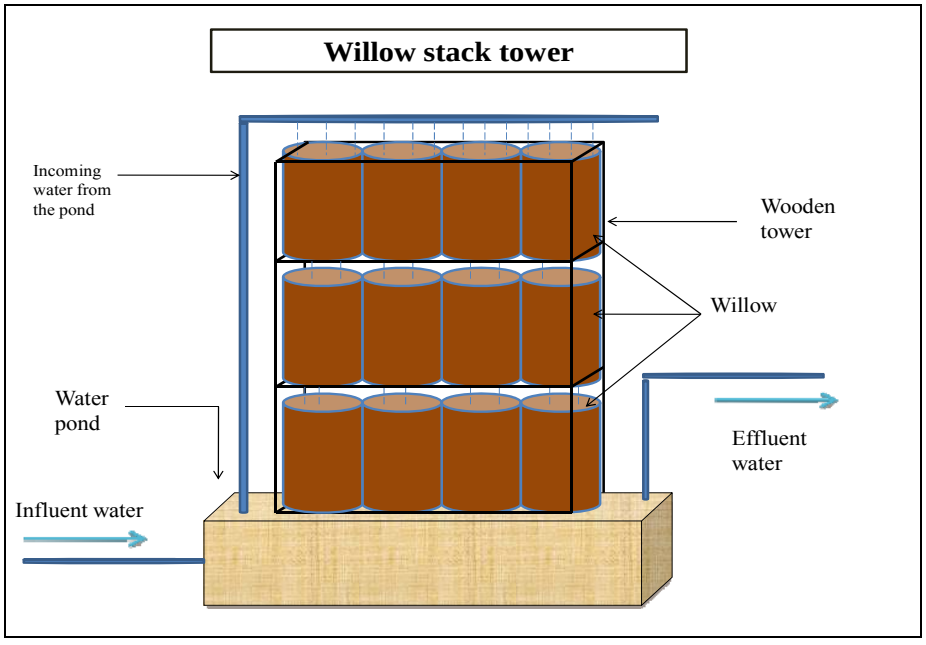

FIGURE 12. Structure of the willow stack tower

2.5.1 Vaasa, Suvilahti: Closed landfill

Since the dimensions of branches varied in both of the towers (Vaasa, Suvilahti landfill and sludge treatment field of Pälkäne) in the diameter from 1 cm to 6 cm and in length from 150 cm to 240 cm, in the calculations an approximate average of 3 cm for thickness was used. For length 170 cm for Pälkäne and 240 cm for Vaasa were used.

Estimated diameter of one Branch (d) = 3cm
Estimated height of the branch (h) = 240 cm
Length of the willow stack floor (L) = 1220 cm
Width of the willow stack floor (W) = 235 cm

FIGURE 13. Willow branches in a stack in Vaasa

2.5.2 Pälkäne, Ruokola: Sludge treatment field of Aukeasuo

Same procedure as in Vaasa was used in order to estimate the active surface area of the willow stack tower of Pälkäne.

Estimated diameter of one Branch (d) = 3 cm

Estimated height of the branch (h) = 170 cm

Length of the willow stack floor (L) = 544 cm

Width of the willow stack floor (W) = 131cm

Number of floors= 3

FIGURE 14. Willow branches in a stack in Pälkäne

2.6 Evaporation

The evaporation parameter was estimated by measuring the difference in water level during the test runs. Also when more leachate was added to the pool, the level and time were recorded. The difference in water level was calculated as volume by using the dimensions of the pool and the difference as depth. The calculations and formulas are presented in the results section.

3 RESULTS

Leachates from Suvilahti landfill and sludge treatment field of Aukeasuo were both analysed with the same parameters, except that oxygen was only measured in Pälkäne. The results from Vaasa and Pälkäne are dealt with separately.

3.1 Vaasa, Suvilahti: Closed landfill

In the table 5 are shown the results and other variables which were recorded before and soon after sampling. Pump 1 transferred influent water from the storage pond to the willow stack tower and pump 2 transferred a small volume of treated water which came through willow stack tower and sedimentation pool, to the gravel and sand filters and wetlands. Most of the water after the sedimentation pool was channelled back to the storage pond and so forth back to the tower with untreated leachate from the landfill. The volumes in the table 5 present the amount of leachate which has gone through the willow stack tower, and how much has continued to the gravel and sand filter and the wetlands.

The influent samples were collected from the storage pond and effluent samples were collected from the dripping water under the willow stacks. The analyses of $BOD_{7\ ATU}$, COD_{Cr}, *Coliforms* and Fecal *Streptococci* were done by the environmental laboratory of the City of Vaasa (Vaasan kaupungin ympäristölaboratorio). The concentration of *Coliforms* in the first replica of 10 l/s test run are missing. The definitions for the markings used in the tables are found from the definitions list in the beginning of the final thesis and from below the tables.

TABLE 5. Results from Vaasa, Suvilahti samples

Vaasa Suvilahti landfill leachates									
	Sample parameters	10 l/s - 12h between test runs				5 l/s - 24h between test runs			
		Test run 1		Test run 2		Test run 1		Test run 2	
		Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
Field	Date of sampling	5.7.2010	5.7.2010	5.7.2010	5.7.2010	7.7.2010	7.7.2010	8.7.2010	8.7.2010
	Time	7:25	8:30	19:20	19:45	7:30	8:00	7:10	7:30
	Air temperature	20,5	20,5	21,5	21,5	16,8	16,8	12,7	12,7

	(°C)								
	Wind direction	S 185°	S 188°	S 214°	S 207°	N 13°	N 13°	E 99°	E 103°
	Wind speed (m/s)	5,7	4,9	8,2	6,5	2,1	2,2	0,7	0,9
	Cloudiness	Sunny	Sunny	Sunny	Sunny	Cloudy	Cloudy	S/C	S/C
	Rainfall	No							
	Relative humidity (RH %)	73	67	45	47	82	82	100	100
	Sample temperature (°C)	16,3	15,1	19	14,5	18,5	15,4	17,3	14
	pH ~	**7,5**	**7,9**	**7,7**	**8**	**7,9**	**8**	**7,8**	**7,9**
	Pump P1								
	Time	9:01		19:56		8:09		7:41	
	Volume (m^3)	254175		254581		255269		255718	
	Flow rate (l/s)	10,35		10,37		5,27		5,31	
	Pump P2								
	Time	9:02		19:57		8:09		7:41	
	Volume (m3)	42067		42083		42122		42148	
Lab	**Date of analysing**	6.7.2010	6.7.2010	6.7.2010	6.7.2010	7.7.2010	7.7.2010	8.7.2010	8.7.2010
	Appearance	lY/hG	lY	lY/hG	lY	lY/hG	lY	lY/hG	lY
	Odour	No							
	Phosphate phosphorus (PO_4^-P mg/l)								
	R1	0,31	0,41	0,22	0,62	0,27	0,22	0,21	0,73
	R2	0,43	0,58	0,27	0,53	0,22	0,32	0,17	0,42
	Average ~	**0,37**	**0,50**	**0,25**	**0,58**	**0,25**	**0,27**	**0,19**	**0,58**
	Nitrate (NO_3 mg/l)								
	R1	1,10	1,30	1,10	0,60	0,70	1,80	0,50	1,10
	R2	1,00	1,30	0,70	2,00	0,50	1,50	0,70	1,00
	Average ~	**1,05**	**1,30**	**0,90**	**1,30**	**0,60**	**1,65**	**0,60**	**1,05**
	Nitrite (NO_2 mg/l)								
	R1	2,50	8,20	6,10	6,10	8,50	8,30	6,20	9,70
	R2	5,10	6,50	5,90	6,40	6,50	8,40	6,40	4,30
	Average ~	**2,50**	**8,20**	**6,00**	**6,25**	**7,50**	**8,35**	**6,30**	**7,00**
Vaasa Lab	**$BOD_{7\ ATU}$ (mg/l)**	**26**	**29**	**25**	**29**	**27**	**23**	**31**	**20**
	COD_{Cr} (mg/l)	**290**	**280**	**290**	**290**	**300**	**290**	**300**	**300**
	***Coliforms* (pmy/100ml)**	-		**250**	**140**	**180**	**150**	**270**	**240**
	Fecal *Streptococci* (pmy/100ml)	**240**	**100**	**70**	**80**	**64**	**110**	**390**	**190**

Wind speed, wind direction (degrees) and relative humidity were given by Finnish Meteorological Institute (Vaasa, Klemettilä)

Sampling and analysing done on the following day due to the sampling timetable

3.1.1 Phosphate phosphorus, nitrate and nitrite (PO_4^-P, NO_3 and NO_2)

In the graph 15 are presented the 10 l/s flow rate and 5 l/s flow rate test runs as averages of two test run replicas of both flow rates.

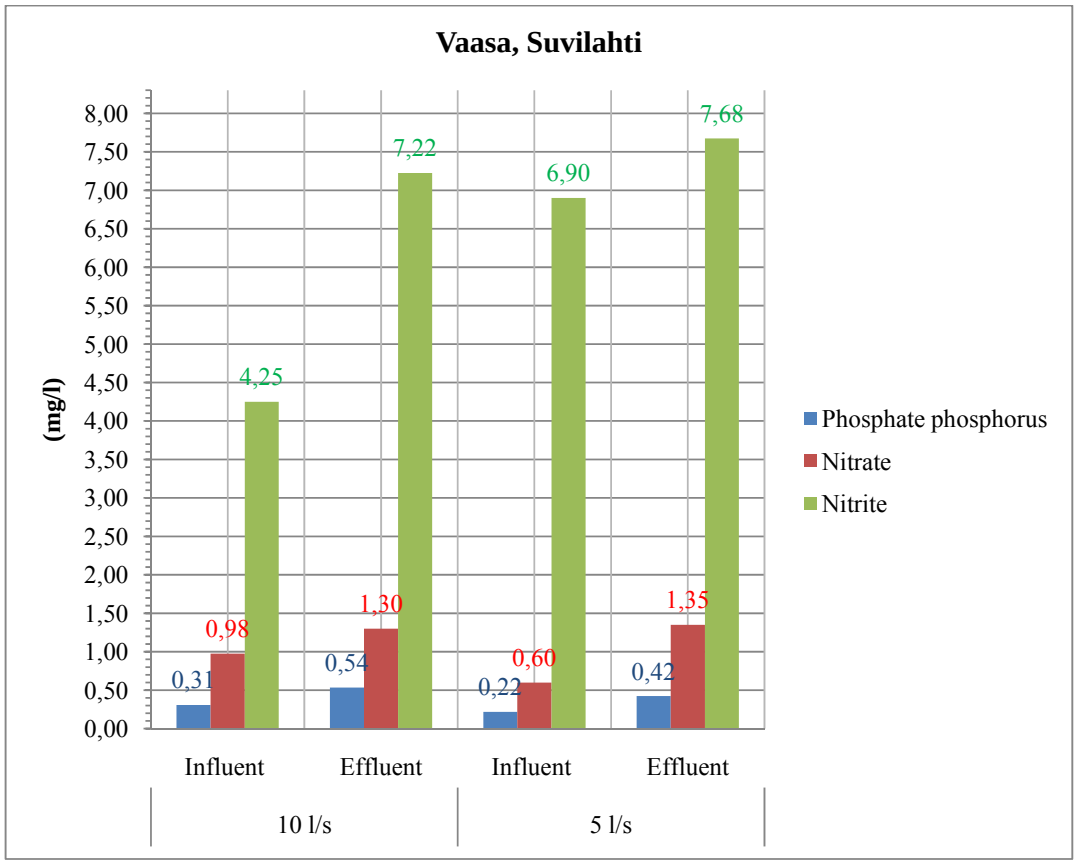

FIGURE 15. Average concentrations of phosphate phosphorus, nitrate and nitrite for 10 l/s and 5 l/s flow rate test runs from Vaasa, Suvilahti

3.1.2 Biochemical and chemical oxygen demand ($BOD_{7\ ATU}$ and COD_{Cr})

In the graph 16 are shown the biochemical and chemical oxygen demand as mass of oxygen consumed per litre of solution from the flow rate test runs done in Vaasa, Suvilahti. The graph presents averages of two test run replicas of both flow rates.

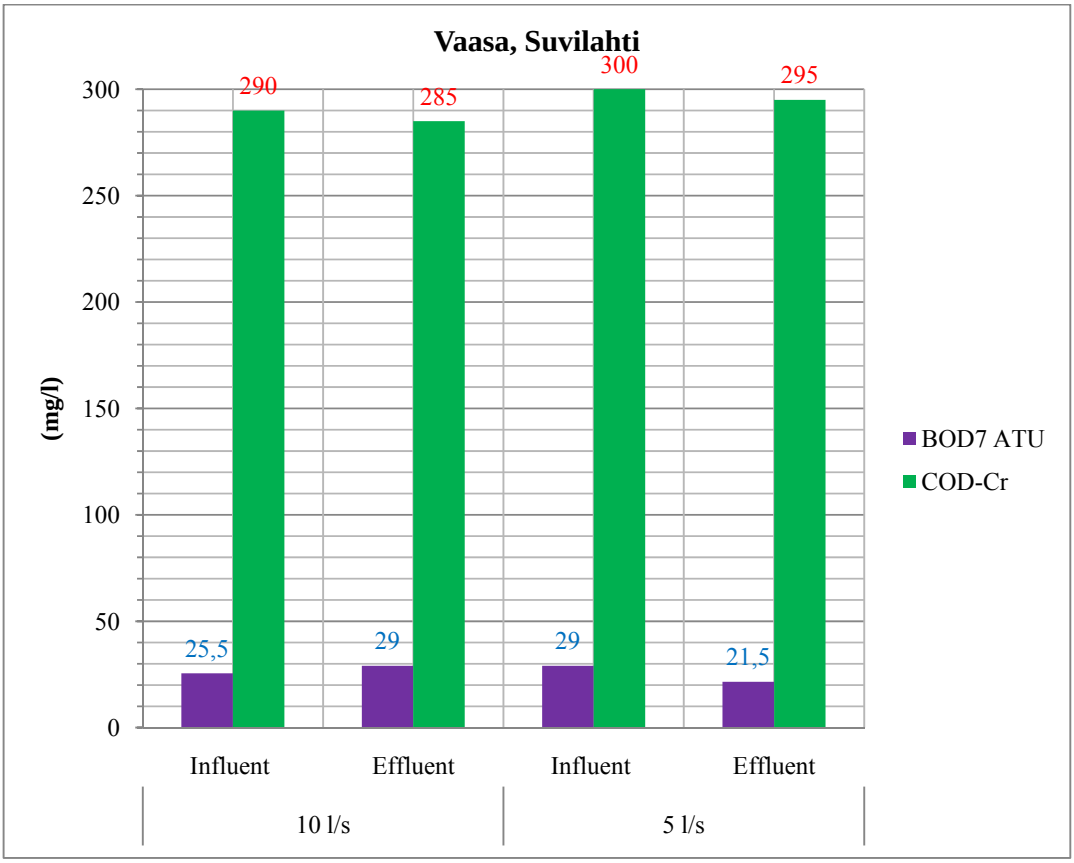

FIGURE 16. Average biochemical and chemical oxygen demand for 10 l/s and 5 l/s flow rate test runs from Vaasa, Suvilahti

3.1.3 *Coliform* and Fecal *Streptococci* bacteria

In the graph 17 are presented the *Coliform* and Fecal *Streptococci* bacteria from Vaasa, Suvilahti in concentrations of colony forming units per 100 ml of sample. The concentration of Fecal *Streptococci* for influent in second replica of 5 l/s test run is 390 pmy/ 100 ml, and due to its height lies way outside the graph. The concentrations of *Coliforms* are missing from the first replica.

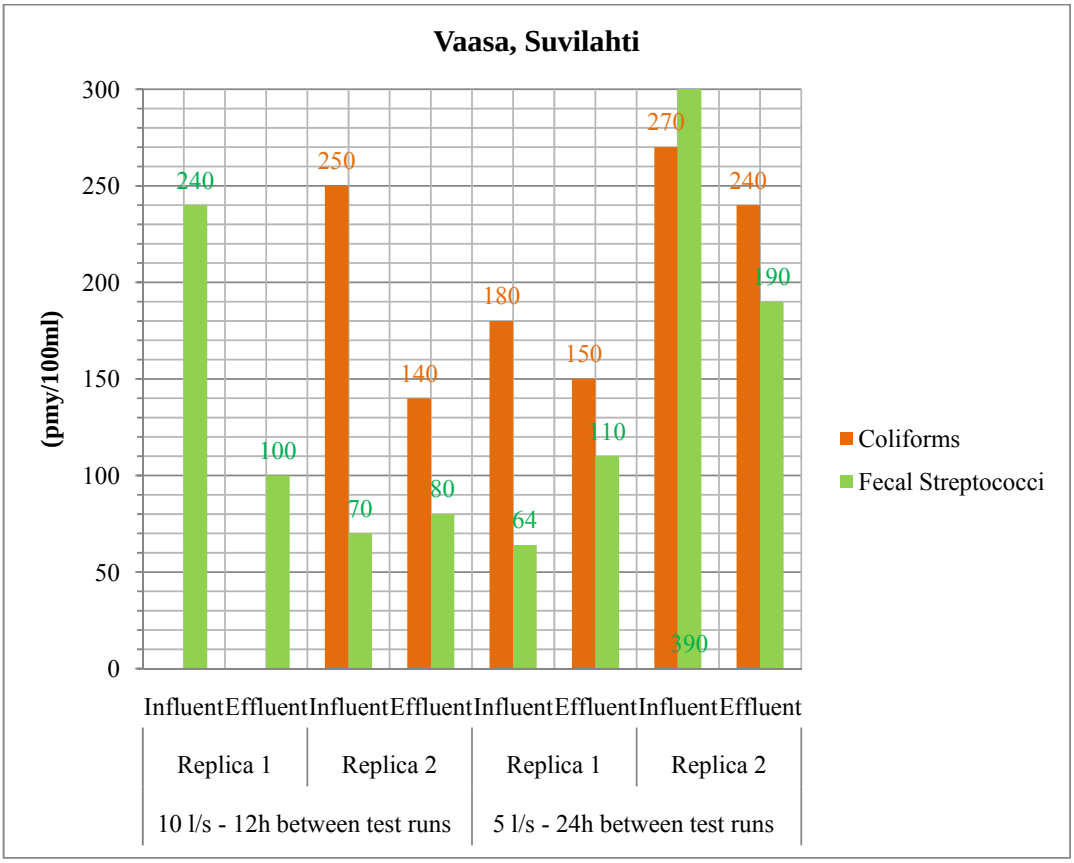

FIGURE 17. Concentrations of *Coliforms* able to ferment lactose at 44°C and Fecal *Streptococci* of colony forming units per 100 ml of sample from Vaasa, Suvilahti samples

3.1.4 Appearance

The colour of the influent (i) and effluent (E) from 10 l/s and 5 l/s flow rate test runs are demonstrated with the figures 18 and 19 which were taken from the first test run replicas.

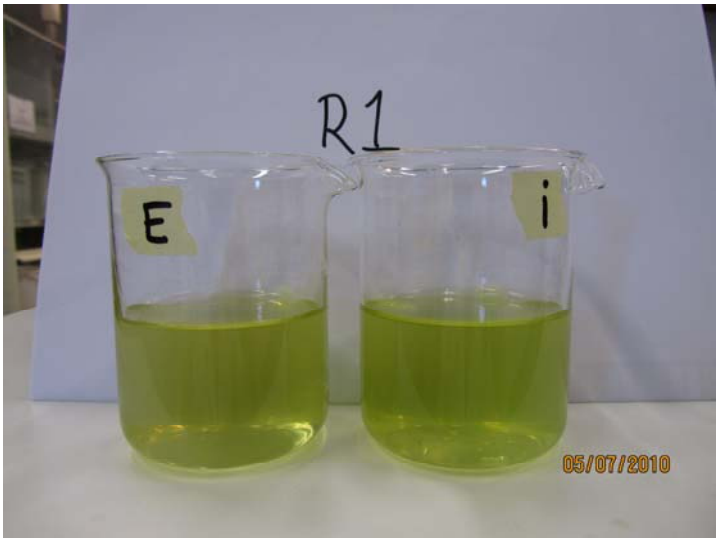

FIGURE 18. First replica samples from 10 l/s flow rate test run

FIGURE 19. First replica samples from 5 l/s flow rate test run

3.1.5 Total suspended solids (TSS)

In the table 6 are shown the results of total suspended solids as milligrams per litre from Vaasa, Suvilahti. The TSS was calculated by the formula shown below and an average was taken from the two replicas of effluents and influents:

$$TSS = \frac{ma-mb}{c}$$

Where

ma= Filter mass after filtration (mg)

mb= Filter mass before filtration (mg)

c= Sample volume (l)

TABLE 6. Total suspended solids from Vaasa, Suvilahti samples

Vaasa Suvilahti landfill leachates																
	10 l/s - 12h between test runs								5 l/s - 24h between test runs							
TSS (mg/l)	Replica 1				Replica 2				Replica 1				Replica 2			
	Influent		Effluent		Influent		Effluent		Influent		Effluent		Influent		Effluent	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
ma	513,2	507,5	509,1	508,9	541,5	526,9	529,7	525,3	518,6	520,4	517,2	517,6	521,9	520,8	519,8	518,1
mb	512,6	507,9	509,2	509	541,4	526,1	529,8	522,9	517,6	517,7	517,2	517,6	520,6	520,5	519,3	517,8
c	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
TSS	12	-8	-2	-2	2	16	-2	48	20	54	0	0	26	6	10	6
Average	2		-2		9		23		37		0		16		8	

Exposure of samples to humidity

3.1.6 Heavy metals (Cd, Cr, Fe, Pb, Zn, Cu and Ni)

Iron (Fe), zink (Zn), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb) and cadmium (Cd) from Suvilahti landfill samples were analysed with AAS at Tampere University of Applied Sciences and from the results none are presented in this report due to the concentrations being in many occasions low.

3.1.7 Total nitrogen (TN)

In the table 7 are shown the average results for total nitrogen which were analysed with wet digestion, distillation and titration. The total nitrogen was calculated with this formula:

$$TN = \frac{(V1-VBI)*c*f*M(N)*1000}{V}$$

Where

TN= Total nitrogen (mg/l)

V1= Consumption of acid in titration (ml)

VBI= Consumption of acid in blank sample (ml)

c= Concentration of sulphuric acid (0,005 mol/l)

f= factor of acid (2)

M(N)= Mole mass of nitrogen (14g/mol)

V= Original sample volume(50 ml)

TABLE 7. Average concentration of total nitrogen from Vaasa, Suvilahti samples

Sample	Average TN (mg/l N)
10-01-i	113,12
10-01-E	91,75
10-02-i	106,48
10-02-E	80,71
05-01-i	96,55
05-01-E	84,13
05-02-i	107,14
05-02-E	80,06

Analysed on 3-12.01.2011

In the graph 20 are shown the average concentrations of TN from Vaasa, Suvilahti samples. The average was taken from two test run replicas.

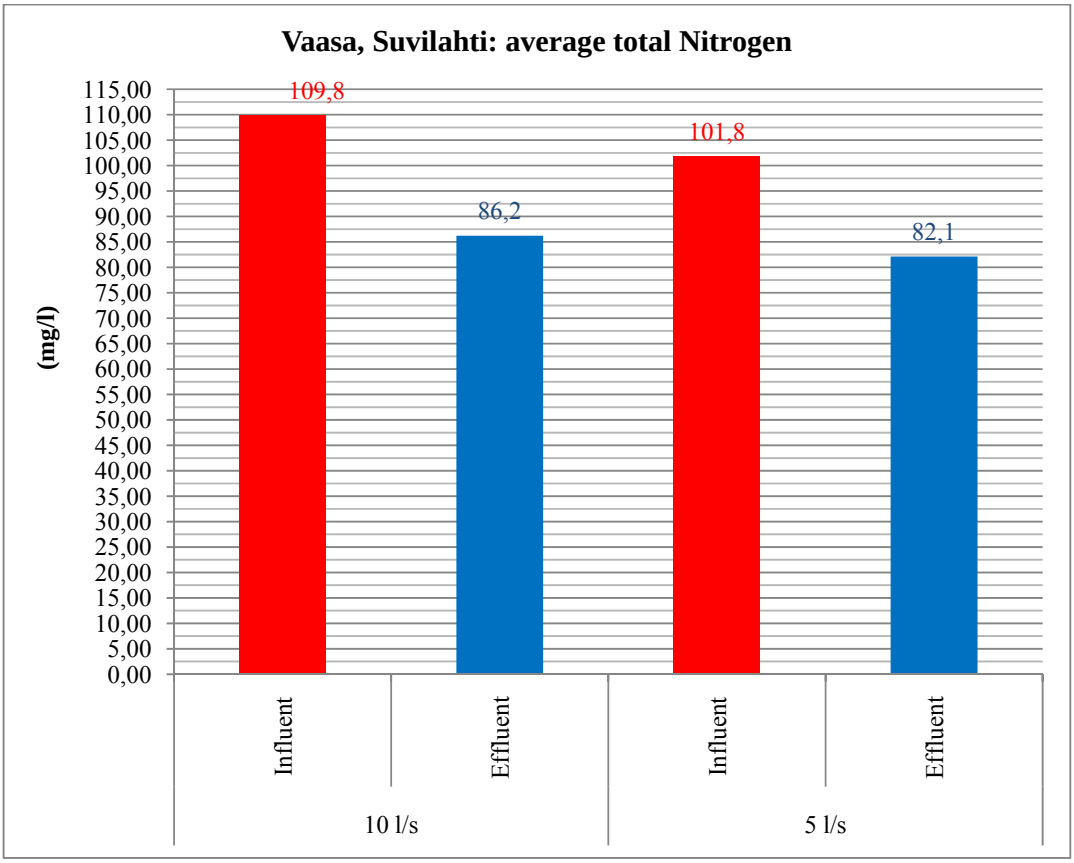

FIGURE 20. Average concentrations of TN from Vaasa, Suvilahti samples

3.1.8 Total phosphorus (TP)

The total phosphorus was analysed with DR 2800 Portable Spectrophotometer and the average was calculated from two replicas done per sample.

TABLE 8. Average concentration of total phosphorus from Vaasa, Suvilahti samples

Sample	Average TP (mg/l)
10-01-i	0,32
10-01-E	0,39
10-02-i	0,10
10-02-E	0,49
05-01-i	0,04
05-01-E	0,40
05-02-i	0,08
05-02-E	0,46

Analysed on 16-18.02.2011 and 13.03.2011

In the graph 21 are shown the average concentrations of total phosphorus from Vaasa, Suvilahti.

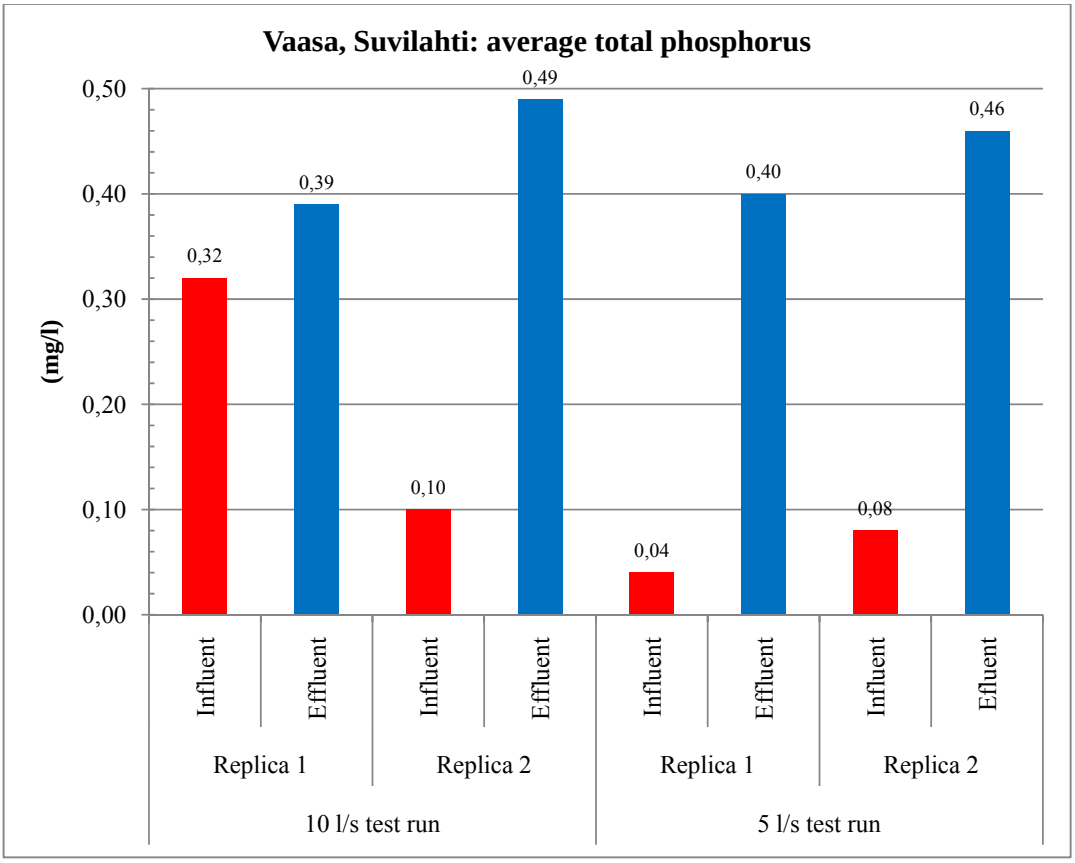

FIGURE 21. Average concentration of total phosphorus from Vaasa, Suvilahti samples

3.1.9Active surface area

Active surface area of one branch:

By assuming that the branch has a cylindrical shape, the active surface area was calculated based on the surface area of a cylinder.

$$A_B = 2\pi r^2 + 2\pi rh \quad (3)$$

Where:

A_B= Surface area of one branch (cm^2)

r= $\frac{Diameter\ of\ the\ branch}{2}$ (cm)

h= Height of the branch (cm)

$$A_B = 2 \times \pi \times (1{,}5\ cm)^2 + 2 \times \pi \times 1{,}5\ cm \times 240\ cm = 1144{,}5\ cm^2 = \mathbf{1{,}1\ m^2}$$

The active surface area of one floor:

The calculation of the active surface area of the willow stacks in one floor was done by calculating the number of branches in one floor and their joint area. The space between the branches was reduced by dividing the length and width of the rectangular shaped floor by the diameter of the branch.

$$A_F = A_B \times \frac{L}{3cm} \times \frac{W}{3cm} \quad (4)$$

Where:

A_B = Surface area of one branch (cm^2)

A_F= Surface area in one floor (cm^2)

L= Length of the floor (cm)

W= Width of the floor (cm)

3= Diameter of one branch (cm)

$$A_F = 1144{,}5\ cm^2 \times \frac{1220\ cm}{3\ cm^2} \times \frac{235\ \text{cm}}{3\ cm^2} = 36458683{,}33\ cm^2 = \mathbf{3645{,}9\ m^2}$$

Total active surface area:

The total active surface area of the tower was calculated simply by multiplying the active surface area of one floor by the number of floors in the tower.

$$A_S = A_F \times 3 \quad (5)$$

Where:

A_S= Total active surface area of the tower (cm^2)

3= Number of floors

$$A_S = 36458683{,}33\ cm^2 \times 3 = 109376050\ cm^2 \approx \mathbf{10938\ m^2}$$

The active surface area of the tower was **10938 m^2**.

3.2 Pälkäne, Ruokola: Sludge treatment field of Aukeasuo

In Pälkäne three test runs were conducted - 6 hours, 16 hours and 22 hours test run, with three replicas. The hours represented the time between sampling of influent and effluent. In Pälkäne the willow stack tower was isolated from the other treatment units and from the storage pond during the test runs to obtain results based only on the willow stack tower. The definitions for the markings used in the tables can be found from the beginning of the final thesis and from the end of the tables. Leachate levels in the pool under the willow stack tower were recorded when the pool was full and when the test run ended to estimate the evaporation. The COD_{Cr}, $BOD_{7\ ATU}$, *Coliforms* and Fecal *Streptococci* were analysed by the Water Protection Association of The River Kokemäenjoki (Kokemäenjoen Vesistön Vesiensuojeluyhdistys Ry, KVVY).

3.2.1 6 hours test run

In the table 9 are shown the results and other variables taken during the 6 hours test run.

TABLE 9. Results of 6 hours test run from Pälkäne samples

Leachates from Humuspehtoori Ltd, Pälkäne							
	Sample parameters	6h test run					
		Replica 1		Replica 2		Replica 3	
		Influent	Effluent	Influent	Effluent	Influent	Effluent
Field	Date of sampling	11.8.2010	11.8.2010	12.8.2010	12.8.2010	26.8.2010	26.8.2010
	Time	7:15	14:05	7:20	14:10	6:35	13:30
	Air temperature °C	16	22	12	22	10	13
	Wind direction	SW 210°	SW 230°	SE 120°	E 100°	W 290°	N 10°

	Wind speed (m/s)	3,6	5,1	1	2,1	1,5	3,1
	Cloudiness	Cloudy	Cloudy	Foggy	Sunny	Cloudy	Cloudy
	Rainfall	No	No	No	No	No	Drizzle
	Relative humidity (RH %)	95	64	94	53	100	88
	Sample temperature °C	17,4	16,6	16	17,8	11,1	10
	pH ~	**6,8**	**7,9**	**6,9**	**7,8**	**6,7**	**7,9**
	Water level before emptying (cm)				27,0		20,5
	Date				12.8.2010		26.8.2010
	Time				14:00		13:30
	Time when tower was put on	8:20		8:03			
Laboratory (laboratorio)	**Date of analysing**	11.8.2010	12.8.2010	12.8.2010	13.8.2010	26.8.2010	26.8.2010
	Appearance	dB	BY	dB	BY	dB	BY
	Odour	B3C5D14	B1D1	B3C5D14	B1D1	B3C5D15	B1D2
	Phosphate phosphorus (PO_4^-P mg/l)						
	R1	16,00	1,48	7,00	1,69	11,00	0,75
	R2	20,00	1,83	14,00	1,71	12,00	0,68
	Average ~	**18,00**	**1,66**	**10,50**	**1,70**	**11,50**	**0,72**
	Nitrate (NO_3 mg/l)						
	R1	-0,30	0,70	-0,10	-0,30	0,30	0,10
	R2	-0,20	0,80	-0,20	-0,30	0,20	0,30
	Average ~	**-0,25**	**0,75**	**-0,15**	**-0,30**	**0,25**	**0,20**
	Nitrite (NO_2 mg/l)						
	R1	-0,007	0,219	-0,006	0,235	-0,007	0,103
	R2	-0,007	0,228	-0,005	0,237	-0,006	0,103
	Average ~	**-0,01**	**0,22**	**-0,01**	**0,24**	**-0,01**	**0,10**
Tampere Lab	**$BOD_{7\ ATU}$ (mg/l)**	170	31	190	32	230	48
	COD_{Cr} (mg/l)	820	510	820	500	860	500
	***Coliforms* (piece/100ml)**	35000	160	30000	180	70000	8100
	Fecal *Streptococci* (pmy/100ml)	12000	200	39000	>2000	18000	4900

Wind speed, wind direction (degrees) and relative humidity was given by Finnish Meteorological Institute (Pirkkala)

Sampling and analysing done on the following day due to the sampling timetable

Phosphate phosphorus, nitrate and nitrite (PO_4^-P, NO_3 and NO_2)

The graph 22 displays the concentrations of phosphate phosphorus, nitrate and nitrite analysed from 6 hours test run in Pälkäne.

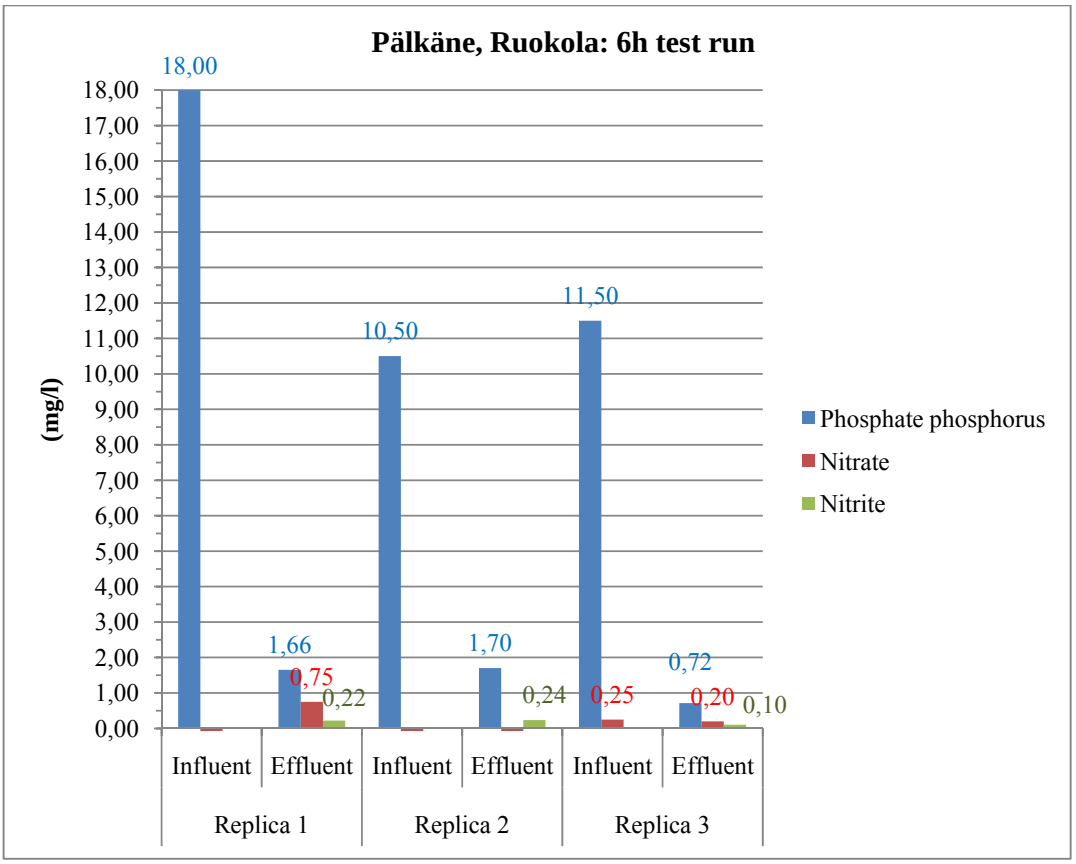

FIGURE 22. Average concentrations of phosphate phosphorus, nitrate and nitrite from 6 hours test run from Pälkäne samples

Biochemical and chemical oxygen demand ($BOD_{7\ ATU}$ and COD_{Cr})

In the graph 23 are displayed the average results of biochemical oxygen demand and chemical oxygen demand from 6 hours test run. The average is taken from three test run replicas.

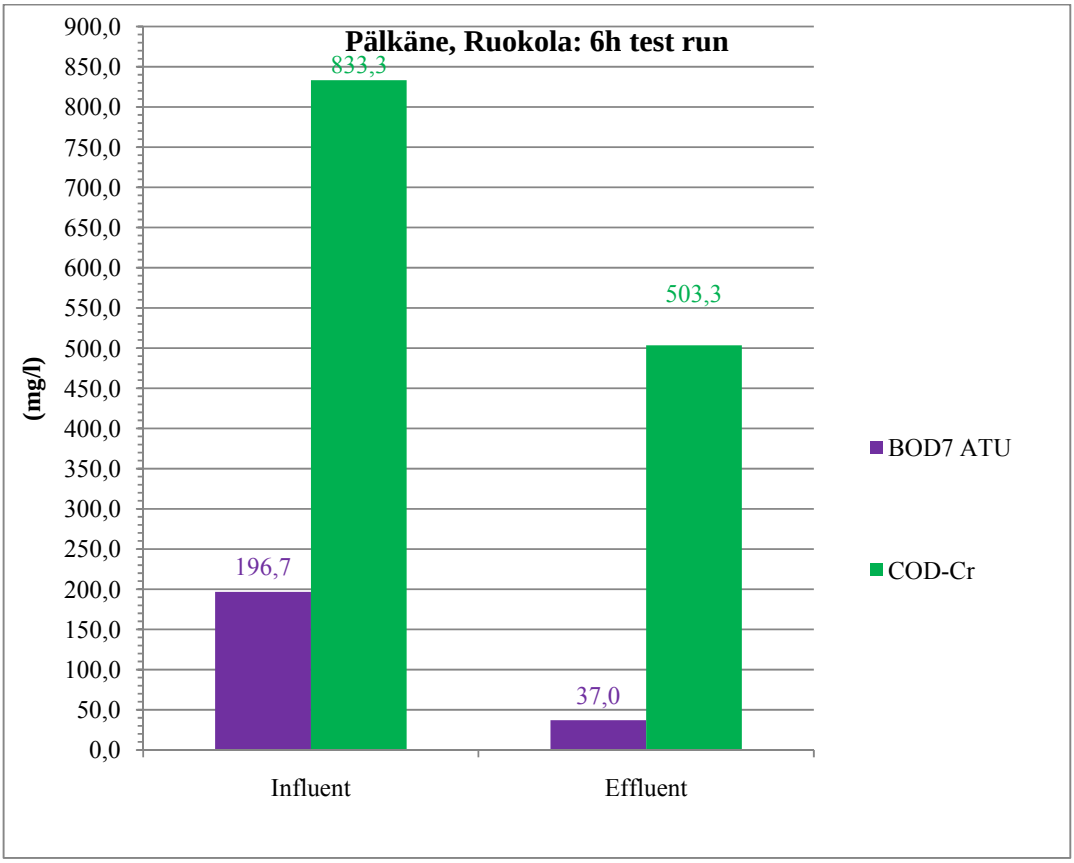

FIGURE 23. Average concentrations of biochemical and chemical oxygen demand for 6 hours test run from Pälkäne samples

Coliform and Fecal *Streptococci* bacteria

The graph 24 presents the concentrations of *Coliform* and Fecal *Streptococci* bacteria in 6 hours test run. The units of *Coliforms* and Fecal *Streptococci* were presented in the results given by the KVVY in pmy/ 100 ml and piece/ 100 ml, which were confirmed by the KVVY to mean the same.

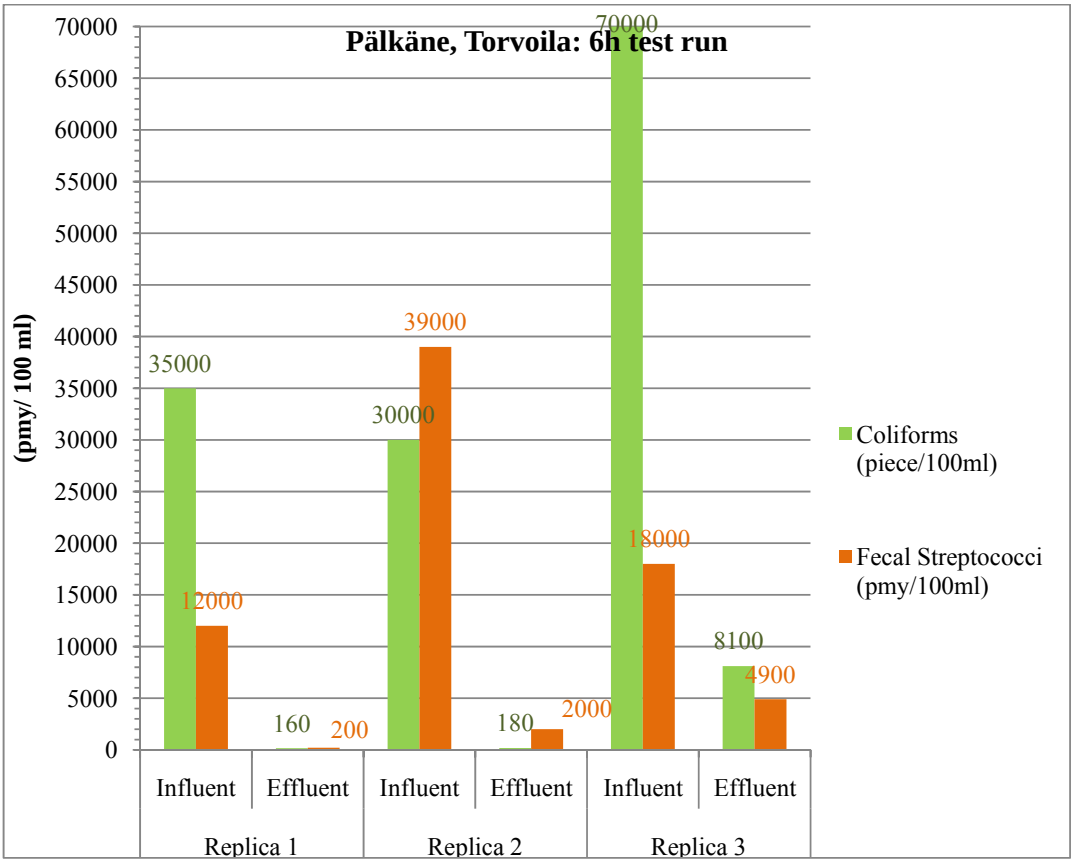

FIGURE 24. Concentrations of *Coliforms* able to ferment lactose at 44°C and Fecal *Streptococci* of colony forming units per 100 ml of sample from Pälkäne samples

Appearance

The colour of the influent and effluent from 6 hours test run are demonstrated with the figure 25 taken from the first test run replica.

FIGURE 25. First replica samples from 6 hours test run

3.2.2 16 hours test run

In the table 10 are shown the results of phosphate phosphorus, nitrate, nitrite, $BOD_{7\ ATU}$, COD_{Cr}, *Coliforms*, Fecal *Streptococci* and other variables taken during the 16 hours test run. One result from Fecal *Streptococci* is missing.

TABLE 10. Results of 16 hours test run from Pälkäne samples

Leachates from Humuspehtoori Ltd, Pälkäne							
	Sample parameters	16h test run					
		Replica 1		Replica 2		Replica 3	
		Influent	Effluent	Influent	Effluent	Influent	Effluent
Field	Date of sampling	16.8.2010	17.8.2010	17.8.2010	18.8.2010	18.8.2010	19.8.2010
	Time	13:20	7:00	13:25	5:35	13:00	6:00
	Air temperature °C	18	7	19	17	20	10
	Wind direction	N 10°	E 100°	NE 70°	N 20°	NE 70°	N 20°
	Wind speed (m/s)	3,6	2,6	4,6	1,5	6,2	2,1
	Cloudiness	Sunny	Sunny	Sunny	Cloudy	Sunny	Dawn
	Rainfall	No	No	No	Drizzle	No	No
	Relative humidity (RH %)	42	93	52	75	56	76
	Sample temperature °C	16,7	7,5	15,9	12	17,2	6,9
	pH ~	**6,8**	**8,1**	**6,7**	**7,5**	**6,5**	**8,1**
	Water level before emptying (cm)		22,0		25,0		12,0

	Date		17.8.2010		18.8.2010		
	Time		7:00		5:35		
	Time when tower was put on	15:00		13:30		14:00	
Laboratory	**Date of analysing**	16.8.2010	17.8.2010	17.8.2010	18.8.2010	18.8.2010	19.8.2010
	Appearance	dB	BY	dB	BY	dB	BY
	Odour	B3C5D14	B1D1	B3C5D14	B1D1	B3C5D14	B1D1
	Phosphate phosphorus (PO_4^-P mg/l)						
	R1	27,00	1,46	6,00	1,53	9,00	1,50
	R2	12,00	1,58	11,00	1,42	10,00	1,62
	Average ~	**19,50**	**1,52**	**8,50**	**1,48**	**9,50**	**1,56**
	Nitrate (NO_3 mg/l)						
	R1	0,10	-0,10	0,20	-0,10	0,40	-0,40
	R2	0,10	-0,10	0,20	-0,20	0,10	-0,30
	Average ~	**0,10**	**-0,10**	**0,20**	**-0,15**	**0,25**	**-0,35**
	Nitrite (NO_2 mg/l)						
	R1	-0,015	0,03	-0,026	0,058	-0,024	0,028
	R2	-0,016	0,028	-0,023	0,06	0,004	0,028
	Average ~	**-0,02**	**0,03**	**-0,02**	**0,06**	**-0,01**	**0,03**
Tampere Lab	**$BOD_{7\ ATU}$ (mg/l)**	180	38	180	29	190	30
	COD_{Cr} (mg/l)	790	500	770	460	790	500
	***Coliforms* (piece/100ml)**	1000	4100	~80000	900	180000	3000
	Fecal *Streptococci* (pmy/100ml)	16000	1300	23000	500	-	1200

Wind speed, wind direction (degrees) and relative humidity was given by Finnish Meteorological Institute (Pirkkala)

Under measuring range (HACH)

Phosphate phosphorus, nitrate and nitrite (PO_4^-P, NO_3 and NO_2)

In the graph 26 are shown the average results from phosphate phosphorus, nitrate and nitrite from 16 hours test run.

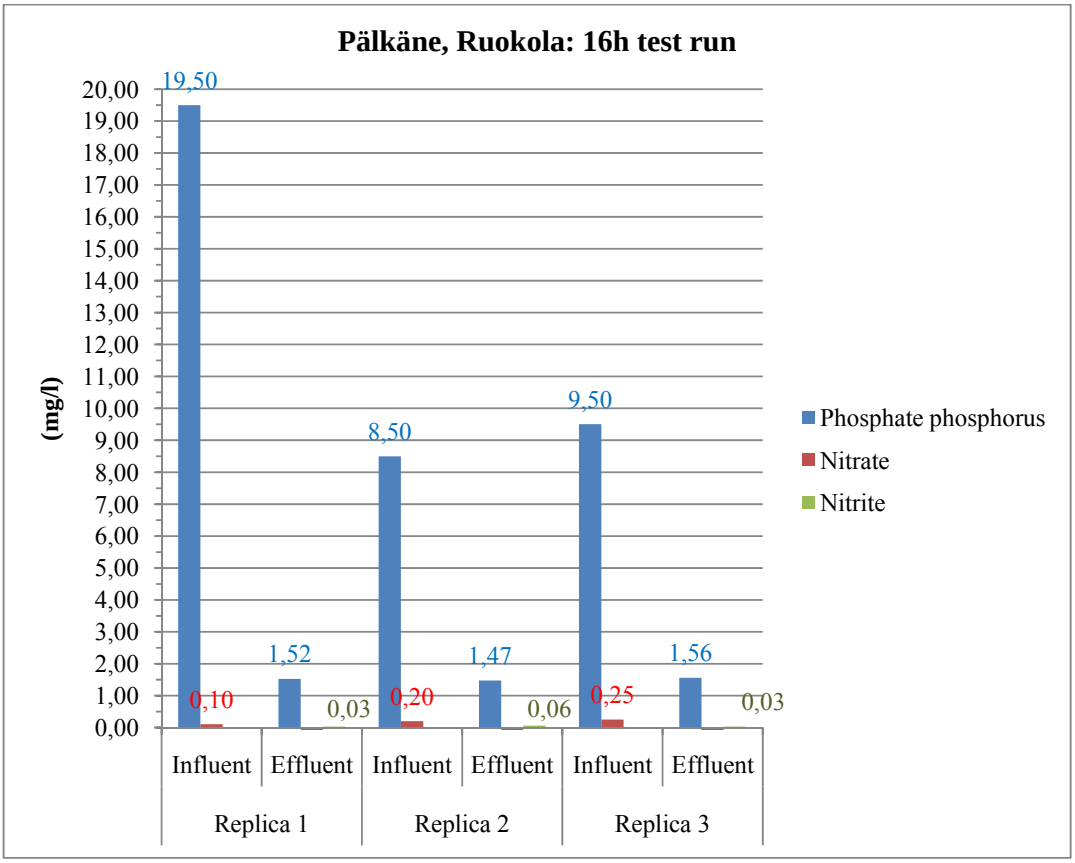

FIGURE 26. Average concentrations of phosphate phosphorus, nitrate and nitrite from 16 hours test run from Pälkäne samples

Biochemical and chemical oxygen demand ($BOD_{7\ ATU}$ and COD_{Cr})

In the graph 27 are the average concentrations of biochemical and chemical oxygen demand of leachate after 16 hours of treatment through the willow stack tower. The average was taken from three test run replicas.

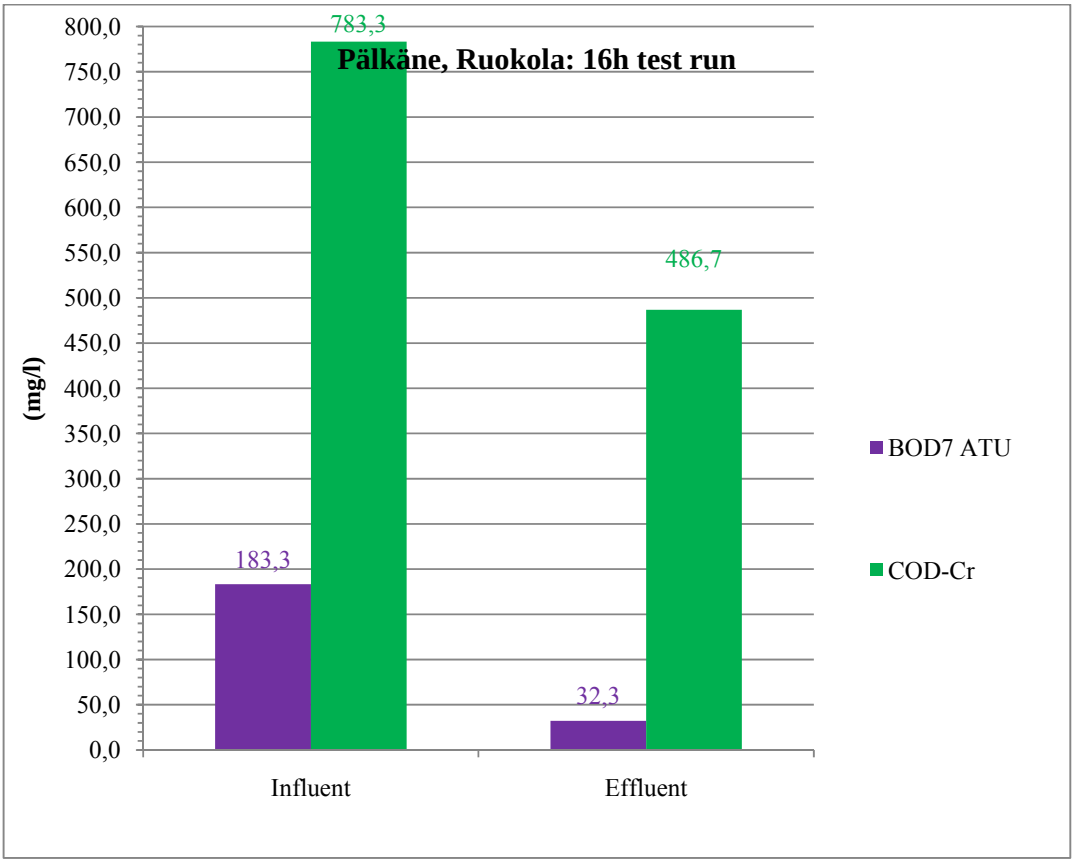

FIGURE 27. Average concentrations of biochemical and chemical oxygen demand from Pälkäne samples

Coliform and Fecal Streptococci bacteria

In the graph 28 the influent of replica two contains 80 000 pmy/ 100 ml and influent of replica three contains 180 000 pmy/ 100 ml of *Coliform* bacteria, and therefore the top of the columns representing the second and third replica of influent, lie way outside the graph. The third replica influent is missing the concentration of Fecal *Streptococci*.

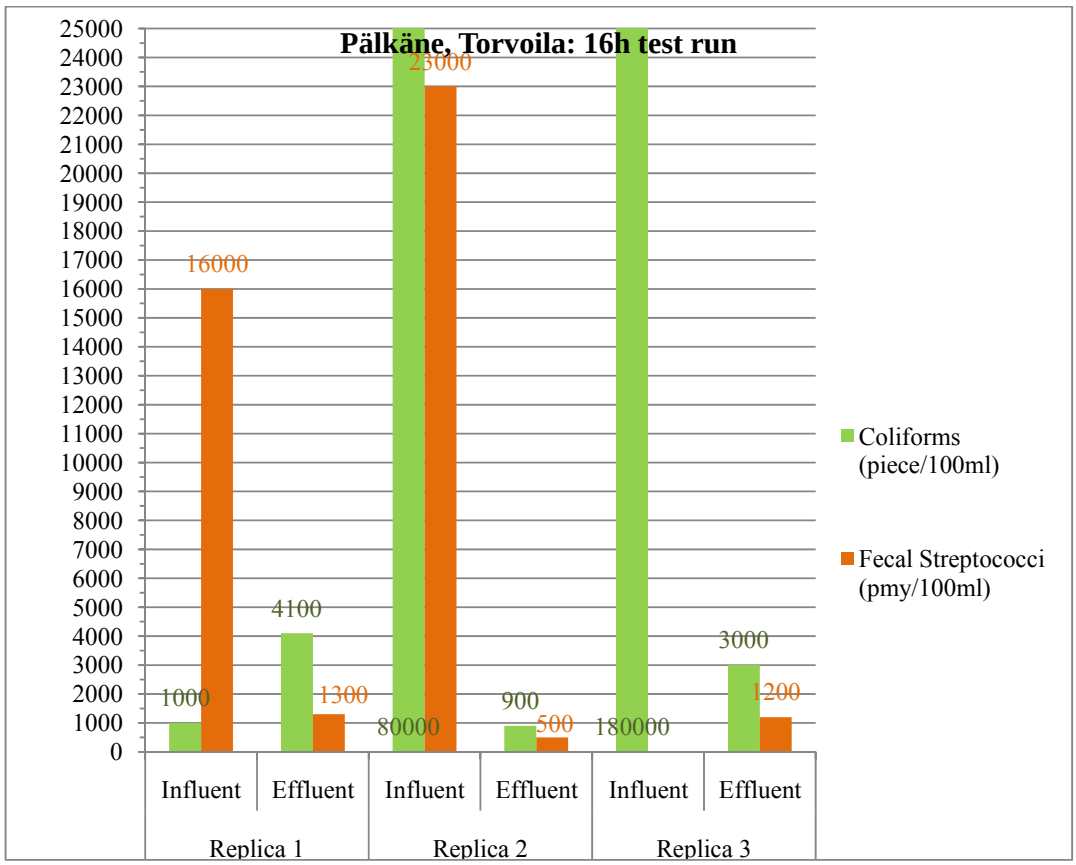

FIGURE 28. Concentrations of *Coliforms* able to ferment lactose at 44°C and Fecal *Streptococci* of colony forming units per 100 ml of sample for 16 hours test run from Pälkäne samples

Appearance

The colour of the influent and effluent from 16 hours test run are demonstrated with the figure 29 which was taken from the first test run replica. Influent sample is on the left and effluent sample is on the right.

FIGURE 29. First replica samples from 16 hours test run

3.2.3 22 hours test run

In the table 11 are the results of phosphate phosphorus, nitrate, nitrite, $BOD_{7\ ATU}$, COD_{Cr}, *Coliforms*, Fecal *Streptococci* and other variables which were analysed from 22 hours test run. The 22 hours test run results cannot be directly compared to 6 hours or 16 hours test runs because more leachate was added during the test run to avoid drying of the willow.

TABLE 11. Results of 22 hours test run from Pälkäne samples

Leachates from Humuspehtoori Ltd, Pälkäne							
	Sample parameters	22h test run					
		Replica 1		Replica 2		Replica 3	
		Influent	Effluent	Influent	Effluent	Influent	Effluent
Field	Date of sampling	23.8.2010	24.8.2010	24.8.2010	25.8.2010	25.8.2010	26.8.2010
	Time	9:45	8:00	8:40	7:00	7:45	6:00
	Air temperature °C	13	9	9	10	10	10
	Wind direction	W 270°	NE 60°	NE 70°	SE 140°	SE 140°	NS 300°
	Wind speed (m/s)	4,6	2,1	3,1	1,5	2,6	1,5
	Cloudiness	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy
	Rainfall	No	No	No	No	No	No
	Relative humidity (RH %)	88	93	93	100	100	100

	Sample temperature °C	15,2	7,1	13	9,7	11,9	9,6
	pH ~	**6,1**	**8**	**6,7**	**7,8**	**6,6**	**8**
	Water level before emptying (cm)				17,0		25,0
	Date				25.8.2010		26.8.2010
	Time				7:00		6:00
	Water level before adding (cm)		19		18		17
	Date		23.8.2010		24.8.2010		25.8.2010
	Time		20:00		19:30		-
	Time when tower was put on	10:20		9:15		8:15	7:30
Laboratory	**Date of analysing**	23.8.2010	24.8.2010	24.8.2010	25.8.2010	25.8.2010	26.8.2010
	Appearance	dB	BY	dB	BY	dB	BY
	Odour	B3C5D14	B1D1	B3C5D14	B1D1	B3C5D14	B1D1
	Phosphate phosphorus (PO_4^-P mg/l)						
	R1	14,00	0,77	26,00	1,10	23,00	0,95
	R2	25,00	0,77	40,00	0,80	45,00	0,99
	Average ~	**19,50**	**0,77**	**33,00**	**0,95**	**34,00**	**0,97**
	Nitrate (NO_3 mg/l)						
	R1	0,20	-0,10	0,10	-0,10	0,00	0,10
	R2	0,20	-0,10	0,30	-0,10	0,20	0,00
	Average ~	**0,20**	**-0,10**	**0,20**	**-0,10**	**0,10**	**0,05**
	Nitrite (NO_2 mg/l)						
	R1	-0,014	0,022	-0,021	0,033	-0,012	0,035
	R2	-0,012	0,022	-0,018	0,034	-0,013	0,032
	Average ~	**-0,01**	**0,02**	**-0,02**	**0,03**	**-0,01**	**0,03**
Tampere Lab	**$BOD_{7\ ATU}$ (mg/l)**	160	34	190	27	210	27
	COD_{Cr} (mg/l)	700	430	730	390	790	420
	***Coliforms* (piece/100ml)**	40000	3300	50000	1000	80000	2200
	Fecal *Streptococci* (pmy/100ml)	7300	700	8000	100	20000	~1900

Wind speed, wind direction (degrees) and relative humidity was given by Finnish Meteorological Institute (Pirkkala)

Under measuring range (HACH)

Added leachate during the test run

Phosphate phosphorus, nitrate and nitrite (PO_4^-P, NO_3 and NO_2)

In the graph 30 are the phosphate phosphorus, nitrate and nitrite concentrations from 22 hours test run.

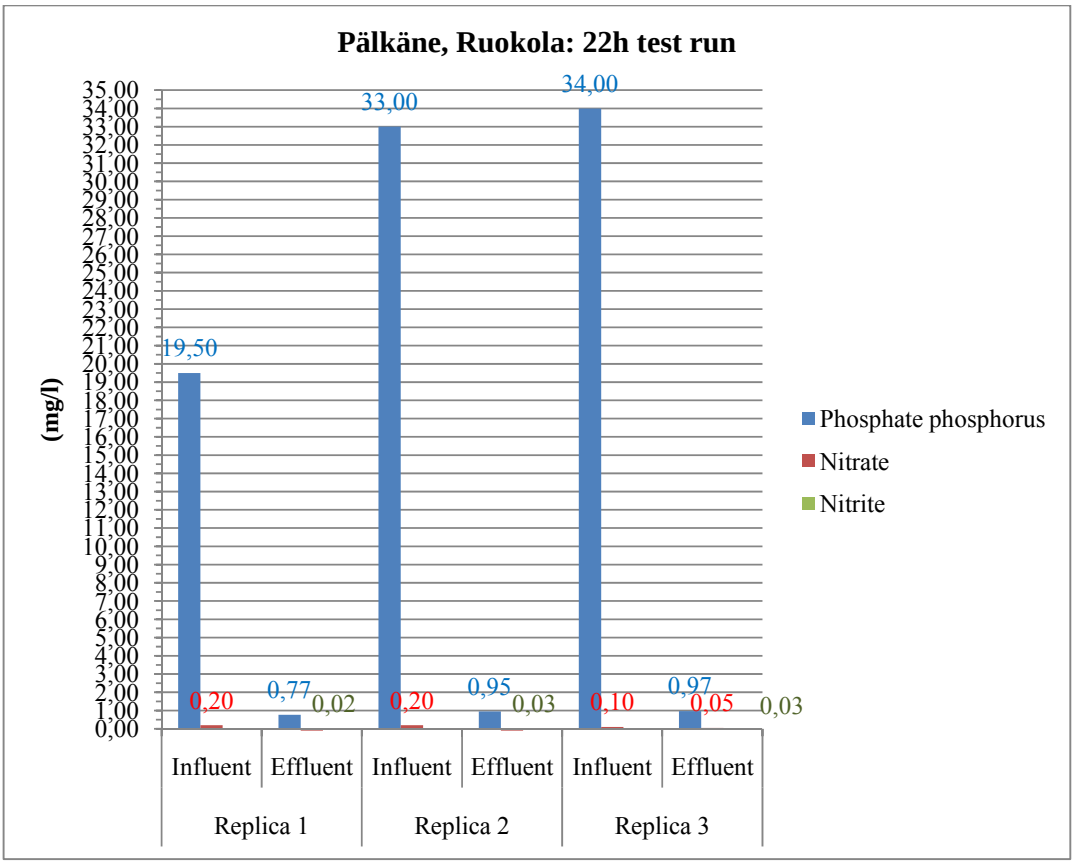

FIGURE 30. Average concentrations of phosphate phosphorus, nitrate and nitrite for 22 hours test run from Pälkäne samples

Biochemical and chemical oxygen demand ($BOD_{7\ ATU}$ and COD_{Cr})

In the graph 31 are presented the average concentrations of biochemical and chemical oxygen demand from 22 hours test run. The average is taken from three test run replicas.

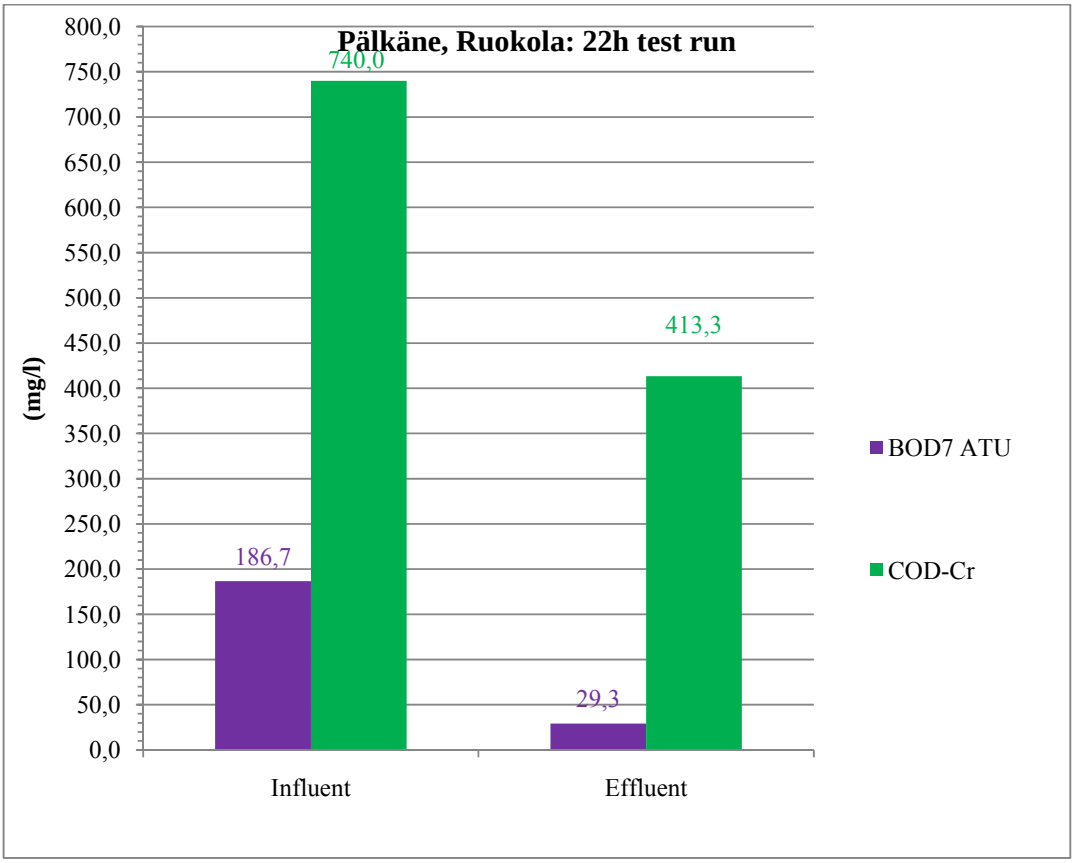

FIGURE 31. Average concentrations of biochemical and chemical oxygen demand for 22 hours test run from Pälkäne samples

Coliform and Fecal *Streptococci* bacteria

In the graph 32 are presented the results of *Coliform* and Fecal *Streptococci* bacteria from 22 hours test run. The concentration of *Coliforms* for first replica influent was 40 000 pmy/ 100 ml, 50 000 pmy/ 100 ml for second replica influent and 80 000 pmy/ 100 ml for third replica influent.

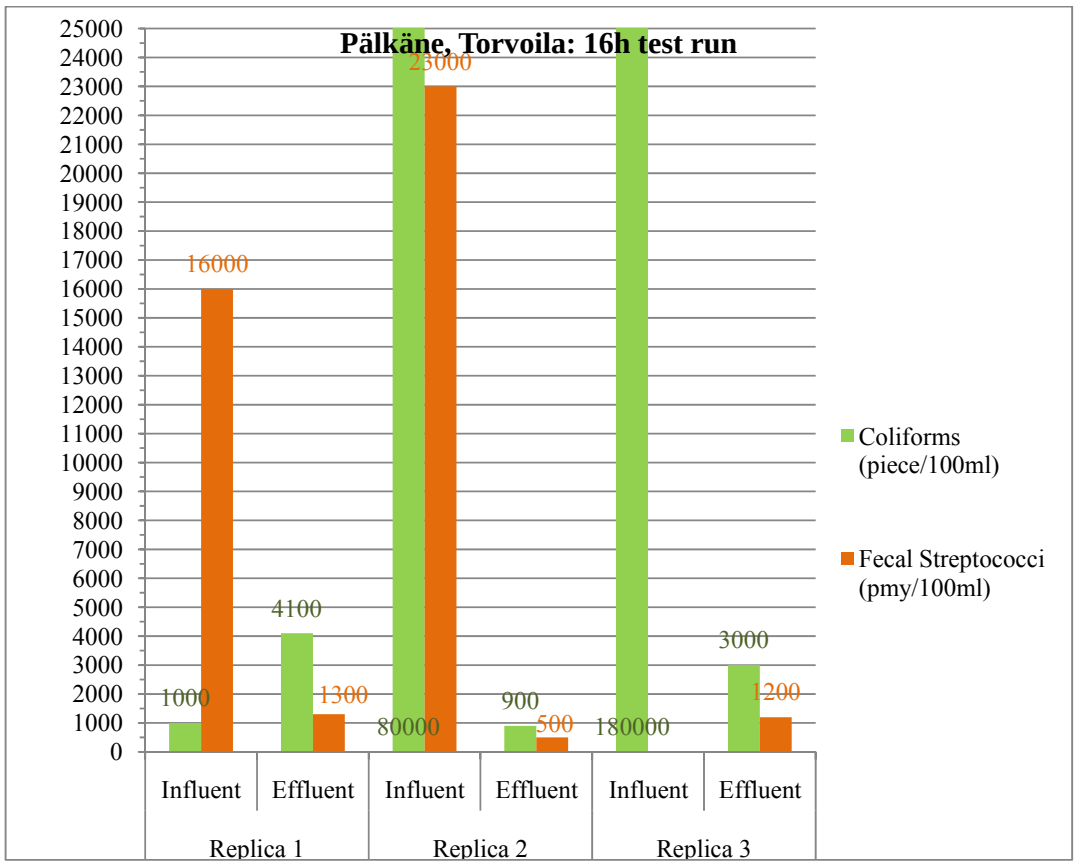

FIGURE 32. Concentrations of *Coliforms* able to ferment lactose at 44°C and Fecal *Streptococci* of colony forming units per 100 ml of sample for 22 hours test run from Pälkäne samples

Appearance

The colour of the influent and effluent from 22 hours test run are demonstrated with the figure 33 which was taken from the first test run replica. The influent sample is on the left and effluent sample is on the right.

FIGURE 33. First replica samples of 22 hours test run

3.2.4 Total suspended solids (TSS)

In the tables 12-14 are presented the total suspended solids from 6 hours, 16 hours and 22 hours test runs.

TABLE 12. Total suspended solids of 6 hours test run from Pälkäne samples

Leachates from Humuspehtoori Ltd, Pälkäne												
	6h test run											
TSS (mg/l)	Replica 1				Replica 2				Replica 3			
	Influent		Effluent		Influent		Effluent		Influent		Effluent	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
ma	525,7	528,9	516,7	525,3	525,7	530,1	522,4	521,5	548	530,1	526,5	522
mb	519,4	522,3	514,2	523,7	518,3	524,5	520,3	518,7	534,9	516,7	523	517,9
c	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
TSS	126	132	50	32	148	112	42	56	262	268	70	82
Average	129		41		130		49		265		76	

TABLE 13. Total suspended solids of 16 hours test run from Pälkäne samples

Leachates from Humuspehtoori Ltd, Pälkäne												
16h test run												
TSS (mg/l)	Replica 1				Replica 2				Replica 3			
	Influent		Effluent		Influent		Effluent		Influent		Effluent	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
ma	531,8	531,3	527,7	524,3	522,6	528,3	527	526,3	542,1	540,1	538,6	538,8
mb	526,4	524,9	526,3	520,4	517,6	518,7	525,6	523,6	536,8	535	537,6	535,7
c	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
TSS	108	128	28	78	100	192	28	54	106	102	20	62
Average	118		53		146		41		104		41	

TABLE 14. Total suspended solids of 22 hours test run from Pälkäne samples

Leachates from Humuspehtoori Ltd, Pälkäne												
22h test run												
TSS (mg/l)	Replica 1				Replica 2				Replica 3			
	Influent		Effluent		Influent		Effluent		Influent		Effluent	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
ma	542,9	542,4	535	544,8	540,5	542,8	539,8	517,1	516	515,7	510,4	540
mb	539	535,3	533,4	543	536,9	537,7	538,2	513,3	511,9	510,3	509,6	536,6
c	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
TSS	78	142	32	36	72	102	32	76	82	108	16	68
Average	110		34		87		54		95		42	

ma= Filter mass after filtration (mg)

mb= Filter mass before filtration (mg)

c= Sample volume (l)

TSS= (ma-mb)/c

In the graph 34 are the average amounts of total suspended solids from 6, 16 and 22 hours treatment with willow stack tower. The influent of third replica of 6 hours test run was taken few minutes earlier during the filling of the willow stack tower than other replicas or test runs, which has to be taken into consideration when comparing to the other replicas or other test runs.

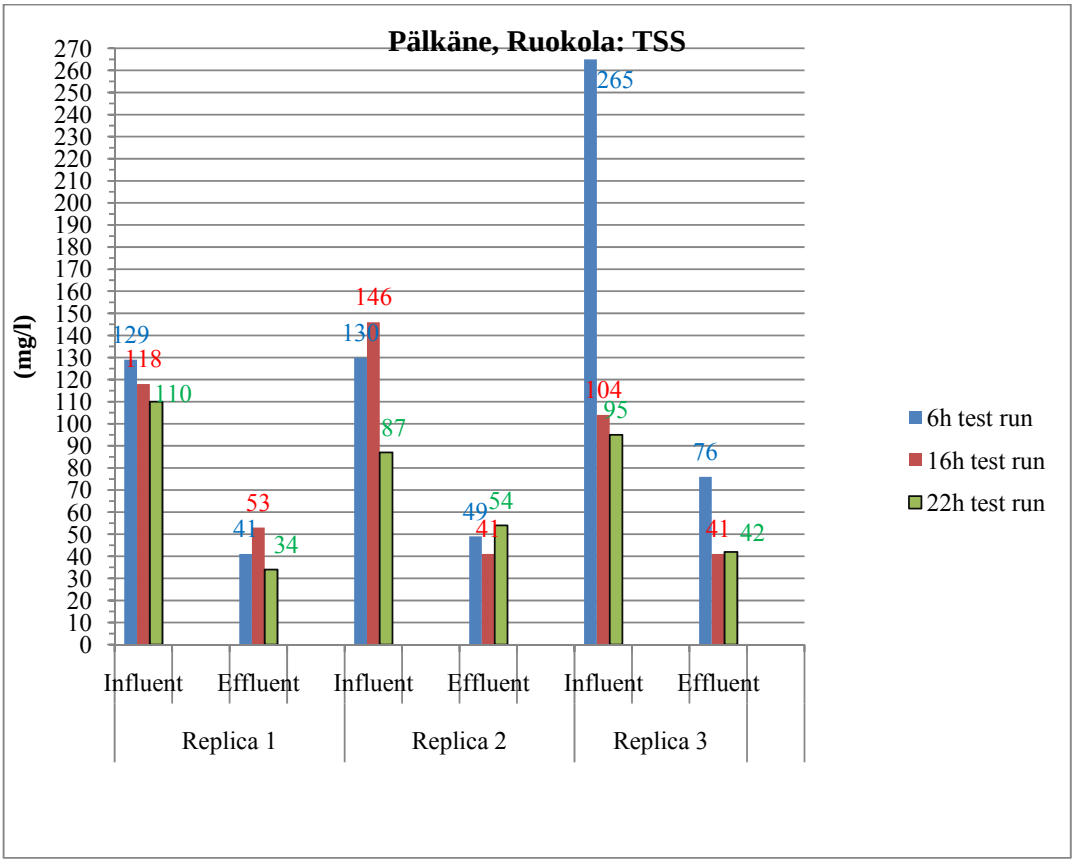

FIGURE 34. Average total suspended solids from Pälkäne samples

In the graph 35 is the more simplified average version of total suspended solids from which the third replica of 6 hours test run is ignored due to different sampling time to gain more accurate average.

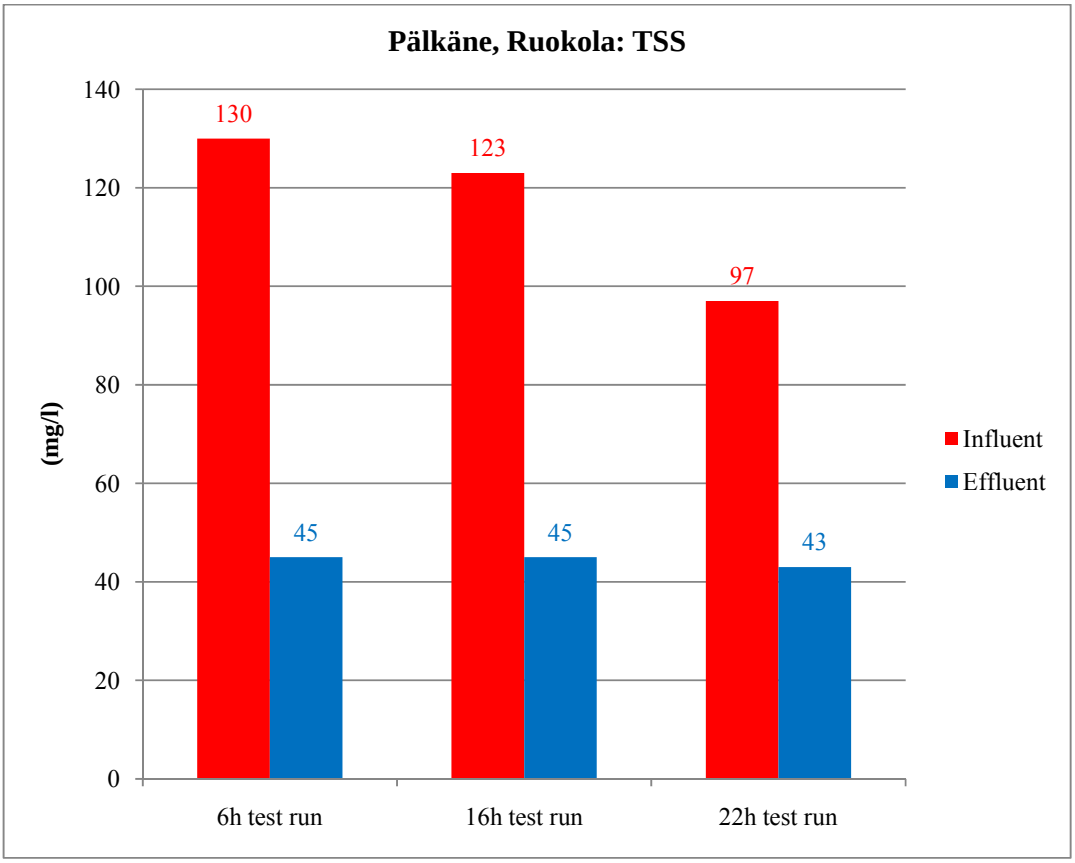

FIGURE 35. Average total suspended solids from Pälkäne samples

3.2.5 Heavy metals (Cd, Cr, Fe, Pb, Zn, Cu and Ni)

Iron (Fe), zink (Zn), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb) and cadmium (Cd) from Pälkäne samples were analysed with AAS. The samples were taken to Tampere University of Applied Sciences to be preserved and later on analysed. From the results only iron is presented in the report, as other elements were discarded due to the high occurrence of zero values in their results.

TABLE 15. Average concentration of iron from Pälkäne samples

Sample	iron (mg/l)
06-01-i	1,5359
06-01-E	1,6779
06-02-i	1,3634
06-02-E	1,3886
06-03-i	0,6657
06-03-E	1,7254
16-01-i	1,6355
16-01-E	1,9970
16-02-i	1,7027
16-02-E	1,9936
16-03-i	2,1409
16-03-E	1,8650
22-01-i	1,8636
22-01-E	1,5148
22-02-i	1,1599
22-02-E	1,3430
22-03-i	1,2672
22-03-E	1,6465

Analysed on 28.12.2010

In the graph 36 are shown the results of iron concentrations in Pälkäne samples.

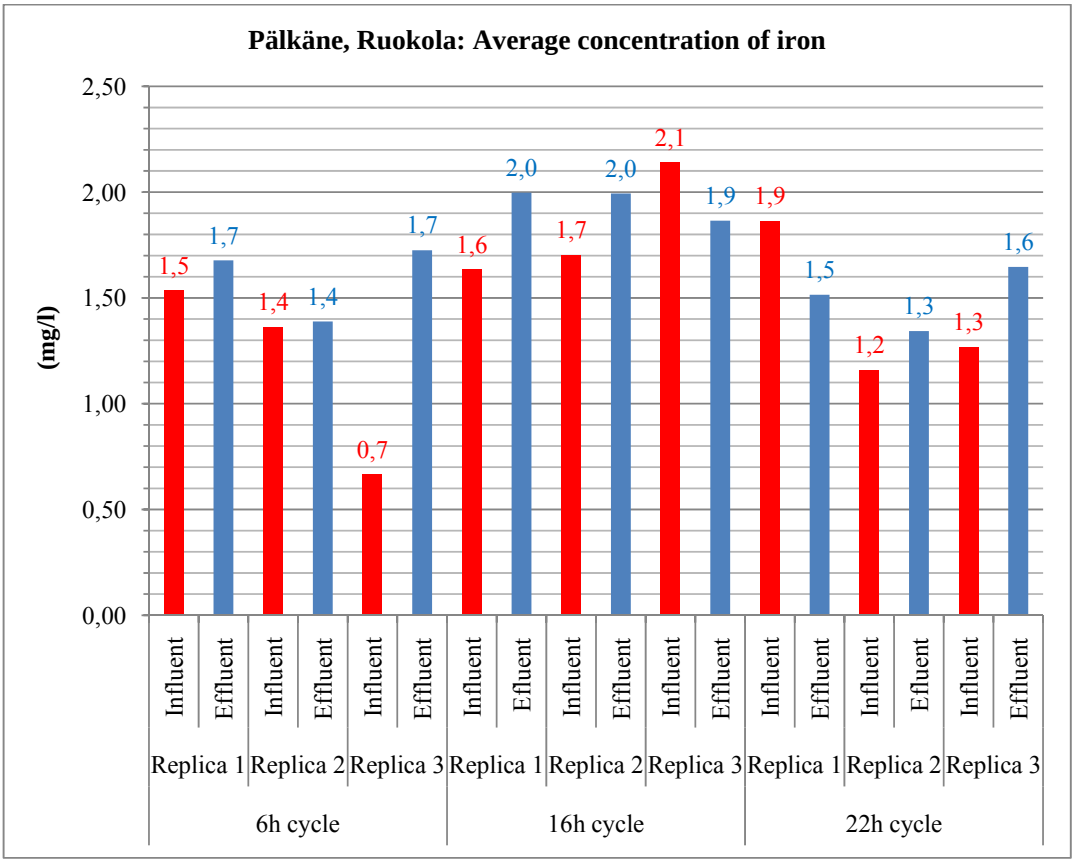

FIGURE 36. Average concentrations of iron from Pälkäne samples

3.2.6 Total nitrogen (TN)

In the table 16 are the average results of total nitrogen analysed from samples taken from Pälkäne.

TABLE 16. Average concentrations of total nitrogen from Pälkäne samples

Sample	Average TN (mg/l N)
06-01-i	30,48
06-01-E	14,68
06-02-i	30,76
06-02-E	14,93
06-03-i	38,23
06-03-E	11,93
16-01-i	40,79
16-01-E	26,05
16-02-i	99,59
16-02-E	44,00
16-03-i	109,39
16-03-E	43,24
22-01-i	124,21
22-01-E	21,27
22-02-i	90,22
22-02-E	25,77
22-03-i	94,88
22-03-E	26,52

Analysed on 3-12.01.2011

In the graph 37 is shown the average total nitrogen from Pälkäne samples. The average is taken from three test run replicas.

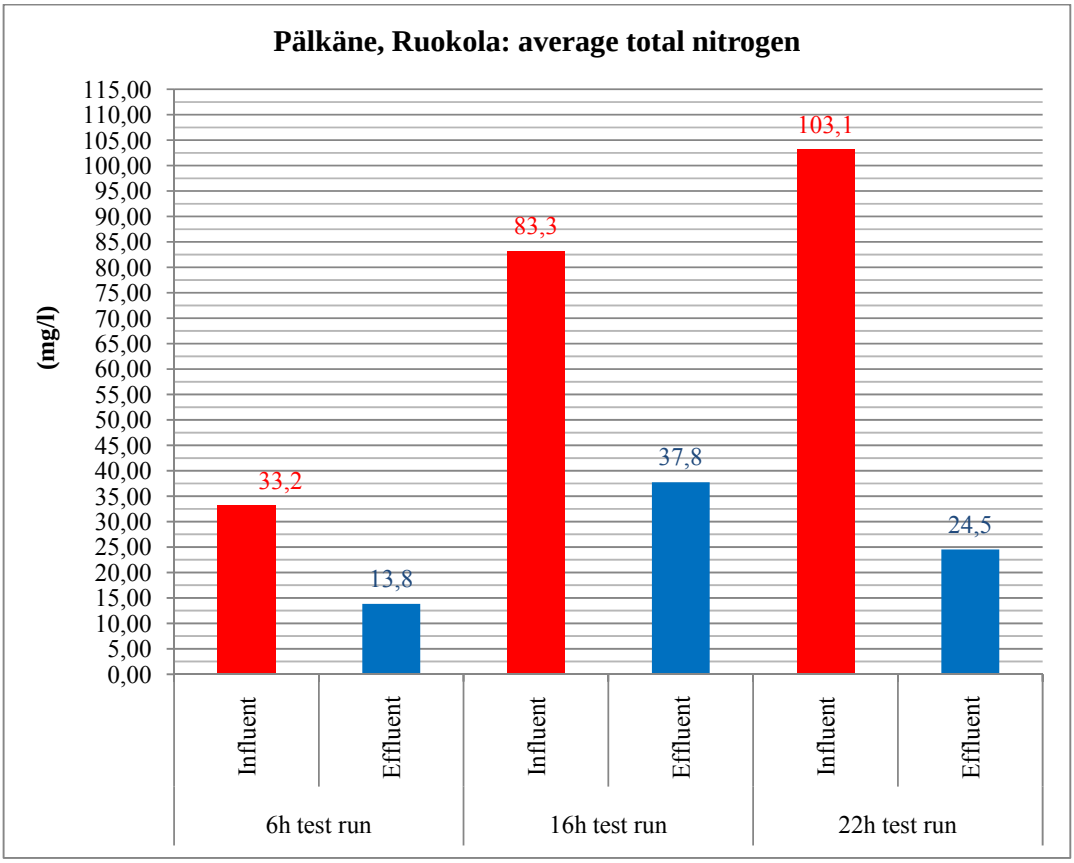

FIGURE 37. Average TN from Pälkäne samples

3.2.7 Total phosphorus (TP)

In the table 17 are presented the average results of total phosphorus from Pälkäne samples.

TABLE 17. Average concentration of total phosphorus from Pälkäne samples

Sample	Average TP (mg/l)
06-01-i	6,00
06-01-E	3,50
06-02-i	4,00
06-02-E	3,50
06-03-i	11,50
06-03-E	3,00
16-01-i	1,85
16-01-E	2,00
16-02-i	1,90
16-02-E	2,05
16-03-i	2,05
16-03-E	2,10
22-01-i	1,15
22-01-E	3,55
22-02-i	1,00
22-02-E	1,40
22-03-i	5,60
22-03-E	1,35

Analysed on 16-18.02.2011 and 13.03.2011

In the graph 38 are shown the average TP from Pälkäne samples.

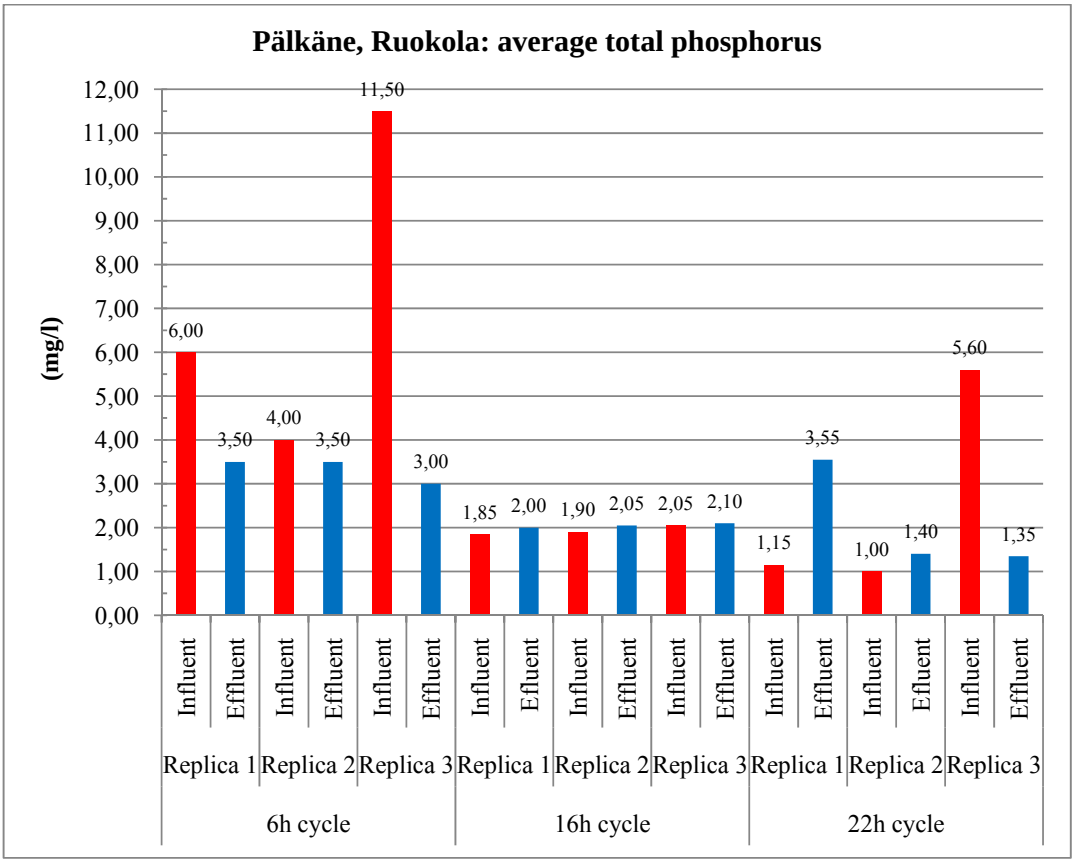

FIGURE 38. Average total phosphorus from Pälkäne samples

3.2.8 Oxygen (O_2)

In the table 18 are the results of oxygen measurements from Pälkäne samples.

TABLE 18. Oxygen levels from Pälkäne samples

Analysed	Sample	Temperature (°C)	Pressure (mmHg)	O2 (%)	O2 (mg/l)
16.8.2010	**Tap water**	20,9	736,8	96	**8,76**
26.8.2010	**06-03-i**	20,6	739,7	3,2	**0,28**
26.8.2010	**06-03-E**	17,6	739,8	89,1	**8,5**
16.8.2010	**16-01-i**	-		2	**0,17**
17.8.2010	**16-01-E**	15,3	748,4	88	**8,8**
17.8.2010	**16-02-i**	19,7	748,3	22	**2,4**
18.8.2010	**16-02-E**	15,1	743,8	86,1	**8,64**
18.8.2010	**16-03-i**	22,6	743,7	2,5	**0,22**
25.8.2010	**22-02-E**	15,6	736,6	88	**8,75**
25.8.2010	**22-03-i**	16,2	735,7	1,3	**0,12**
26.8.2010	**22-03-E**	20,6	739,7	81,2	**7,29**

In the graph 39 are the average oxygen levels of the samples from Pälkäne. The average was taken from the three test run replicas.

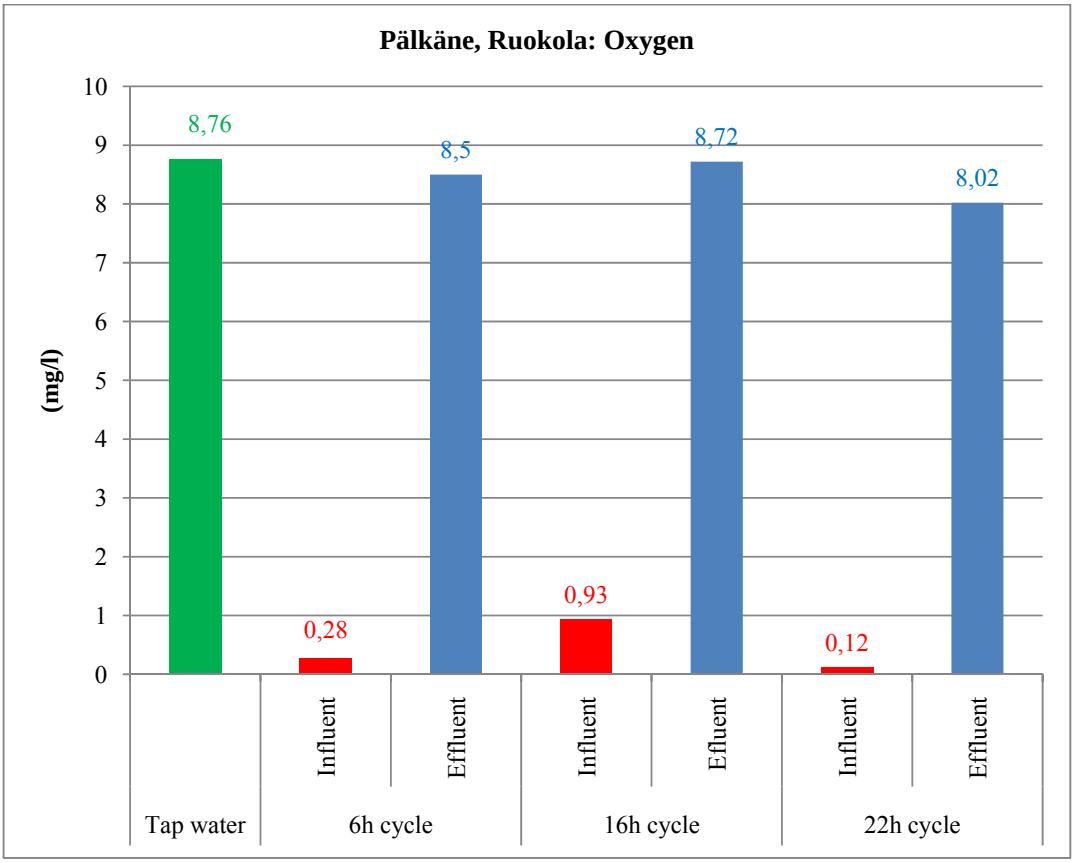

FIGURE 39. Average oxygen levels taken from Pälkäne samples

3.2.9 Evaporation

The evaporation was observed by measuring the depth when the pool below the willow stack tower was full, when it was going to be emptied (end of test run) and also before more leachate was added until the maximum capacity of the pool.

In the figure 40 is shown the structure of the pool under the willow stack tower as an overview. The pool had six support poles for the tower with ~99 cm long circumference. The poles are in the figure shown as brown circles. The pool was ~680 cm long, ~259 cm wide and 31-35 cm deep. The volume of the pool was approximately 6 m^3, which was measured with two water apparatus attached to two pumps. The estimated errors for the pool were ±1cm Δ length, ±1 cm Δ width, ±4 cm Δ depth and ±1 cm Δ for pole radius. In the calculations the average of 33 cm was used for depth to get the amount of evaporation.

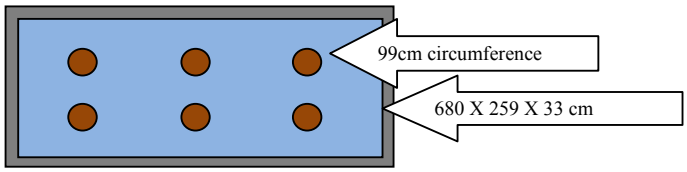

FIGURE 40. Overview of the pool under the willow stack tower in Pälkäne

The calculations of evaporation for 6, 16 and 22 hours test runs are presented by the formulas 6-10. First replica of 6 hours treatment is not presented here, because leachate levels were not yet recorded then.

Formulas of the pool volume and the poles:

$$V_{pool} = l * w * h \quad (6)$$

$$V_{poles} = \pi r^2 * h * 6 \quad (7)$$

$$C = \pi d \quad (8)$$

To get the radius from the equation $c = \pi d$ we needed to alter it with the following method:

Diameter equals radius multiplied by two:

$$d = 2r \quad (9)$$

Radius equals circumference divided by π divided by two

$$r_{pole} = \frac{\frac{C}{\pi}}{2} \approx 15{,}7\ cm \quad (10)$$

Where

V_{pool}=Volume of the pool (cm^3)

l= Length of the pool (680 cm)

w= Width of the pool (259 cm)

h= Depth of the pool (33 cm)

r= Radius of pole (cm)

C= Circumference of the pole (99 cm)

d= Diameter of the pole (cm)

Calculations of the error of the volume

$$V_{\Delta} = V_{max} - V_{min} \quad (11)$$

$$V_{Pool_{Max}} = 681\ cm * 260\ cm * 35\ cm = 6197100\ cm^3 = 6{,}2\ m^3$$

$$V_{Pool_{Min}} = 679\ cm * 258 * 31cm = 5430643\ cm^3 = 5{,}4\ m^3$$

$$V_{Pool_{\Delta}} = 6197100\ cm^3 - 5430643\ cm^3 = 766457\ cm^3 = \mathbf{0,8\ m^3}$$

$$V_{Poles_{Max}} = \pi * 16{,}7^2 * 35\ cm * 6 = 183993{,}3\ cm^3 = 0{,}2\ m^3$$

$$V_{Poles_{Min}} = \pi * 14{,}7^2 * 31cm * 6 = 126269{,}2\ cm^3 = 0{,}1\ m^3$$

$$V_{Poles_{\Delta}} = 183993{,}3\ cm^3 - 126269{,}2\ cm^3 = 57724{,}1\ cm^3 = \mathbf{0,06\ m^3}$$

The volume of the pool under the willow stack tower was $\mathbf{5,8\ m^3}$ with an approximate error of $\pm\mathbf{0,8\ m^3}$. The joint volume of the poles was $\mathbf{0,15\ m^3}$ with an approximate error of $\pm\mathbf{0,06 m^3}$.

TABLE 19. The volume and errors of the pool and poles

Volume of the 6 poles (min)	Volume of the 6 poles (average)	Volume of the 6 poles (max)	Error (max-min)
127239,0 cm^3	154427,9 cm^3	185236,9 cm^3	57997,9 cm^3
0,127 m^3	0,154 m^3	0,185 m^3	0,058 m^3
Volume of the pool (min)	**Volume of the pool (average)**	**Volume of the pool (max)**	**Error (max-min)**
5430642,0 cm^3	5811960,0 cm^3	6197100,0 cm^3	766458,0 cm^3
5,4 m^3	5,8 m^3	6,2 m^3	0,8 m^3

Evaporation in the test runs

The results of evaporation during the treatment are presented in the table 20 in cubic meters. The evaporation before adding more leachate and the evaporation in the end of the test run are added together to get the maximum evaporation during the test run.

TABLE 20. Evaporation of leachate during the test runs

Test run	R	Depth before adding more leachate (cm)	Time	Depth in the end (cm)	Time	Evaporation (m^3)	Average evaporation (m^3)
6h	2			27	14:00	1,1	**1,6**
	3			20,5	13:30	2,2	
16h	1			22,0	7:00	1,9	**2,3**
	2			25,0	5:35	1,4	
	3			12,0	6:00	3,7	
22h	1	19,0	20:00			**2,5**	**4,1**
	2	18,0	19:30	17,0	7:00	5,5	
	3	17,0	-	25,0	6:00	4,2	

The weather information during the test runs is presented in the table 21.

TABLE 21. Weather information for evaporation

Test run	R	Air (°C)	Wind speed (m/s)	Cloudiness	Rainfall	Humidity (%)
6 h	2	22	2,1	Sunny	No	53
6 h	3	13	3,1	Cloudy	Drizzle	88
16 h	1	7	2,6	Sunny	No	93
16 h	2	17	1,5	Cloudy	No	75
16 h	3	10	2,1	Dawn	No	76
22 h	1	9	2,1	Cloudy	No	93
22 h	2	10	1,5	Cloudy	No	100
22 h	3	10	1,5	Cloudy	No	100,0

3.2.10 Active surface area

Active surface area of one branch:

$$A_B = 2 \times \pi \times (1{,}5cm)^2 + 2 \times \pi \times 1{,}5cm \times 170cm = 1616{,}34cm^2 = \mathbf{0,16\ m^2}$$

The active surface area of one floor:

$$A_F = 1616{,}34cm^2 \times \frac{544cm}{3cm^2} \times \frac{131\text{cm}}{3cm^2} = 12795847{,}11cm^2 = \mathbf{1279,6\ m^2}$$

Total active surface area:

$$A_S = 12795847{,}11\ cm^2 \times 3 = 38387541{,}33\ cm^2 \approx \mathbf{3839\ m^2}$$

The active surface area of the willow stack tower was **3839 m²**.

4 CONCLUSIONS AND DISCUSSION

In this study the effectiveness of the willow stack tower as a component of a leachate treatment system in two different sites was studied. The two case studies included the sludge treatment field of Humuspehtoori Ltd in Ruokola and the closed landfill of Vaasa City in Suvilahti. In this chapter the efficiency of the willow stack tower was expressed in percentage of reduction regarding to the studied parameter and the type of treatment, and this in order to simplify the outcome of the study.

4.1 Vaasa, Suvilahti: Closed landfill

4.1.1 Phosphate phosphorus, total phosphorus, nitrate and nitrite (PO_4^-P, TP, NO_3 and NO_2)

In the case of the closed landfill in Vaasa, the outcome of the analyses suggested that the willow stack tower did not decrease the concentrations of phosphate phosphorus, total phosphorus, nitrate and nitrite but **increased it up to** 74,2 % (PO_4^-), 390 % (TP), 32,7 % (NO_3) and 69,9 % (NO_2) respectively for the **10 l/s flow rate test run**. For the **5 l/s flow rate test run** concentrations **increased up to** 90,9 % (PO_4-), 900 % (TP), 125 % (NO_3) and 11,3 % (NO_2) (graph 15 and 21). However the increase can be explained by the submerged inlet in the storage pond which made it difficult to obtain a undisturbed sample. Another possible explanation is that the influent which had low concentrations in nutrients increased in effluent due to particles collected from the surface of the willow during the flowing. This is due to the continuous demand of energy to restore structures and for reproduction of the living cells. If there is no energy (nutrients) available or very little, the cells start to deteriorate and die, and in this way release more nutrients in the effluent. (Water and Wastewater Microbiology, 145)

4.1.2 Total nitrogen (TN)

In the **10 l/s flow rate test run** there was **reduction down to** 21,5 % in total nitrogen, and for the **5 l/s flow rate test run** there was **reduction down to** 19,4 %. These results suggest that the willow has a positive effect in lowering the TN with no significant difference between the used flow rates (graph 20).

4.1.3 Biochemical and chemical oxygen demand ($BOD_{7\ ATU}$ and COD_{Cr})

When comparing the results in the graph 16, the effluent showed in the COD_{Cr} a **decrease** of 1,7 % for the **10 l/s and 5 l/s flow rate test runs** respectively, which suggested that the willow treatment had a slight improvement in the reduction of COD_{Cr} regardless to the flow rate. The $BOD_{7\ ATU}$ had contradictory results since the results from the **10 l/s flow rate test run** suggested that the $BOD_{7\ ATU}$ **increased** by 12 % in the effluent while it **decreased** by 25,9 % in the effluent of **5 l/s flow rate test run**. These results cannot be used to draw a definitive conclusion on the effectiveness of the willow in the reduction of $BOD_{7\ ATU}$.

4.1.4 Appearance and odor

When comparing the samples, the effluent was easily distinguished from the influent as it can be seen from the pictures 18 and 19. The influent from Suvilahti landfill had a greenish colour, while the effluent had a light yellow colour. This led us to the conclusion that the willow tower had by reducing the turbidity and algae clearly improved the appearance of leachate and therefore was efficient in the improvement of appearance. Concerning the odor parameter, no odor was detected from leachate of Suvilahti before or after the treatment.

4.1.5 *Coliforms* and Fecal *Streptococci*

From graph 17 a **decrease to** 44 % in the amount of *Coliforms* for **10 l/s flow rate test run** and a **decrease down to** 11,1 % for **5 l/s flow rate test run** are seen in the samples from Vaasa. The reduction of Fecal *Streptococci* was contradictory in both test runs. The flow rates of 5 and 10 l/s did not affect the results significantly.

4.1.6 Total suspended solids (TSS)

Based on the results from TSS in table 6 it seems that in the **10 l/s flow rate test run** the amount of the suspended solids **increased** after the willow treatment, where as in **5 l/s flow rate test run** it **decreased**, which possibly could be explained by the water drag force caused by the increased flow rate.

As an overall conclusion the willow stack treatment in Vaasa, Suvilahti did not show a high efficiency in the removal of nutrients and suspended solids from influent, but that could be explained by the type of leachate which was originally poor in nutrients and had a low turbidity. The effects of **flow rates 10 l/s and 5 l/s** on the treatment capacity differed from a parameter to another and therefore cannot be considered as an affecting element. The landfill leachate might have been too diluted for maintaining the functioning of the willow treatment. However the willow stack tower from Vaasa was surprisingly efficient in the removal of biological agents. Heavy metal concentrations were low and therefore were not used for comparison. No significant correlation was detected when comparing the results of the analysed parameters with variables such as air temperature, relative humidity and wind speed. Due to the difficulty of obtaining representative influent samples, the research should be continued for conforming the results.

4.2 Pälkäne, Ruokola: Sludge treatment field of Aukeasuo

The values shown in the reduction tables were taken either from replicas with the highest treatment outcome, or from the average of the three replicas depending on the graphs presented in the results. In the cases of contradictory results, the maximum and minimum values were taken into consideration. For example the third replica of six hours test run was included in the reduction tables only in the cases where the values were similar to the previous replicas, this was because the sample of the influent was taken prematurely. The effects can be seen as higher peaks in the *Coliforms*, TSS and total phosphorus results (graphs 24, 34 and 38).

4.2.1 Phosphate phosphorus, total phosphorus, nitrate, nitrite and total nitrogen (PO_4^-P, TP, NO_3, NO_2 and TN)

Reduction %					
Test run	**PO_4-P**	**TP**	**NO_3-N**	**NO_2-N**	**TN**
6h	90,8	73,9	**Inc.** 75/ **Dec.** 20	**Inc.** 24	58,4
16h	92,2	**Inc.** 8,1	70	**Inc.** 6	54,6
22h	97,1	**Inc.** 208/ **Dec**. 75,9	50	**Inc.** 3	76,2

From the reduction table we can see that the willow treatment of Pälkäne was very efficient in the reduction of phosphate phosphorus since it **decreased down to** 97,1 % in the **22 hours test run** (graph 30), when nitrites **increased** from 0 **up to** 24 % in **6 hours test run** (graph 22). For nitrates the results were contradictory in the **6 hours test run**, since they **increased up to** 75 % and **decreased down to** 20 %, but were **decreasing** for the **16 hours** (graph 26) and **22 hours test runs**.

The total nitrogen **decreased** in all the test runs of Pälkäne, with highest reduction results from **22 hours test run** (graph 37). No consistent conclusion could be drawn from the influence of the duration of treatment, since in some parameters the longest treatment time improved the quality, while in others it did not have a remarkable effect or even reduced the efficiency of the treatment.

4.2.2 Appearance and odor

From figures 25, 29 and 33, we can clearly see the difference in the colour after the willow treatment. The colour had changed from dark brown to brownish yellow, which proves the efficiency of the willow stack tower treatment in Pälkäne in the reduction of turbidity, and by this improved the appearance of leachate. The effect of the duration of the treatment (6, 16 and 22 hours test runs) on the appearance could not be distinguished by eye.

Concerning the odor parameter, a strong and unpleasant odor due to the decaying organic matter was clearly detected in the influent, however after the willow treatment the odor disappeared from all of the effluent samples from Pälkäne regardless to the duration of treatment.

4.2.3 Biochemical and chemical oxygen demand ($BOD_{7\ ATU}$ and COD_{Cr})

Reduction %		
Test run	**$BOD_{7\ ATU}$**	**COD_{Cr}**
6h	81	39,6
16h	82,2	37,9
22h	84,3	44,1

$BOD_{7\ ATU}$ and COD_{Cr} were reduced the most by **22 hours test run** with **reduction** of 84,3 % and 44,1 % in the samples from Pälkäne (graph 31).

4.2.4 *Coliforms* and Fecal *Streptococci*

Reduction %		
Test run	***Coliforms***	**Fecal *Streptococci***
6h	99,5	100
16h	**inc.** 310/**Dec.** 98,3	97,8
22h	97,2	100

6 hours is the most suitable duration of treatment when compared to 16 and 22 hours treatments, due to the instability of 16 hours treatment and the reduced efficiency of 22 hours treatment for *Coliforms*. Also the best reduction value for Fecal *Streptococci* is reached already with 6 hours treatment (graphs 24, 28 and 32).

4.2.5 Total suspended solids (TSS)

Reduction %	
Test run	**TSS**
6h	**65,4**
16h	63,3
22h	55,7

Cycling leachate in the willow stack tower for 6 hours seems to be the most suitable duration of treatment when compared to 16 and 22 hours treatment (graphs 34 and 35).

As an overall conclusion the willow stack tower in Pälkäne proved to be very efficient in the removal of nutrients except for nitrite which increased substantially with the increase in treatment time, and total phosphorus which was unstable in the 16 and 22 hours treatment. The biochemical and chemical oxygen demand were reduced the most in 22 hours treatment. The willow stack tower turned out to be very efficient in the removal of the biological agents and suspended solids, especially in the 6 hours treatment. Heavy metal concentrations were low and therefore were not used for comparison. No significant correlation was detected when comparing the results of the analysed parameters with the variables such as air temperature, relative humidity and wind speed.

Based on the results the 6 hours treatment is efficient enough and also fulfils the emission requirements of $BOD_{7\ ATU}$ (65 % reduction) in the environmental permit PIR-2005-Y-9-111, which was delivered by the Environmental Administration of Pirkanmaa region on 23rd of November, 2006. The environmental permit has been given for the leachate treatment system in the sludge treatment field of Aukeasuo as a whole and therefore the emission limit values present higher values than what would be

required from one unit (willow stack tower) of the whole treatment system. The requirement of the environmental permit for total phosphorus (1,5 mg/l) was fulfilled with 22 hours treatment. Due to the size of the tower and longer treatment time in Pälkäne the increased evaporation could lead to the drying of the willow if not supervised and more leachate added, and so reduce the efficiency of the micro-organisms on the surface of the willow. Therefore 22 hours treatment is not suitable for towers with large area (dimensions) and windy weather conditions which could lead to drying of the willow but could be used with towers which have larger pools to ensure continuous flow of leachate.

If the willow stack tower results from the sludge treatment field of Aukeasuo would be examined in the light of the Government Decree on Urban Waste Water Treatment 888/2006 which was created for wastewater treatment facilities, the emission requirement of $BOD_{7\ ATU}$ (70 % reduction) and total phosphorus (80 % reduction) were already achieved with 6 hours of treatment, but total nitrogen (70 % reduction) was achievable with 22 hours treatment. COD_{Cr} (75 % reduction) and total suspended solids (90 % reduction) were not reached in any of the treatments.

As an unit of a treatment system the tower would be efficient and low cost option to have, but the tower could also be used as a independent treatment unit depending on the reduction requirements on the site, since the tower is efficient in reduction of parameters such as $BOD_{7\ ATU}$, phosphate phosphorus, bacteria, COD_{Cr}, suspended solids and total nitrogen.

4.3 Some observations

This work was challenging but turned out to be an interesting task to manage. Furthermore the study was delayed due to changes in analysing timetable caused by delayed laboratory construction, which consequently led to the postponing of the analyses to be done on the preserved samples for total phosphorus, total nitrogen and heavy metals, and therefore the research should be continued especially for further studying of these parameters.

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Formulas

Tables

Figures

APPENDIXES

APPENDIX 1. Odor circle

Environmental laboratory of Vaasa City

HAJUYMPYRÄ – (LUFTCIRKEL)
LUKT CIRKEL