Master’s Thesis 2014

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Title: Investigation to improve the coagulation process at Lillevik WWTP, Larvik

Abstract

Investigation to improve the wastewater treatment, focusing on the coagulation process, at Lillevik WWTP has been performed. Four activities were carried out for this purpose:
1. Investigate variations and correlations for all plant process data. 2. Study coagulation process in Jar test experiment. 3. Analysis of decentralized food processing wastewater treatment possibility theoretically and experimentally with biogas potential test and by economic feasibility estimation. 4. Theoretically evaluate the option of adding a biological contact process to the main treatment process.

The existing data from the full scale plant since January 2012 show insufficient organics removal (measured as BOD and COD). It is seasonal and related to food processing wastewater, so local treatment of such was investigated. Local biological wastewater treatment can be efficient at a few companies to reduce COD inlet at Lillevik WWTP. Economic feasibility estimation suggests it as a reasonable solution.

Jar tests using the coagulants presently in use gave consistent results showing that the method can be used to investigate chemical coagulation process improvements such as using different coagulants. The coagulation efficiency was reduced by the long distance from rapid mixing to flocculation. The chemical addition spot should therefore be moved closer to the flocculation. Adding a biological contact process to the main treatment process by aerobic treatment of the sludge reject water before it is returned to the coagulation appears to be an efficient measure. It can be a good way to improve the coagulations since active biomass can absorb dissolved organics before they are removed as sludge by coagulation.

Since none of above mentioned measures alone is expected to enhance wastewater treatment as needed to always fulfil discharge requirement, integration of some of these solutions can be sufficient and should be further investigated.

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Preface

This report was made on the topic "Investigation to improve the coagulation process at Lillevik WWTP, Larvik" as a Master Thesis of M.Sc. Programme in Telemark University College, Faculty of Technology under supervision of Prof. Rune Bakke.

Theoretical and practical aspects of research, results, and recommendations for future investigation are presented in the following report. Master Thesis was focused on optimization of existing treatment process to increase the removal efficiency of nutrients at Lillevik wastewater treatment plant, Norway. The aim was to help to establish efficient solutions to the existing challenges.

The author express great appreciation to main supervisor of the Master Thesis Prof. Rune Bakke for help and significant contribution, to representatives of Lillevik wastewater treatment plant Ragnar Kløverød, Runar Olsen, Geir Pedersen for productive cooperation, to administration of food processing industries in Larvik Municipality for significant input, to Associate Professor Carlos Dinamarca and Senior Laboratory Engineer Hildegunn H. Haugen for assisting the performance of the experiments.

Porsgrunn, May 30, 2014

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Nomenclature

AD	= Anaerobic Digestion
AN	= Ammonical Nitrogen
BOD	= Biochemical Oxygen Demand
CAPEX	= Capital Cost
COD	= Chemical Oxygen Demand
D	= Diameter
H	= Height
HRT, τ	= Hydraulic Retention Time
FOG	= Fat-Oil-Grease
M	= Mass flow rate
MLSS	= Mixed Liquor Suspended Solids
MLVSS	= Mixed Liquor Volatile Suspended Solids
NR	= Nitrification Reactor
OPEX	= Operational Cost
PAX	= Polyaluminium Chloride
PCA	= Principle Component Analysis
PIX	= Ferric Chloride Sulphate
Q	= Volume of Gas
sCOD	= Soluble Chemical Oxygen Demand
T	= Temperature
tCOD	= Total Chemical Oxygen Demand
TN	= Total Nitrogen
TP	= Total Phosphorus
TS	= Total Solids
TSS	= Total Suspended Solids
UASB	= Upflow Anaerobic Sludge Blanket reactor
V	= Volume of Liquid
$\dot{V}$	= Volume Flow Rate
v	= Velocity
VS	= Volatile Solids
VSS	= Volatile Suspended Solids
WWTP	= Wastewater Treatment Plant

Overview of tables and figures

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1 Introduction

1.1 Regulations for municipal wastewater treatment in Norway

There are environmental, economic and global issues related to wastewater treatment which makes it necessary to introduce relevant limits and regulations into process. The Norwegian Pollution Control Authority is responsible for the formulation of the municipal waste treatment and sewage directives. The directives previously were mostly focused on the phosphorus removal from chemical treatment. Whereas, installation of additional biological treatment is recommended for the nutrient sensitive areas after 2007. It is also emphasized that the Norwegian treatment plants have to adapt the requirements of the European Union - The Urban Wastewater Treatment Directive (UWWTD) (Official Journal of Europian Comminities, 1991). The summary of existing regulations for Norwegian and European Union wastewater treatment processes (minimum required reduction of nutrients in process and maximum allowed concentration of nutrients at discharge) is presented in Table 1-1 (Kibiakova, et al., 2013).

Table 1-1 : Summary of Regulations for municipal wastewater treatment in Norway.

	The Urban Wastewater Treatment Directive, EU		Regulations for municipal wastewater treatment in Norway	
Parameter	Primary Treatment	Secondary Treatment	Primary Treatment	Secondary Treatment
BOD_5	> 20% reduction	> 70% reduction, < 25 mg O_2/l	> 20% reduction, < 40 mg O_2/l	> 70% reduction, < 25 mg O_2/l
Suspended solids	> 50% reduction	> 90% reduction, < 35 mg O_2/l	> 50% reduction, < 60 mg O_2/l	
COD		> 75% reduction, < 125 mg O_2/l		> 75% reduction, <125 mg O_2/l
Phosphorus		- for <100 PE: > 80 % reduction, <2 mg O_2/l; - for >100 PE: > 80 % reduction, <1 mg O_2/l.		> 90 % reduction.
Nitrogen		- for <100 PE: > 70 % reduction, <15 mg O_2/l - for >100 PE: >70 % reduction, <10 mg O_2/l		> 70 % reduction.

Regarding (Larvik Kommune, 2013): Removal efficiencies at Lillevik WWTP established by authority have to be as following: For COD - 75 %, for BOD – 70%, for P – 90 %. The authorities are now focusing increasingly on removal of organic matter, which amount is growing with population rise and new industrial facilities appearance.

1.2 Lillevik wastewater treatment plant

Lillevik wastewater treatment plant was opened in 2001. The current process scheme is presented on Figure 1-1.

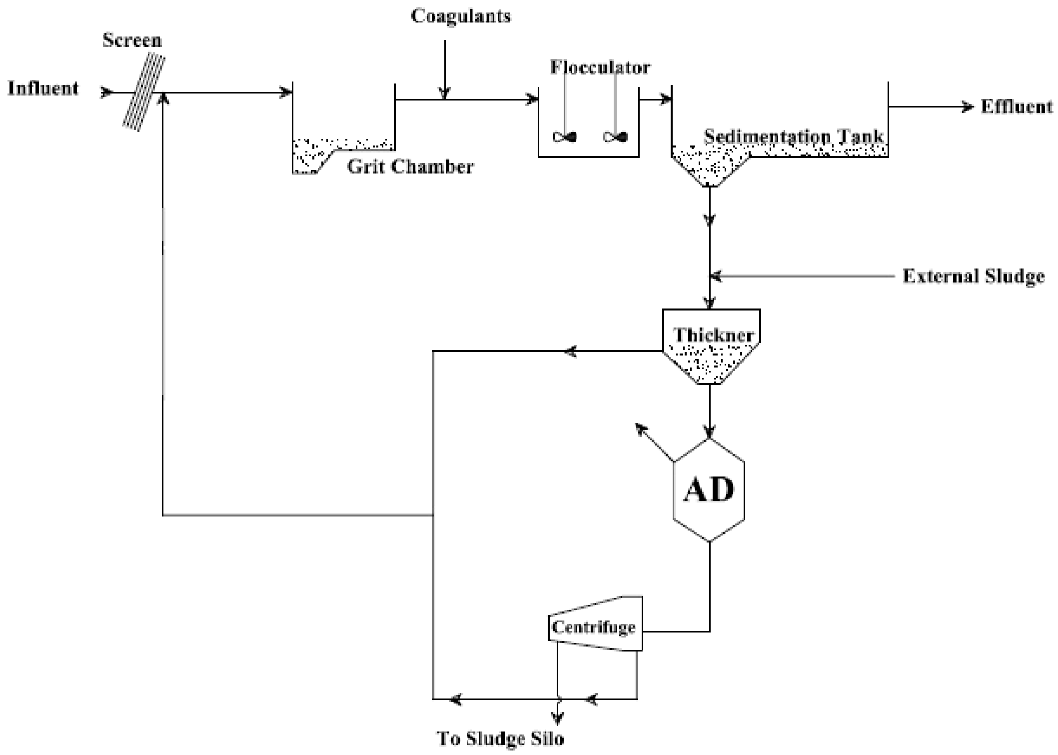


Figure 1-1: Process diagram of Lillevik WWTP

Wastewater from Larvik municipality is collected and supplied to the WWTP by pipeline in the sea across Larviksfjord. The current capacity of this plant is 65000 PE and the operating load is 37000 PE (Larvik Kommune, 2013). Process part of the plant includes installations for cleaning of wastewater and sludge. Treatment of wastewater is a combination of the mechanical and chemical with PAX and PIX coagulants addition in amount of: For normal water - 110 ml/m^3 and 70 ml/m^3 respectively; for diluted water - 50 ml/m^3 and 50 ml/m^3. The system for estimation of the optimum coagulant dosage, DOSCON (Doscon AS, n.d.), will be installed at Lillevik WWTP in 2014. Chemicals are added to main stream after preliminary treatment around 10 m before flocculation chamber.

In main treatment stages hydraulic retention time is about 1 day. External sludge from Kvelde, Hvarnes and Lardal is treated also. The sludge from the thickener is heated to about 65-70 ^{o}C, according to regulations.

Lillevik WWTP works as the control center for the wastewater sector in Larvik with an operational control system that monitors treatment plants and pumping stations online.

Municipality including treatment plant is quality and environmentally certified (ISO 9001 and ISO 14001).

Removal efficiency limits are established by government as mentioned in previous chapter. A variety of external and internal factors make it increasingly challenging to comply with discharge limits. An MSc student project (Kibiakova, et al., 2013) investigation shows that organic matter (COD, BOD) removal is the main challenge and that it is especially hard to meet the discharge limits during the seasons when receiving wastewater from commercial food processing. Improved chemical coagulation, adding a biological process and decentralized food processing wastewater treatment are measures that can be implemented to meet the challenge.

1.3 Problem description and objectives of research

Nowadays discharge limits are reconsidered and wastewater treatment plants have to modify or reconstruct their current process.

The main goal for this research is to make experimental and theoretical investigations of the possible measures identified to improve the Lillevik WWTP performance.

The main objectives of the research are to investigate inlet wastewater composition variations, to check the location of the dosage of chemical coagulants, to study control of dosage of chemical coagulants, to explore the possibility of alternative chemical coagulants usage, to study and simulate biological contactor process effects, to simulate decentralized food processing wastewater treatment. One of the purposes of this study is to extract information from existing data and to generate new information that can be used to improve process performance.

Variety of possible solutions for these problems was considered using theoretical and experimental results of MSc student project (Kibiakova, et al., 2013). Jar test was held with Phosphorus, Turbidity, pH and sludge height measurements. Biogas potential test was performed to examine the possibility and extent of COD and nutrients local removal at food processing companies, Phosphorus, Turbidity, pH, COD and BOD were measured also.

Following chapters will introduce above mentioned issues in more detailed way: Laboratory experiment, calculations, derivations and theoretical analysis.

2 Theoretical part

2.1 Coagulation and Flocculation Process Optimization

2.1.1 General description of the processes and system

The main keywords and definitions for coagulation and flocculation process parameters are listed in 0. Normally three types of basins are needed for coagulation and flocculation system: Rapid mixing tank, flocculation tank, settling basin (Figure 2-1).

According to (Tambo, 1965) coagulant is a substance with opposite charge than that of suspended solids present in water. Coagulation is the process of mixing of coagulant in order to neutralize the negative charges on the suspended particles and make them to settle. After the neutralization of charges suspended particles are capable to stick with each other to form slightly larger particles called microflocs. The water surrounding those microflocs will be purified. If it is not then the charges on the particles are not completely neutralized and we need to add more amount of coagulant. For effective coagulation, a high energy rapid mixing is needed to ensure proper dispersion of coagulant and better collisions between the particles.

After coagulation, the slow mixing process in which the particle size increases from submicroscopic microfloc to visible suspended particles is known as flocculation. Due to slow mixing the microflocs come in contact with each other and collide to form larger and visible flocs known as pin flocs. The flocs go on increasing their size due to repeated collisions and interactions with the inorganic polymers formed by coagulation or with organic polymers added. At this point higher molecular weight polymers can be added to facilitate the formation of macroflocs of increased size, weight, strength, bonds and settling rate.

The water is finally ready for sedimentation after it reaches its optimum size (Minnesota Rural Water Association, 2012).

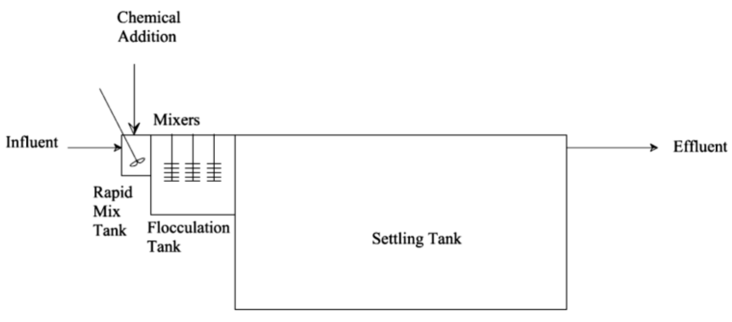


Figure 2-1: Coagulation/ Flocculation – Three tank system (Safferman, n.d.)

2.1.2 Selection of proper coagulant

2.1.2.1 Main purposes of chemical coagulation at Lillevik WWTP

The main goals of chemical precipitation process at Lillevik WWTP are: Destabilisation of the stable particles and phosphorus removal.

Destabilization of particles (suspended or colloidal) described in previous chapter can be achieved by the addition of suitable coagulant: Inorganic or organic, is described further in this chapter.

The removal of phosphorus from wastewater involves: Incorporation of phosphate into solids (biological or chemical precipitates) and removal of solids as described above. Chemical precipitation of phosphorus can be done by salts and multivalent metal ions addition or usage of polymers. It can take place in different sections in the plant: Pre-precipitation, co-precipitation, post-precipitation. Advantages of phosphorus removal via primary treatment used at Lillevik compared to treatment at other levels are: Increased BOD and suspended solids removal, lowest degree of metal leakage (Tchobanoglous , et al., 2004).

Different types of coagulants used in wastewater treatment process have various advantages as well as disadvantages. The following factors should be considered before selection of coagulants (Welty, 2001; Tchobanoglous , et al., 2004):

1. Effectiveness and Cost.
2. Reliability of supply.
3. Conditions of raw water.
4. Sludge considerations.
5. Compatibility with other treatment processes.
6. Environmental effects.
7. Labor and equipment requirements for storage, feeding, and handling.

The final selection must be done based on Jar Test and plant scale experiments, with required effluent quality, cost of the chemical coagulants, cost and method of sludge handling/disposal.

2.1.2.2 Chemical Coagulants at Lillevik WWTP

The commercial names of the coagulants that are being used in Lillevik waste water treatment plant are PIX 18 (ferric chloride sulphate) and PAX 318 (polyaluminum chloride). PIX is available in liquid form whereas PAX is available in liquid and solid form. They are inorganic coagulants. In Lillevik WWTP, both of these coagulants are used in liquid form simultaneously. PIX is used primarily to control hydrogen sulfide formation, odor and for phosphorus removal applications (Kemira, 2014). PAX is used for phosphorus and particle removal. Additional benefits claimed for PAX compared to alternative coagulants are reduced sludge production, minimized pH adjustment, improved treatment and good performance in cold-water applications (Kemira, 2014).

2.1.2.3 Alternative Coagulants

Coagulants and coagulant aids are classified mainly into inorganic coagulants and polyelectrolytes. Polyelectrolytes are further divided into synthetic organic polymers and natural organic polymers.

Inorganic coagulants

Inorganic coagulants are classified as the following three types: Alum derivatives; iron derivatives; lime.

All common aluminium and iron coagulants are acid salts except sodium aluminates. Therefore the pH of treated water decreases due to addition of these coagulants. The pH affects particle surface charge and floc precipitation during coagulation. Thus based on alkalinity and pH, lime may be used to compensate the pH depression (Welty, 2001).

Table 2-1 describes briefly the advantages and disadvantages of different commonly used coagulants (Welty, 2001).

Table 2-1: Inorganic alternative coagulants

Name	**Advantages**	**Disadvantages**
Aluminium Sulphate (Alum) $Al_2(SO4)_3.18H_2O$	Easy to handle and apply; most commonly used; produces less sludge than lime; most effective between pH 6.5 and 7.5	Addition of dissolved solids (salts) to water; effective over a limited pH range.
Sodium Aluminates $Na_2Al_2O_4$	Effective in hard waters; small dosage usually needed	Often used with alum; high cost; ineffective in soft waters
Polyaluminum Chloride (PAC) $Al_{13}(OH)_{20}(SO_4)_2.Cl_{15}$	In some applications, floc formed is more dense and faster settling than alum	Not commonly used; little full scale data compared to other aluminium derivatives
Ferric Sulphate $Fe_2(SO_4)_3$	Effective between pH 4–6 and 8.8–9.2	Adds dissolved solids (salts) to water; usually need to add alkalinity
Ferric Chloride $FeCl_3.6H_2O$	Effective between pH 4 and 11	Adds dissolved solids to water; consumes twice much alkalinity as alum
Ferrous Sulphate (Copperas) $FeSO_4.7H_2O$	Not as pH sensitive as lime	Adds dissolved solids (salts) to water; usually need to add alkalinity
Lime $Ca(OH)_2$	Commonly used; very effective; may not add salts to effluent	Very pH dependent; produces large quantities of sludge; overdose can result in poor effluent quality

Polyelectrolytes

Polyelectrolytes are water soluble organic polymers. They are used as primary and secondary coagulants and coagulant aids. Polyelectrolytes are cationic, anionic and non-ionic in types. The advantages of polyelectrolytes over inorganic coagulants are as follows (Welty, 2001).

1. The sludge volume produced can be reduced by 50 to 90% during treatment.
2. The sludge formed can be dewatered easily as it contains less water.
3. There is very less or no need for an alkaline chemical such as lime, caustic, or soda ash, as polyelectrolytes have no effect on pH.
4. Polymeric coagulants do not add to the total dissolved solids concentration.
5. Polymeric coagulants can reduce the problem of soluble iron or aluminum carry over in the clarifier resulting from inorganic coagulant use.

2.1.3 Initial mixing importance

As stated in (Hudson & Wolfner, 1967): "Coagulants hydrolyze and begin to polymerize in a fraction of second after being added to water". Immediate rapid and uniform mixing after addition of metal salts is therefore necessary according to (Tchobanoglous , et al., 2004). For alum and ferric chloride coagulants used in the process at Lillevik WWTP typical mixing times for coagulation of colloidal particles is <1 s and for sweep flocs precipitation – 1-10 s (Tchobanoglous , et al., 2004). After homogenous distribution of flocculent molecules by rapid mixing, the following slow mixing leads to collision of small flocs (not breaking) and growth to their hydrodynamically-stable final sizes. With too low or too high intensity of mixing, or pause in the middle of mixing process only partial flocculation may occur because of inhomogeneous distribution of flocculent (Tuba Taşdemir, 2012).

2.2 Anaerobic treatment

2.2.1 General description

Anaerobic digestion (AD) is a process in which organic and inorganic matter are decomposed and converted to biogas (mainly CH_4 and CO_2) in the absence of molecular oxygen via activity of several groups of anaerobic microorganisms linked trophically to each other.

There are four key biological and chemical stages of anaerobic digestion presented on Figure 2-2.

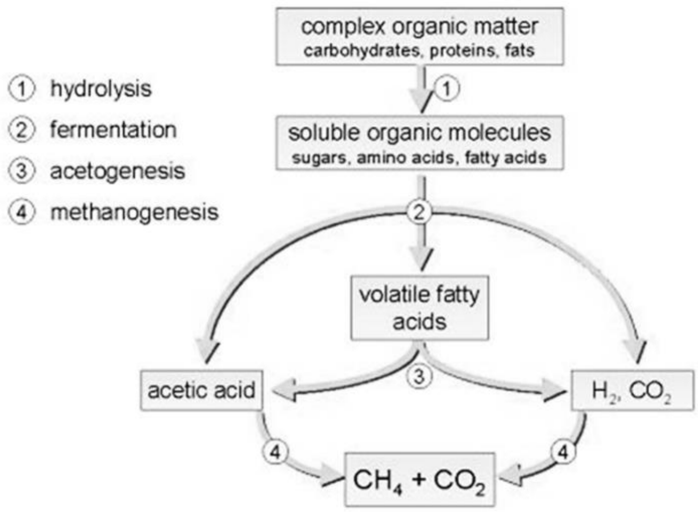


Figure 2-2: Anaerobic pathway of complex organic matter degradation (Grilc & Zupančič, 2012)

Material flows in anaerobic digestion process are presented Figure 2-3.

Anaerobic digestion has many environmental benefits comparing to aerobic systems: Energy production, less energy required for operation, nutrient recycling possibility, reduction of waste volumes, smaller reactor volume required, etc (Tchobanoglous , et al., 2004). Energy carrier produced in anaerobic process is a renewable fuel that can be used to heat the digestion reactors, generate electricity and/or heat for local needs or be fed into the natural gas grid after treatment. The quantity of biogas produced will be variable according to several factors, such as the quantity and quality of the organic matter and the environmental parameters: Temperature, pH value, C:N ratio, redox potential, C:N:P:S ratio, trace elements (Grilc & Zupančič, 2012).

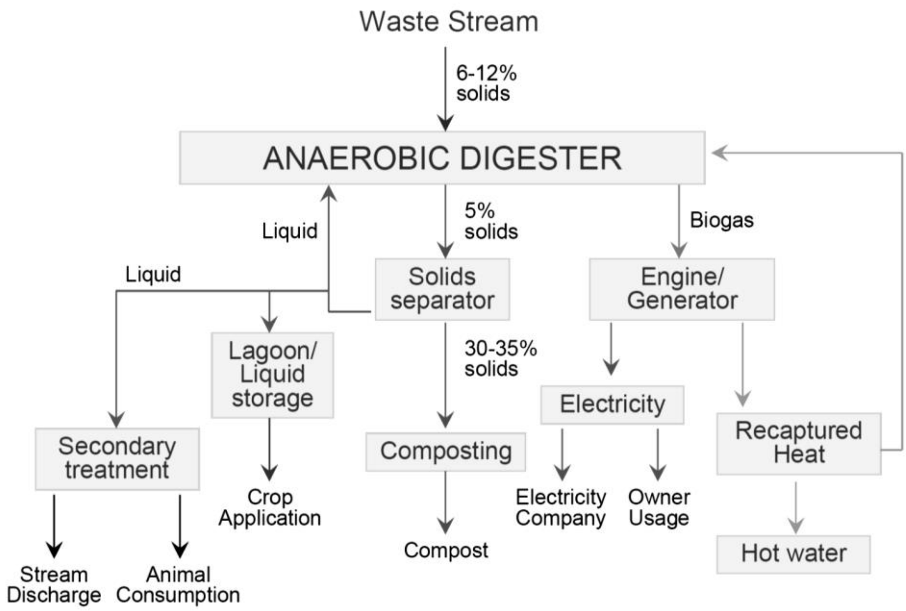


Figure 2-3: Material flows in AD (Çalli, 2011)

To summarize, anaerobic digestion can generate a renewable energy source in an integrated waste management system as stated in (Arsova, 2010). Solids after digestion with high level of nutrients can be a fertilizer (Grilc & Zupančič, 2012).

There are several processes available to conduct anaerobic digestion (Tchobanoglous , et al., 2004): Anaerobic suspended growth, upflow and downflow anaerobic attached growth, fluidized-bed attached growth, upflow anaerobic sludge blanket, anaerobic lagoons, and membrane separation anaerobic processes.

2.2.2 Anaerobic treatment for food processing industries

Development of optimized systems for the treatment of food wastes becomes highly important for food processing industries that are required to reduce quantity of pollution. One of the processes used for this purpose is anaerobic digestion. Main advantages and drawbacks of this treatment process for two different types of food industries compared to other treatment techniques are presented Table 2-2 (Arvanitoyannis, 2008).Proper process design is needed to avoid the possible disadvantages listed in order to obtain only the advantages.

Table 2-2: The advantages and disadvantages of anaerobic food processing waste treatment (Arvanitoyannis, 2008)

Type of industry	Advantages	Disadvantages
Fruit and vegetables processing	1. High reaction rates in relation to the destruction of organic matter 2. Good energy balance of the technology 3. Compact process so low capital cost 4. High stability in sludge bed processes gives good process economy 5. Less waste sludge generation	1. Risk of rapid acidification of fruit and vegetable wastes decreasing the pH in the reactor 2. Risk of volatile fatty acids (VFA) accumulation, which stress and inhibit the activity of methanogenic Achaea 3. Risk of depression of the overall performance of the reactor by increasing the feed concentration 4. Need for good process control to avoid the listed risks
Salads production (meat, fish, vegetables, salad dressings)	1. High reaction rates in relation to the destruction of organic matter 2. High biogas production due to fat content 3. Good energy balance of the technology 4. Low investment costs due to compact process 5. Less waste sludge generation	1. Influent WW characteristics can vary greatly, good process control required to compensate instability 2. High fat and grease inlet concentration, preliminary treatment needed 3. High risk of volatile fatty acids (VFA) accumulation, which stress and inhibit the activity of methanogenic organisms 4. Odor problems

Described wastes types can be treated anaerobically both separately and in co-digestion processes with many kinds of organic waste, such as sewage sludge, other industrial waste, agricultural biomass organic fraction of municipal solid wastes (OFMSW) and agricultural residues. Co-digestion possibilities were studied by Viswanath, Lane, Bouallagui, Resch etc. (Arvanitoyannis, 2008).

2.2.3 Upflow sludge blanket reactor process (UASB)

The basic UASB reactor has influent distribution system, gas-solid separator and effluent withdrawal as main elements (Figure 2-4) (Tchobanoglous , et al., 2004).

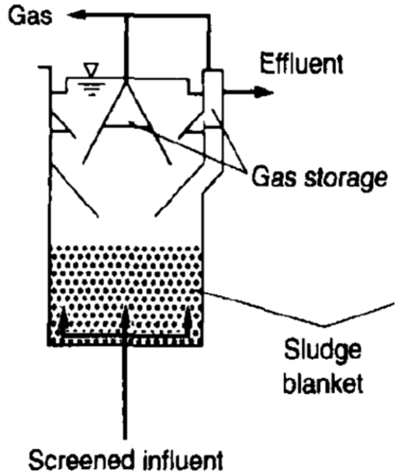


Figure 2-4: Schematic of the original UASB process (Tchobanoglous , et al., 2004).

Important design parameters of UASB reactor are: Wastewater characteristics (composition and solids content), volumetric organic load, upflow velocity, reactor volume, influent distribution system, gas collection system (Tchobanoglous , et al., 2004).

The nominal liquid volume of the reactor is given by (2-1)

$$V_n = \frac{Q \cdot S_o}{L_{org}}, \qquad (2\text{-}1)$$

Where V_n - nominal (effective) liquid volume of reactor, m^3;

Q - Influent flowrate, m^3/h;

S_o - Influent COD, kg COD/m^3;

L_{org} - Organic loading rate, kg COD/ m^3d.

Total reactor liquid volume can be estimated using (2-2)

$$V_L = \frac{V_n}{E}, \qquad (2\text{-}2)$$

where E - Effectiveness factor, equal to 0.8 – 0.9, unitless.

Determination of reactor dimensions.

$$D = \sqrt{\frac{4 \cdot Q}{\pi \cdot v}}, \tag{2-3}$$

$$H_T = H_L + H_G = \frac{V_L \cdot v}{Q} + H_G, \tag{2-4}$$

where D - reactor diameter, m;

v - design upflow superficial velocity;

H_T - total reactor height, m;

H_L - reactor height based on liquid volume, m;

H_G - reactor height to accommodate gas collection and storage.

Reactor hydraulic detention time is calculated by (2-5)

$$\tau = \frac{V_L}{Q}. \tag{2-5}$$

The key features of UASB are: High reduction in organics, high organic loading rates allowed and high hydraulic loading rates, low production of sludge. Limitations of UASB usage are: Unstable treatment with variable hydraulic and organic loads, difficult to maintain proper hydraulic conditions, dependence on wastewater inlet characteristics, sensitive to fat and grease content (Akvopedia, 2013).

2.3 Control Methods for WWTP

Wastewater treatment plants (WWTPs) are complex non-linear systems with significant variations in load, flow, composition of the incoming wastewater due to internal and external disturbances. The operation has to be continuous, reliable and efficient, with increasingly stringent regulations for effluent quality (Shena, X.C. & Corrioub, 2008).

Consequences of inefficient coagulation control are, according to (Ratnaweera & Aasgaard, 1994): “health hazards, high chemical costs, high sludge volumes, negative effects on further treatment processes, corrosion problems, etc.” To overcome mentioned health, environmental and economic challenges different optimization and control methods are examined and used.

Correct dosage of chemicals is one of the most important among all characteristics of the coagulation process which influence the quality of inlet water and efficiency of treatment as mentioned in (Ratnaweera & Aasgaard, 1994). There is the difficulty related to control of such parameter: It is relatively hard to find out the influent water quality or to define optimal coagulants dosage adequately because of high variations in characteristics of wastewater in time, the complexity of the physical and chemical phenomena: Parameters are dependent on internal activities of an industry, weather, human activities, and on unpredictable incidents (Doscon AS, n.d.). Managing of these requires long-term expertise and constant monitoring to ensure specified conditions.

Many control strategies have been proposed in the literature for wastewater treatment plants: Simple control, feedback control, feed forward control, proportional control, control based on experience curves, etc. As stated in (Stare & Vrečko, 2006): “Recent research results show that predictive and feed forward control are more successful in control of nutrient removal than conventional feedback proportional integral PI control.” However, as noticed in (Ratnaweera & Aasgaard, 1994), all of these methods have limitations in different cases. Comparing to methods described above, the real-time wastewater quality evaluation is more efficient for optimization of processes in chemical treatment. To implement on-line results of field studies into existing process it is convenient to establish mathematical models for wastewater treatment. The main parameters that should be necessarily defined for modelling are: Quality of wastewater at the inlet and outlet; conditions of coagulation, flocculation, and sedimentation as main process steps (Ratnaweera & Aasgaard, 1994). The system for estimation of the optimum coagulant dosage based on real-time, direct and indirect measurement of several parameters to secure a better and more even effluent quality, named DOSCON (Doscon AS, n.d.), will be installed at Lillevik WWTP in 2014 and is presented on Figure 2-5

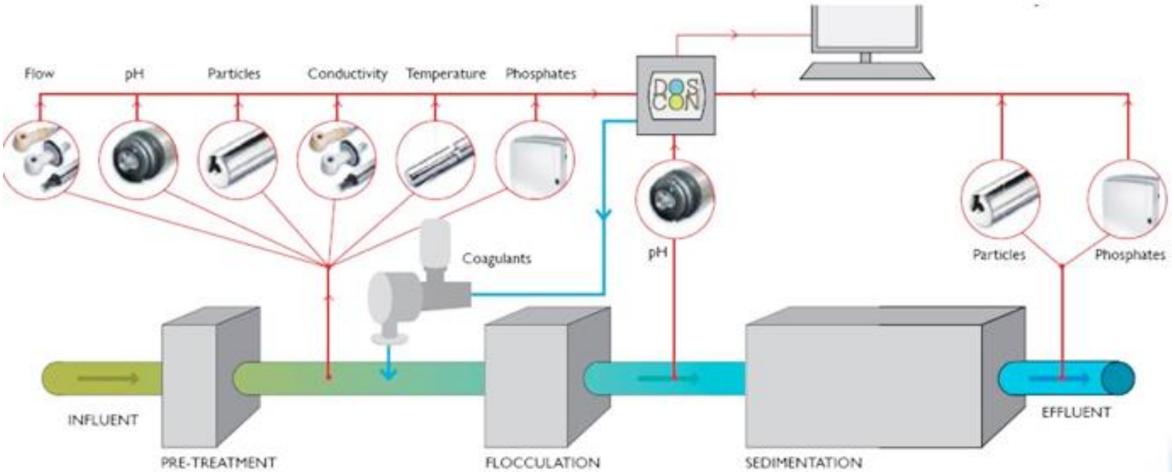


Figure 2-5: Optimal coagulant control based on measuring several parameters DOSCON (Doscon AS, n.d.)

2.4 Contact stabilization process

Contact stabilization is fast initial removal of organic matter by contacting with microorganisms that return in recycle stream. Fundamental of this process is: Primary influent enters contact chamber where organic matter is adsorbed by activated sludge afterwards followed by biological consumption. As a result settleability of the organics, that are not yet oxidized, is increased. The raw organics and MLSS sediment in clarifier like in conventional activated sludge. Mixed Liquor Suspended Solids are in charge of removing BOD. It is “active” part of activated sludge. However, instead of acting like return activated sludge, sludge is pumped to stabilization tank. The effluent from stabilization tank goes to contact basin, to support level of MLSS there and process is repeated again. The detention time in the contact basin is from 0,5 to 2 hours. Concentrations of MLSS and diagram of the process are shown on the Figure 2-6. F:M ratio that shows amount of possible BOD removal to one gram of microorganisms can run as high as 0,6 (Tchobanoglous , et al., 2004).

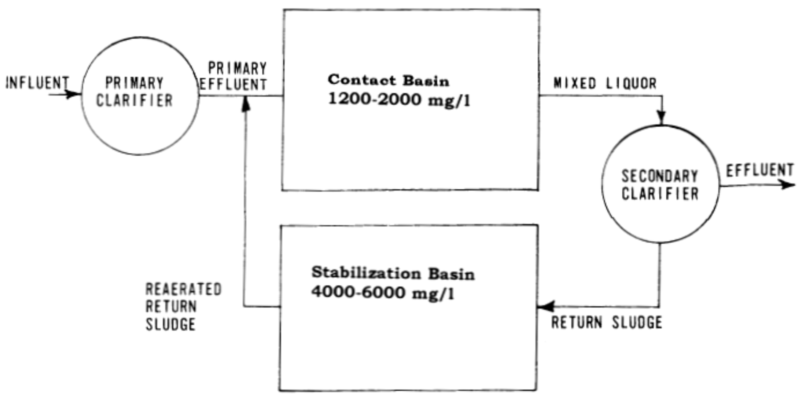


Figure 2-6: Contact stabilization process in WWTP (Tchobanoglous , et al., 2004)

Removal efficiency can reach high values e.g. 85-90% of BOD removal. Laboratory test can be carried out to estimate amount of removable fraction of the organic matter, contact time and sludge concentrations for determining best treatment efficiency.

Biological fundamentals are described because of probable positive effect of contact stabilization process on treatment of Lillevik WWTP. Such effects are not well represented in the literature. Using results, derivations and calculations from (Kibiakova, et al., 2013) that are presented in Appendix D it can be stated that: Return of activated sludge to the main wastewater stream can give contact process effects which can lead to decrease of BOD effluent level in the range from 23,9 g/m^3 to 14,8 g/m^3. In addition to BOD removal COD effluent level was expected to be reduced. Nevertheless results are uncertain while theoretical values that were used to calculate BOD are not so reliable.

3 Methods

3.1 Anaerobic digestion – Syringe test

3.1.1 Design

The biogas potential test is a small scale experimental protocol developed at TUC to investigate the biogas potential of food processing industry wastewater in small scale anaerobic digesters. Wastewater and inoculum were mixed and kept in anaerobic conditions for 3 weeks. pH, turbidity, COD and BOD were measured before the experiment.

3.1.2 Subjects

Filtered and unfiltered water samples of outlet water from food processing industry in Larvik were used. Sludge from wood processing industry is used as inoculum.

3.1.3 Apparatus & Materials

The experiment is performed with following equipment: 100 ml medical syringes (anaerobic digesters (AD), needles, rubber stoppers, pH-meter, turbidity meter, BOD meter, COD meter, pipettes, gloves, glasses.

Biogas reactor setup: Small anaerobic digesters - 100 ml medical syringes - run in parallel with three syringes for filtered and unfiltered wastewater at ambient temperature (20- 25°C) (lower mesophilic temperature range). Figure 3-1 shows a typical experimental setup.
The initial content in the reactors is a mixture of wastewater (10 ml) and inoculum (30 ml). Each syringe is connected to a needle blocked by a small rubber stopper to prevent gas and liquid leakage. The syringes are kept on a rack during the batch test.

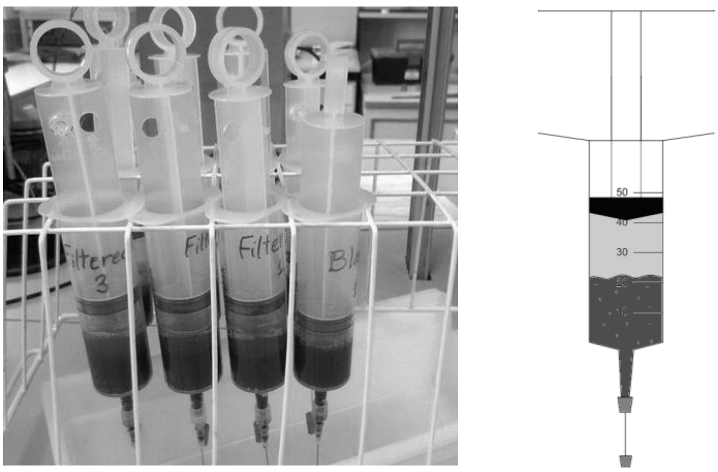


Figure 3-1: Syringe AD reactors on a laboratory shaker (left) and drawing of an AD (right).

The turbidity meter used in this work is the model 2100N supplied by VWR (Kebo Lab). Beckman 390 pH/Temp/mV/ISE meter has been used to measure pH. sCOD and tCOD measurements were performed using the spectrophotometer Spectroquant Pharo 300. BOD was estimated with WTW OxiTop Control 12 using standard respirometric method.

3.1.4 Procedure

Laboratory experiment was performed in two main steps: Wastewater samples preparation and syringe test. To prepare sample for the biogas potential test filtering of 150 ml of water was made. pH and turbidity for filtered and unfiltered samples were carried out for wastewater stored at 17C for 1 day. BOD and COD measurements were made for wastewater stored for 3 and 6 days respectively. sCOD and tCOD were measured for the range 300-3500 mg/l with dilution factor 0,2. BOD was evaluated using parameters presented in Table 3-1.

Table 3-1: BOD measurement parameters

	Expected BOD, mg/l	Volume of sample, ml	Dilution factor	Filtration
1	800	97		
2	400	164	0,025	
3	200	250		Unfiltered (U)
4	800	97		
5	400	164	0,010	
6	200	250		
7	800	97		
8	400	164	0,050	
9	200	250		Filtered (F)
10	800	97		
11	400	164	0,020	
12	200	250		

For the syringe test inoculum and water sample (stored at 17C for 6 days) were mixed well, added to syringes in dosages presented in Table 3-2.

Table 3-2: Quantitative start dosing of substrate and inoculum in the reactors.

№	Inoculum volume, ml	Sample	Sample volume, ml	Parallels
1	30	-	0	2
2	30	U	~10	3
3	30	F	~10	3

The air was removed from the syringe by pressing it through the needle; stopper was placed at the needle tip. The syringes were put on a test tube rack and keep in the hood at ambient temperature. Correct readings of the produced gas are required.

3.2 The Jar Test

3.2.1 Design

The aim of Jar Test experiment was to get qualitative information of intensity of flocs' formation (as a function of the stirring velocity, process performance and dosage of chemical coagulants), the sedimentation properties and characteristics of water after sedimentation. Two types of chemical coagulants, simulation of real and ideal flocculation process and three different fast mixing regimes are the main features of experiment (Kibiakova, et al., 2013).

3.2.2 Subjects

Water samples of the average for 24 hours inlet water from Lillevik WWTP were used as in (Kibiakova, et al., 2013). Chemical coagulants PIX, PAX were added simultaneously to wastewater.

3.2.3 Apparatus and Materials

The experiment is performed with following equipment: wastewater samples, Jar tester, pH-meter, turbidity meter, pipettes, 1000 ml graduated cylinder, gloves, glasses, chemical coagulants as during Master Project 2013 (Kibiakova, et al., 2013).

3.2.4 Procedure

Two different Jar Tests were performed with absolutely the same procedure for both (Kibiakova, et al., 2013).

Briefly, steps of Jar Test performance are:

- filling all beakers of the Jar tester with 1 litter of well-mixed water from Lillevik WWTP;
- setting the rapid mixing, slow mixing and sedimentation times, frequency of mixing according to Table 3-3.

Table 3-3: Settings and volume of coagulant for Jar Test

		Beaker N°									
		1	2	3	4	5	6	7	8	9	10
Volume of PIX/PAX (ml)		0,1/0,1									
Fast mixing	duration, sec	40									
	frequency, RPM	200	280	360	200	280	360	200	360	200	360
Sedimentation 1 duration (min)		1			-			1		-	
Slow mixing	duration, min	10									
	frequency, RPM	50									
Sedimentation 2 duration (min)		10									

For beakers 1, 2, 3, 7, 8: Fast mixing for 40 sec and adding of both chemical simultaneously, imitation of the flow in channel (sedimentation 1) such as in real process for 1 min, slow mixing and second sedimentation;

- For beakers 4, 5, 6, 9, 10: The flocculation process was simulated the same manner, but without first sedimentation stage;
- pH, turbidity, sludge depth, PO_4^{3-} concentration measurement.

Risk assessment for both experiments is presented in Appendix K.

4 Results

4.1 Observation of real data

Actual measured and collected data was provided by Lillevik WWTP. The results of real data observation for period from 01.01.12 to 01.03.14 are presented in following chapter.

4.1.1 Investigation of inlet wastewater composition variations

Inlet wastewater composition could be described with phosphorus, nitrogen, BOD and COD measured concentrations. Measurements for N, P, COD and BOD analysis of all parameters of process and of those influencing the process which are used in further observations were taken approximately two times per month. Dependencies of mentioned nutrients concentrations on season of the year and precipitations amount are presented in Figure 4-1 and Figure 4-2.

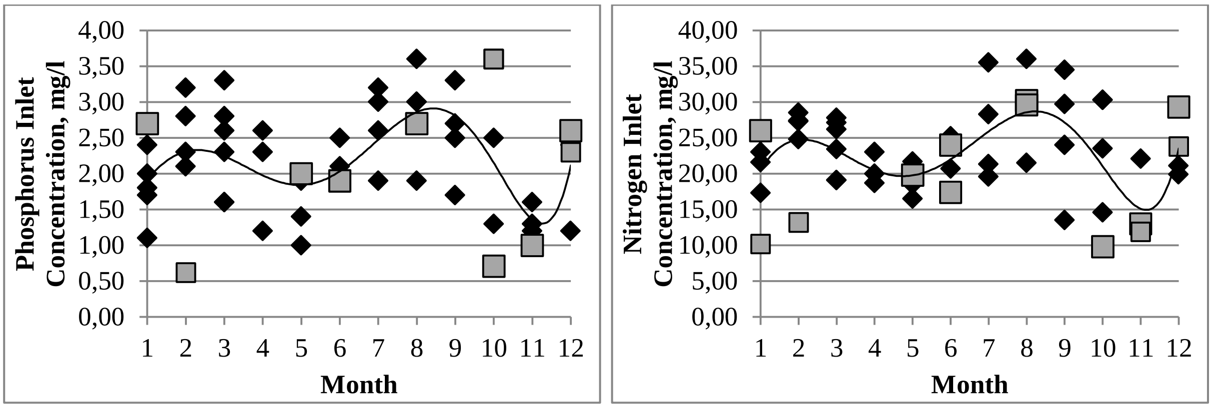


Figure 4-1: Inlet concentration of phosphorus (left) and nitrogen (right) as a function of time (month) and precipitations (grey points), (01.01.12 – 01.03.14)

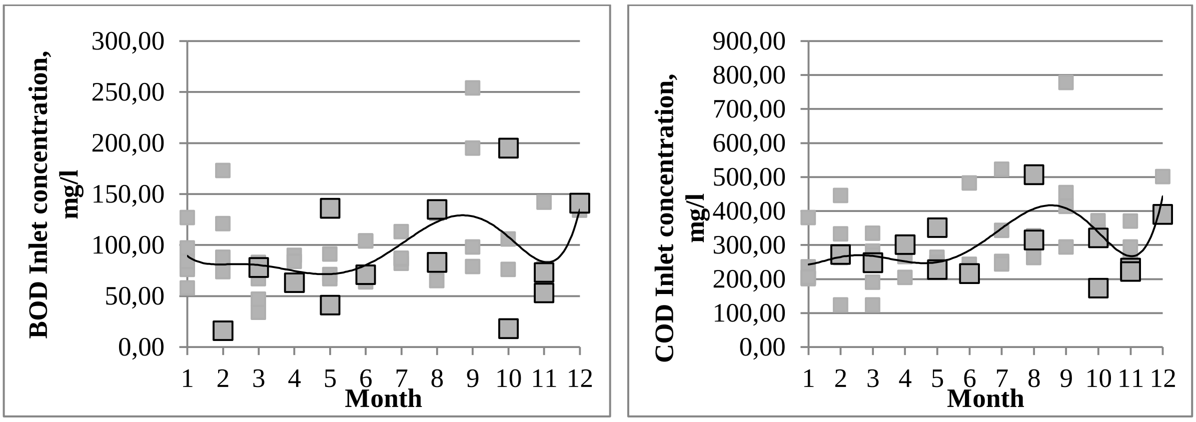


Figure 4-2: Inlet concentration of BOD (left) and COD (right) as a function of time (month) and precipitations (black points), (01.01.12 – 01.03.14)

The following observations are made from Figure 4-1 and Figure 4-2: General behaviour of nutrients concentration variations with time is approximately the same with noticeable peaks in winter and summer time. Phosphorus and nitrogen removal is relatively high in February, March, from July till October. The maximum values of them are not the cause of precipitations. Phosphorus inlet concentration is lower than the typical value of 4 mg/l for untreated domestic wastewater, while inlet concentration of nitrogen is at medium strength according to (Tchobanoglous , et al., 2004).
Real BOD and COD inlet concentrations are generally in range of 50-150 mg/l and 200 – 400 mg/l respectively, which corresponds to values from low strength to medium, however in few cases there are peaks for high strength concentrations (Tchobanoglous , et al., 2004).

4.1.2 Wastewater treatment process parameters correlation

The results of the correlation analysis for the factors influencing the wastewater treatment process (water plant load, dosages of chemical coagulants, temperature and pH, precipitations) are given in Appendix D.
Graphical representation of correlations between process parameters will show the dependencies of these variables on each other. Firstly, wastewater flow and its correlation with precipitations amount are shown on Figure 4-3.

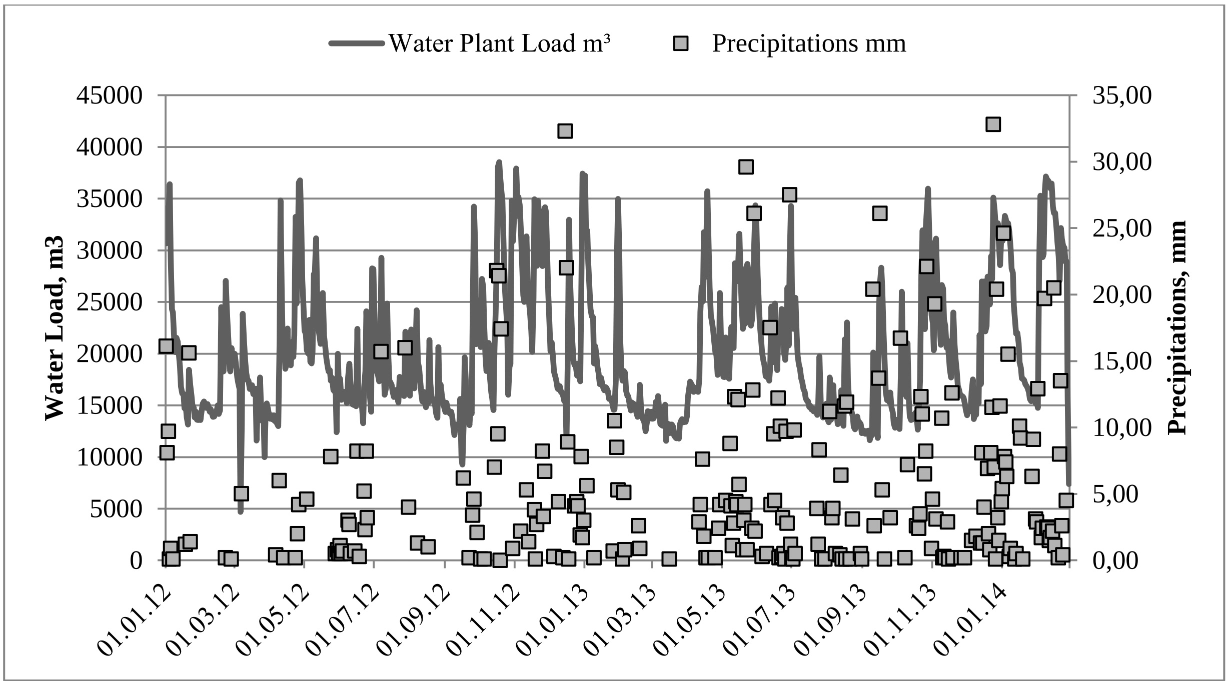


Figure 4-3: Correlation between precipitations amount and water plant load (01.01.12 – 01.03.14)

Observing the results of correlation analysis and Figure 4-3, one of the parameters influencing the flow is precipitations: With high storm water levels high inlet water amount is observed,

but this correlation is not as high as it was expected, 33%.
Furthermore, there is no strong correlation between water flow and season of the year, 10%.

Graphical view of inflow pattern for dry-weather and rainfall period is presented on Figure 4-4.

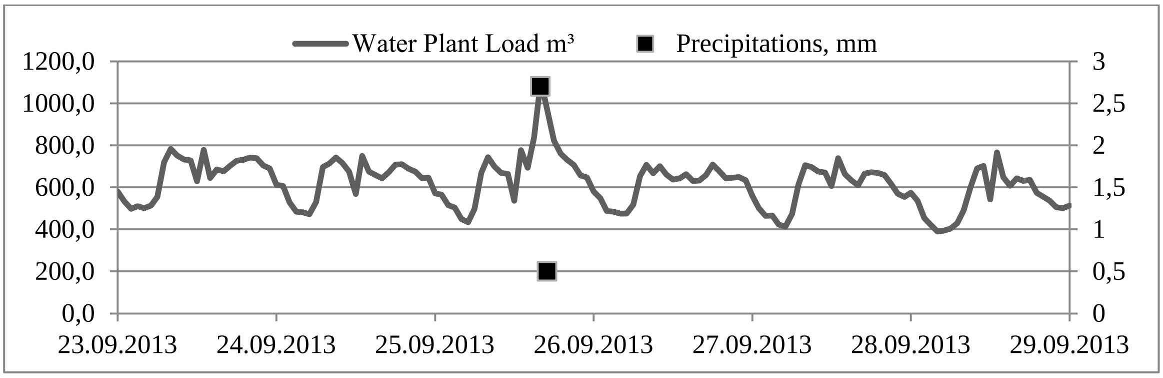


Figure 4-4: Dependency of water plant load on precipitations amount and day of the week (23.09.13 – 29.09.13)

Pattern of variation in water flow rate showed on Figure 4-4 is relatively similar to one given in (Tchobanoglous , et al., 2004), except one peak which is observed at 13:00 almost each day. Regarding precipitations: "during the rain flow event, the amount of storm flow is normally much larger than the dry-weather flow", which can be proved by graph.

Variations in dosage of chemical coagulants with water plant load are presented on Figure 4-5.

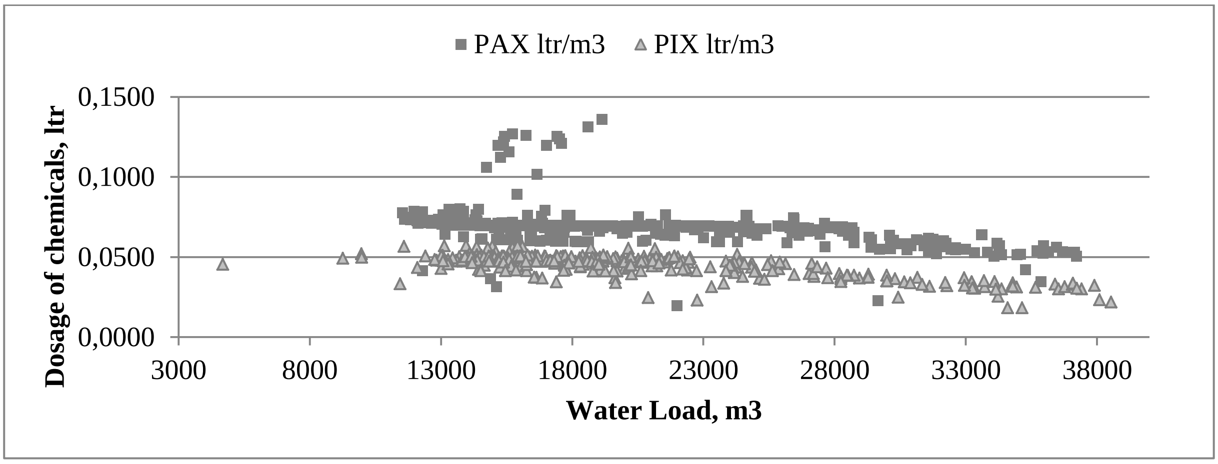


Figure 4-5: Dosage of chemical coagulants as a function of water plant load (01.01.13 – 01.03.14)

Dependence of chemical coagulants dosage on water plant load is quite strong, PAX -82%, PIX - 53% (Appendix D). At Lillevik WWTP there is no proportional dosage control. For diluted water and relatively low wastewater flow, less than ≈ 30000 m^3/d (or 350 l/s) the real dosage of coagulants is: PAX ≈ 0.055 – 0.07 ltr/m^3 and PIX ≈ 0.04 – 0.05 ltr/m^3. For wastewater load higher than ≈ 30000 m^3/d: PAX ≈ 0.05 ltr/m^3 and PIX ≈ 0.03 ltr/m^3.
These variations in dosage due to water plant load fluctuations could are shown on Figure 4-5, but there are also few point on graph related to high dosage of PAX with low flow rate of wastewater which observed in January 2014.

4.1.3 Removal nutrients efficiency of wastewater treatment

The main goal of wastewater treatment process is to comply with established discharge limits for phosphorus, chemical and biological oxygen demands. Real and required removal efficiencies for listed characteristics are presented on Figure 4-6 and Figure 4-7.

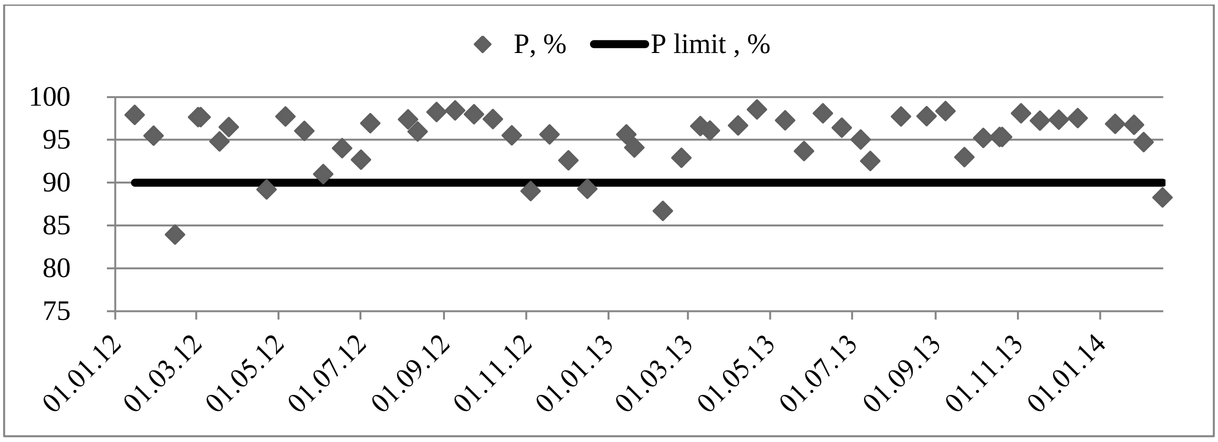


Figure 4-6: Phosphorus removal efficiency (01.01.12 – 01.03.14)

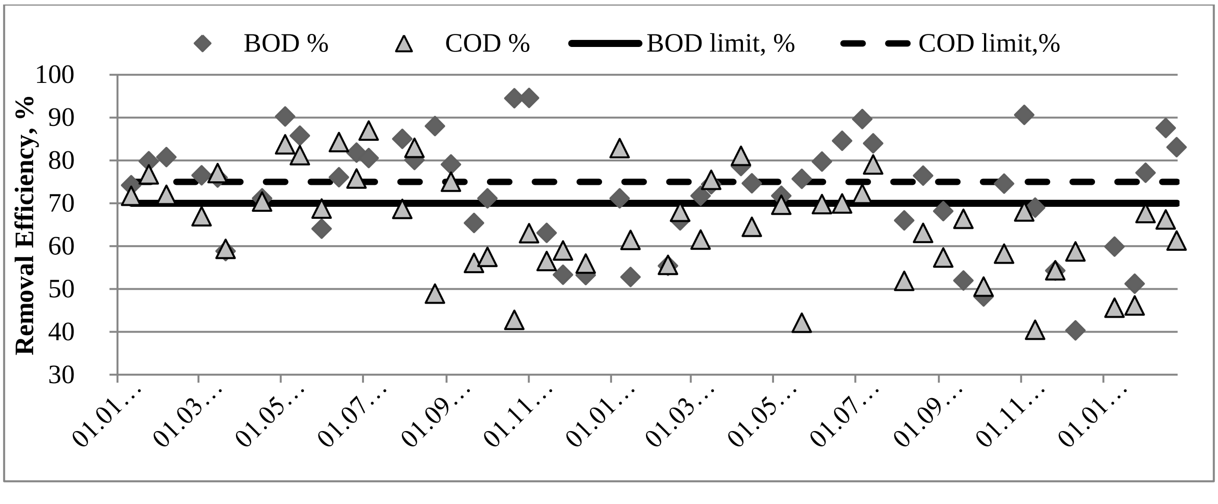


Figure 4-7: BOD and COD removal efficiency (01.01.12 – 01.03.14)

Real removal of phosphorus is better than for BOD and COD, which could be seen from Figure 4-6 and Figure 4-7. There are only few data points below required efficiency level for phosphorus.

Certainly, considerable attention should be given to COD and BOD removal efficiencies: Removing of chemical oxygen demand is worse than of biological, while limit efficiency for it is higher. Important information is that from August to March there is generally lower removal efficiency. Food processing industries with a lot of organic matter in the wastewater which is coming to Lillevik WWTP are working in the same period of time. Both COD and BOD removal is less efficient during autumn and winter 2013-2014 than it was previously.

Observing the results from correlation analysis given in Appendix D it can be seen that:

- Removing efficiency of BOD is little dependent on water flow, temperature and PIX concentration, while it is not correlating with precipitations and outlet pH;
- Removing efficiency of COD is more dependent on precipitations amount and water flow, it has correlations with outlet pH. Its correlation with chemicals dosage is less than for BOD;
- Dependence of BOD and COD on each other is surprisingly low in comparing to what was expected;
- Correlation between P removal and chemicals concentration is higher, as well as for all parameters except water load and precipitations, than for BOD and COD removal.

On phosphorus, COD and BOD removal efficiency dependence on chemical coagulants dosage and water load is shown on Figure 4-8.

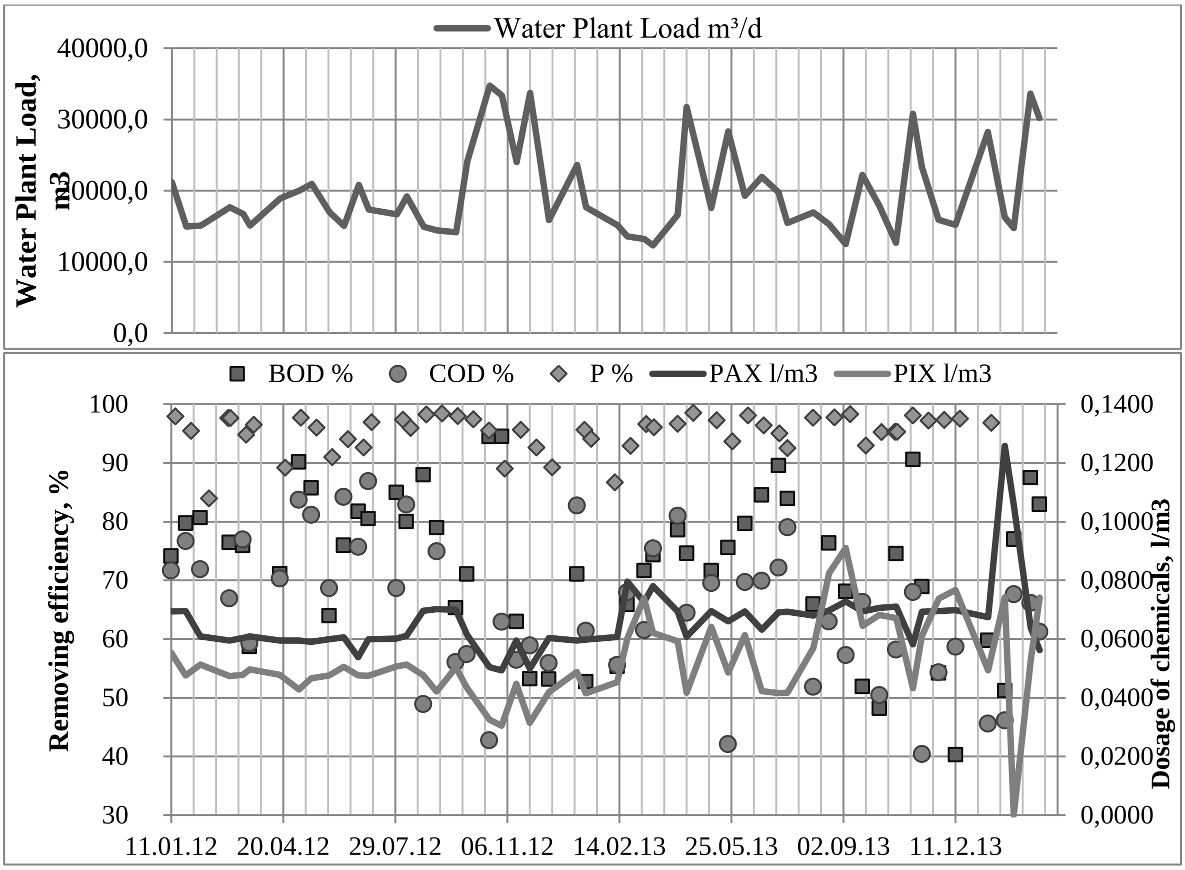


Figure 4-8: Correlations between water plant load, dosage of coagulants, P, BOD and COD removing efficiency (01.01.12 – 01.03.14)

From Figure 4-8 it could be seen that fluctuations in wastewater flow and the dosage of chemicals are interdependent: There is less chemicals added with high flow of water. There is noticeable manual change in average dosage of PAX in February 2013 from ≈ 0.06 ltr/m^3 to ≈0.07 ltr/m^3. The PIX dosage varies significantly with high fluctuations in water flow.

There is sharp increase of PAX dosage followed by decrease of PIX dosage in January 2014, this fluctuation is not caused by flow variations or precipitations.

Phosphorus removal correlation with amount of chemicals added is considerable: With increase in dosage of PAX mentioned above removal efficiency of P become over 90% and does not reach the limit.

The correlation between removal efficiencies of COD, BOD and chemicals dosages is also quite noticeable: Variations in flow rate may cause the changes in dosage added and are the reason of high efficiencies fluctuations.

4.2 Food processing industries analysis

4.2.1 General characteristics of analysed companies

Domestic and industrial wastewater from Larvik municipality is collected and treated at Lillevik WWTP. High seasonal levels of P, COD and BOD inlet concentrations were observed in Chapter 5.1.1, as mentioned before, it could be caused by food processing industries operation in that period of time.

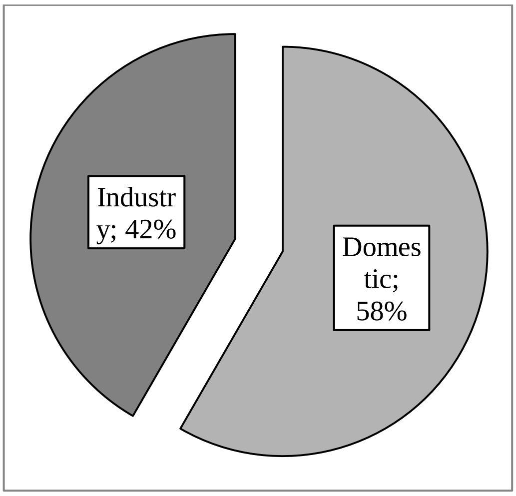
There are 8 large food processing industries in Larvik Municipality. Approximate average total COD amount provided by food processing industries to Lillevik WWTP can be calculated by two methods: Based on total COD in the influent of plant and share from domestic suppliers of Larvik or based on data provided by food processing industries: Average COD inlet concentration at Lillevik WWTP is 320 mg O/l and load is 6000 kg COD/day. To estimate COD inlet amount at WWTP from domestic providers of Larvik municipality it is assumed that there are 43 000 inhabitants (Larvik Kommune, 2013) with 80 g COD/ per capita and per day (Henze & Comeau, 2008). Approximate average daily production of COD by all inhabitants in Larvik is ≈3500 kg COD/day. The rest is assumed to come from industrial suppliers (6000-3500) ≈ 2500 kg COD/day.

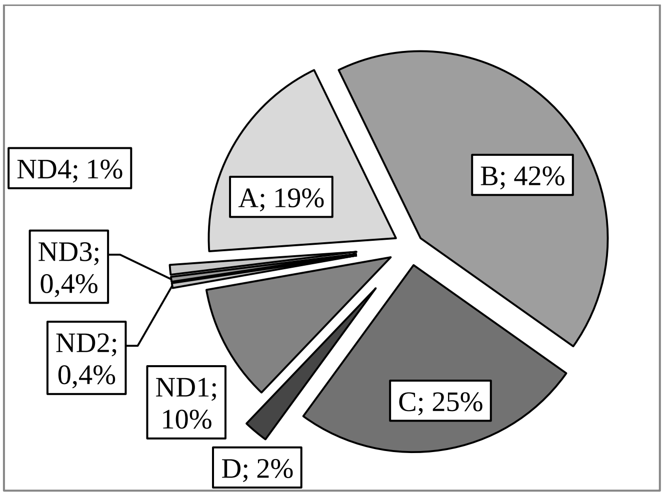
Food processing industries of Larvik Municipality with water loads and COD, P and N concentrations are presented in Table 4-1. Historical data of wastewater nutrients concentrations for this research was provided by 3 of them - A, B, C. Data for other companies is based on: Laboratory experiment results (D). COD measured is < 600 mg/l; Available data from the same industry type (ND1); Data from literature: ND2, ND3 (Arvanitoyannis, 2008), ND4 - COD = 250 mg/l (The Food Processing Environmental Assistance Center, 2012).

Table 4-1: Analysed food processing industries in Larvik

Company	Industry	Water load, m3/year	COD av.		P		N	
			kg/day	mg/l	mg/l	kg/day	mg/l	kg/day
A	Vegetables processing	≈ 200 000	450	750	2,7	1,2	9	3,9
B	Vegetables processing	≈ 20 000	1000	10000	21	3,1	45	6,5
C	Salads production	≈ 10 000	600	10000	no data			
D	Drinks manufacture	≈ 60 000	< 100	no data				
ND1	Vegetables processing	≈ 6 000	≈ 250					
ND2	Vegetables packing	≈ 3000	< 10					
ND3	Vegetables packing	≈ 3000	< 10					
ND4	Toppings production	≈ 2000	≈ 10					
TOTAL		≈ 305 000	≈ 2430					

Total COD amount in the inflow to Lillevik WWTP from food processing industries calculated by mentioned above two methods is equal to ≈ 2500 kg/day (Figure 4-9a). Information presented in Table 4-1 regarding approximate distribution of this industrial COD supplied to WWTP is illustrated by Figure 4-9b.





a) b)

Figure 4-9: Distribution of COD supplied to WWTP from different providers (a) and from different companies (b)

Analysing information from Table 4-1 and Figure 4-9 it can be noticed that:

- Share of COD in the inlet wastewater at Lillevik WWTP from industrial suppliers is quite large.
- Company A and D have highest wastewater load and average COD discharge.
- Company B has 10 times less water load compared to A (same kind of industry), and the highest effluent COD amount per day.
- Company C has relatively low wastewater flow and high COD concentration.
- Company ND1 has low wastewater load and average COD discharge.
- Companies ND2-ND4 have both insignificant water load and COD amount.

4.2.2 Investigation of Company C wastewater parameters

To reduce the organic (COD) amount in the water inflow to WWTP, organic material from industrial wastewater can be treated locally as mentioned in (Kibiakova, et al., 2013). Company C has low flow rate and medium COD concentration which makes it especially relevant to study the possibility of local treatment. Using provided data for years 2012-2013 waste water composition can be described by COD, fat concentrations. Measurements of these parameters of process were done four times per year and are presented in Figure 4-10.

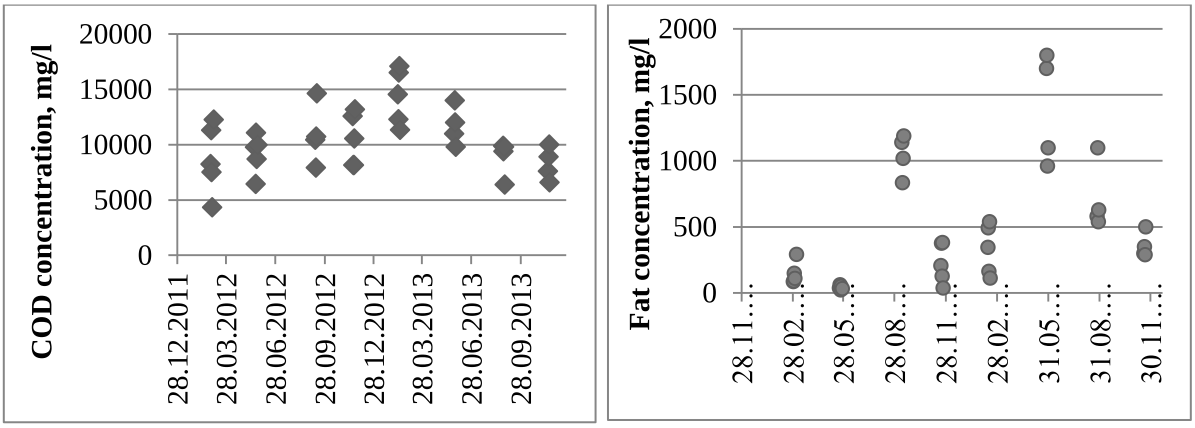


Figure 4-10 : COD and fat concentration in wastewater from Company C (2012-2013)

From Figure 4-10 it can be noticed that COD concentrations vary from 4300 to 17000 mg/l with average value equal to 10371 mg/l; Fat concentration is in the range 25 – 1800 mg/l with average value of 500 mg/l.

4.2.3 Experimental results of biogas potential test

For further investigation of possibility to treat wastewater from Company C locally laboratory experiment - biogas potential test - was performed for filtered and unfiltered water samples as mentioned in Chapter 4.1. Wastewater parameters measurements (25.02.14) and average reported process parameters (2012-2013) are summarised in Table 4-2.

Table 4-2: Wastewater sample characteristics

Sample	BOD_5 average measured, mg/l	COD measured, mg/l	BOD_5/ COD	pH	Turbi-dity	Absorbance	COD average reported, mg/l	pH average reported, upon withdrawal
Unfiltered	6600	10770	1,63	5,72	1448	0,638	10371	6,97
Filtered	4440	7120	1,6	5,94	2	0,471		

Analysing data from Table 4-2 it can be noticed that measured COD (25.02.14) is approximately equal to average reported value (2012-2013), implying that the sample used for the biogas potential test should give realistic values. The ratio of COD to BOD_5 is as typical (1.5-2) for food processing industry wastewater as stated in (Egyptian Environmental Affairs Agency , 2012). BOD and COD values are about 30% higher for unfiltered than filtered samples. Average for two years reported pH measured upon withdrawal at the factory is higher than pH measured after 1 day storage at low temperature. Measured pH is in the range that corresponds to appropriate feed for successful operation of anaerobic digestion processes

(*Tchobanoglous , et al., 2004)*. Turbidity and absorbance of filtered water sample is lower in comparison to unfiltered one.

Wastewater sample and inoculum were mixed and kept in anaerobic conditions as described in Chapter 3 for 3 weeks while observing biogas production. Average volumes of biogas produced for filtered, unfiltered and blank samples at ambient (room) temperature with respect to time are shown on Figure 4-11.

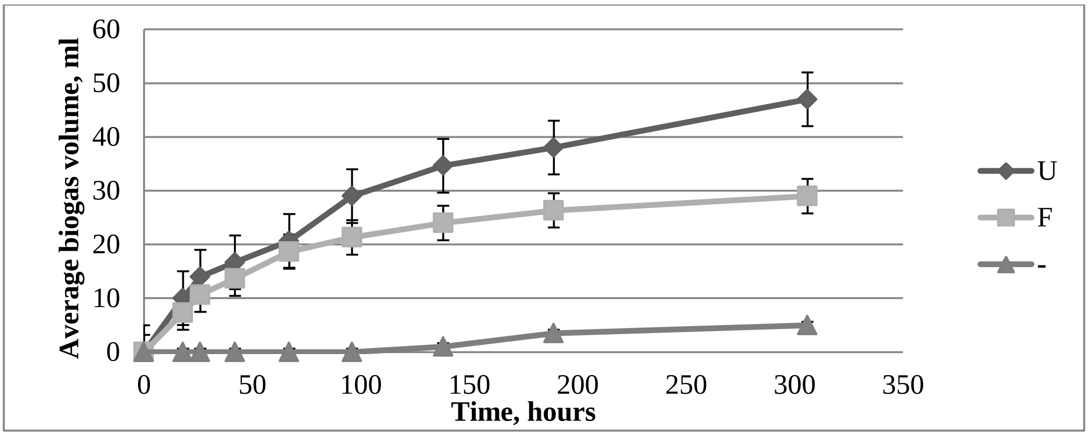


Figure 4-11: Average biogas accumulation for Samples with feed types: U (unfiltered sample); F (filtered sample); - (blank).

From Figure 4-11 it can be observed that syringes with different samples type have different nature of biogas accumulation. Syringes with unfiltered sample have the highest amount of biogas accumulation, while syringes with filtered samples have a third less final biogas amount. Filtered and unfiltered samples have quite the same biogas production during the 70 hours after start of experiment. After that production of biogas in Samples U increases compare to Sample F. Low biogas accumulation is observed in blank syringes showing that biogas production from the inoculum is quite insignificant.

Figure 4-12 shows the production rate of biogas (the volume interval depending on the time interval) versus time of all experiment.

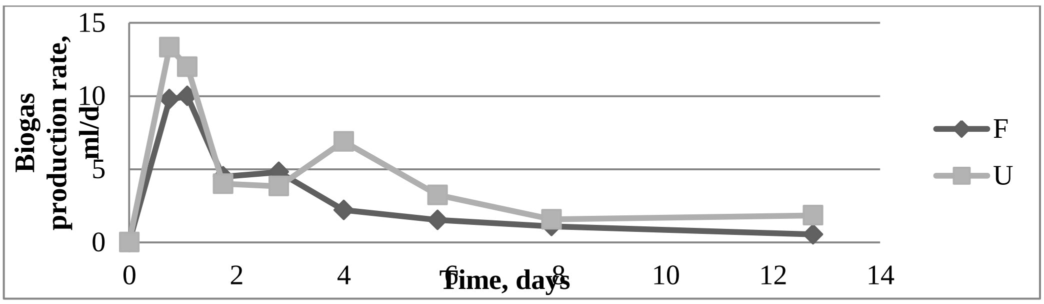


Figure 4-12: Production rate of biogas (days)

According to Figure 4-12 the premier peak of biogas production rate is during first 18 hour after the start of experiment. Higher production rate of biogas comes from the unfiltered sample than from filtered. Unfiltered sample has increase of rate on the 4th day. On the eight day after the feeding rates of are almost stabilized.

Assume that COD removed by anaerobic digester is equal to COD consumed during production of biogas (COD_{biogas}^{total}).Assume all particulate and dissolved organics in unfiltered sample and filtered sample are converted to biogas. It can be estimated for filtered, $COD_{biogas}^{total,F}$, and unfiltered, $COD_{biogas}^{total,U}$, samples by (4-1).

$$COD_{biogas}^{total} = \frac{Q^{e}{}_{gas} - Q^{e}{}_{blank}}{Q^{e}{}_{ww}} \cdot COD_{biogas}, \qquad (4\text{-}1)$$

where $Q^{e}{}_{gas}$ - volume of gas produced in the syringe during experiment, ml

$Q^{e}{}_{ww}$ - volume of WW sample added to syringe during experiment, ml

$Q^{e}{}_{blank}$ - volume of biogas produced by the blank during experiment, ml

COD_{biogas} - approximate amount of COD removed with 1 m^3 biogas produced (Tchobanoglous , et al., 2004), $gCOD/m^3$.

$$COD_{biogas}^{total,U} = \frac{47-5}{10} \cdot 2560 = 10752\ mgCOD/l$$

$$COD_{biogas}^{total,F} = \frac{30-5}{10} \cdot 2560 = 6400\ mgCOD/l$$

Removal COD efficiency is:

$$\eta^{U}{}_{COD} = \frac{COD_{biogas}^{total,U}}{COD_{AD,in}} = \frac{10752}{10770} = 99\%, \quad \eta^{F}{}_{COD} = \frac{COD_{biogas}^{total,F}}{COD_{AD,in}} = \frac{6400}{7120} = 90\%.$$

Removal COD efficiency by anaerobic digester is high and equal to 99% for unfiltered sample and 90% for filtered. Ratio of COD consumed during biogas production from dissolved organics (6400 mgCOD/l) to biogas produced from total organics (10752 mgCOD/l) is 0,6. Ratio of COD of unfiltered influent to filtered is 0,66.

From Figure 4-11 it can be observed that: The reactors with unfiltered wastewater produce 47 ml of biogas. Average food processing plant (Company C) water load is 47 m^3/d.

Approximate biogas volume that can be produced by anaerobic digestion, Q_{biogas} installed at food processing plant C can be calculated by (4-2).

$$Q_{biogas} = \frac{Q^e{}_{gas}}{Q^e{}_{ww}} Q^r{}_{ww} , \qquad (4\text{-}2)$$

Where $Q^r{}_{ww}$ - average food plant daily water load, m3/d.

$$Q_{biogas} = \frac{47}{10} 47 = 221\,m^3 / day .$$

Energy content of the gas can be calculated as (4-3) (Tchobanoglous , et al., 2004):

$$E = \varepsilon \cdot \frac{0.65 \cdot Q_{biogas}}{V^{25C}_{CH_4}} \cdot M_{CH_4} , \qquad (4\text{-}3)$$

Where E - energy content of biogas, kJ/d;

ε - energy content of methane, kJ/g;

0,65 – content of methane in biogas;

Q_{biogas} - biogas potential of anaerobic digestion process installed at food processing plant C.

$$E = 50{,}1\,kJ / g \cdot \frac{0.65 \cdot 220{,}9\,m^3 / d}{24{,}5\,L / mol} \cdot 16\,g / mol = 4{,}7 \times 10^6\,kJ / d .$$

4.3 Experimental Results of Jar Test

Jar Test experiment was done according to methodology and procedure stated in Methods and in (Kibiakova, et al., 2013), and this time it was done on samples collected on a day with dry weather – 02.05.14.

The experimental results of the Jar test are shown in Table 4-3.

Table 4-3: Experimental results of Jar test

№	Mixing Regime	Chemicals Concentration, PIX/PAX, µl/l	Process Description[1]	pH	Turbidity, NTU	PO_4^{3-} Concentration, mg/l	Sludge Height, cm
1	Slow	≈ 100/100	I_1	6,47	2,1	0,067	1,2
2	Medium			6,45	3,83	0,072	1,2
3	Fast			6,42	4,65	0,106	1,1
4	Slow		II_1	6,37	1,99	0,064	1
5	Medium			6,47	2,13	0,07	1,1
6	Fast			6,52	2,9	0,084	1,1
7	Slow		I_2	6,11	2,54	0,065	1,2
8	Fast			6,3	2,5	0,087	1,2
9	Slow		II_2	6,43	1,33	0,053	1,5
10	Fast			6,37	1,42	0,085	1,4
Raw water	-			7,44	80	2,69	-

I - Real process: Chemical addition → Flow through channel → Flocculation

II - Ideal process: Chemical addition → Flocculation

$_1$ First parallel of Jar Test; $_2$ Second Parallel of Jar test

The experimental coagulation and flocculation jar tests were designed to simulate processes with (as it is at Lillevik) and without channel flow (ideal case), as described in Methods. Data obtained for different parallels varies relatively much, so there is no statistically significant difference between cases I and II. Average pH for the first parallel is 6.45 and for second one - 6,3. Turbidity, PO_4^{3-} concentration and sludge height dependency on fast mixing frequency for the 1st and the 2nd parallels of experiment 02.05.14 are shown in Appendix G.

Comparison of the results of Jar experiment performed for dry weather period (02.05.14) to results of previous work presented in (Kibiakova, et al., 2013) for wet period (23.10.13, 14.11.13) is presented on Figure 4-13 - Figure 4-15.

Value of turbidity is higher in case of channel flow simulation for both dry and wet weather and slightly increases with mixing frequency rise in all cases except “With channel simulations, wet". The phosphate concentration seems slightly increasing with increase in frequency of mixing and is higher for dry weather period wastewater after coagulation. Also, it can be stated, that concentration of phosphate with channel simulation is higher, than without. But the values are so small that we cannot make any generalization. The sludge height seems to decrease slowly with increase in mixing frequency with channel flow simulation and increase without.

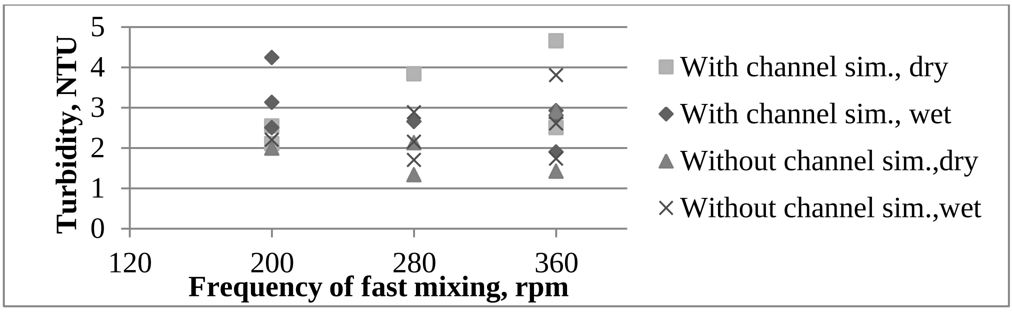


Figure 4-13: Turbidity for the different frequencies with and without channel flow simulation for dry and wet weather

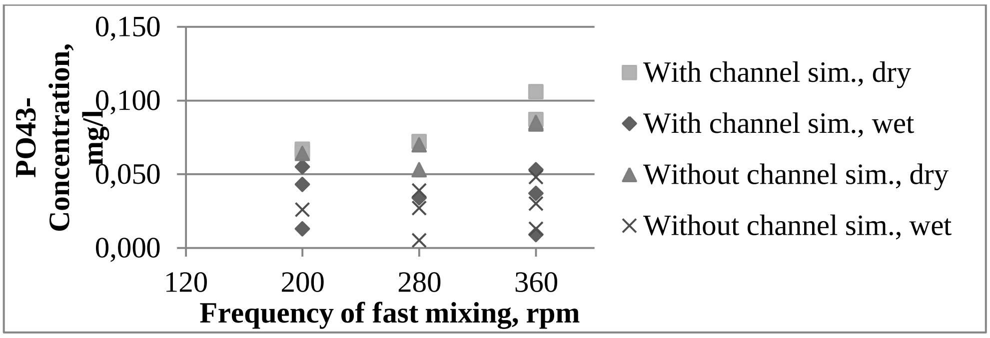


Figure 4-14: *PO_4^{3-} concentrations for different frequencies for dry and wet weather periods.*

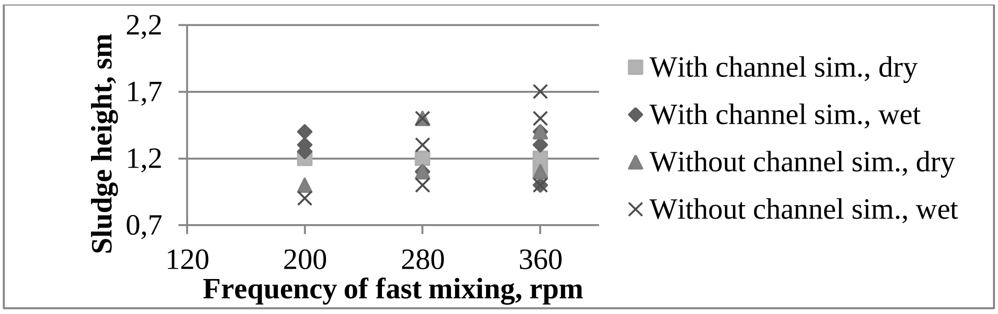


Figure 4-15 : Sludge height for different frequencies with and without channel flow simulation, 1st parallel.

5 Discussion

5.1 Real data analysis

Based on study performed in Master Project 2013 (Kibiakova, et al., 2013) for extended period (01.01.12 - 01.03.14) real data analysis was carried out.

5.1.1 Inlet wastewater composition variations

Wastewater comes to the Lillevik WWTP with specific nutrients concentrations, chemical and physical parameters.

As was stated in (Kibiakova, et al., 2013) and can be proved for extended period: High levels of all nutrients inlet concentrations in early spring, winter and late summer could be influenced by holidays in these periods, with special content of wastewater; or by food processing industry working from August till February. One possible solution studied in this research is that these industries will remove nutrients and organic material from their wastewater locally (Larvik Kommune, 2013).

From observed data it may be noticed that phosphorus inlet concentration is lower than the typical value of 4 mg/l for untreated domestic wastewater, while inlet concentration of nitrogen is at medium strength according to (Tchobanoglous , et al., 2004). Real BOD and COD concentrations are generally in range of 50-150 mg/l and 200 – 400 mg/l respectively, which corresponds to values from low strength to medium, however in few cases there are peaks for high strength concentrations (Tchobanoglous , et al., 2004).

Furthermore, amount of inlet COD and BOD is dependent on water flow rate and on precipitations amount, according to (Tchobanoglous , et al., 2004): "r*ain in volumes of more than 4 mm/d has an impact on the influent and its nutrients content"*, which can be seen from results of correlation analysis, but not clear from inlet nutrients variation graphs, should be investigated further with continuous measurement of all nutrients inlet concentrations for higher certainty.

5.1.2 Correlation between process parameters and control of the dosage

Discussing observations based on correlation analysis, it can be said that dependency between water load and precipitations is relatively medium, equal to 33%, and on season of the year is low, equal to 10%. While on the pattern of variation in water flow for one week dependency of water flow on precipitation amount is considerable. To explain results of correlation analysis: There are some other parameters influencing water flow more in general.

Two coagulants dosages (PAX and PIX) do have better correlation - 64%, then it was observed previously in (Kibiakova, et al., 2013), but it is not ideal which is reasonable, as soon as control of dosage depending on outlet water flow was simple proportional with no continuous on-line control. According to information presented in Theoretical Part regarding control techniques and as was suggested earlier in (Kibiakova, et al., 2013): Definition of the empirical model based on parameters measured at WWTP and advanced control technique implementation will correct and optimize existing control strategy. During 2014 year the DOSCON system for estimation of the optimum coagulant dosage based on real-time, direct and indirect measurement of several parameters to secure a better and more even effluent quality (Doscon AS, n.d.) will be installed at Lillevik WWTP.

5.1.3 Removal nutrients efficiency of wastewater treatment

Comparing real removal of phosphorus and governmental limit it can be stated that treatment of wastewater from phosphorus is efficient. Phosphorus removal still can be slightly improved by chemicals dosage variations with respect to temperature and inlet wastewater load.

Real chemical and biological oxygen demands removal efficiencies are lower than these established by the government at Lillevik WWTP. Results of correlation analysis show that removal efficiency of BOD is sensitive to water flow, temperature and PIX concentration, of COD - to precipitations amount and water flow. It can be also noticed from graphical results that higher dosage of chemicals will not necessarily cause higher removal efficiency for BOD and COD. From August to March there is generally lower removal efficiency which can be caused by a lot of organic matter in the wastewater from food processing industries operation.

During autumn and winter 2013-2014 COD and BOD removal is less efficient which makes analysis of food companies locally and implementation of DOSCON system significantly important.

Since, P, COD and BOD measurements were performed only approximately two times per month, deeper research with continuous monitoring of mentioned parameters, its multivariate data analysis and modelling of phosphorus, COD and BOD behaviour would be beneficial.

5.2 Food Industries analysis

5.2.1 General companies characteristics

Food companies in Larvik Municipality with different wastewater flow and COD, P and N concentrations provided their wastewater characteristics data for this study. COD inlet amount at WWTP from domestic providers of Larvik municipality and from industrial suppliers are ≈60 % and 40%, respectively, which makes detailed analysis of food companies with higher COD, P and N outlet concentrations reasonable. The observation that Lillevik WWTP has problems with the discharge limits during the seasons when food processing plants are most active also makes detailed analysis of food companies relevant. Food companies B and C have higher nutrients concentrations than others and are therefore especially interesting.

5.2.2 Biogas potential test

Company C has low flow rate and relatively high COD concentration which make it relevant to assume that biological wastewater treatment can be an efficient solution to reduce nutrients amount in its wastewater.

Measured COD of water from Company C is approximately equal to real average value estimated from data provided by plant (Chapter 4.2.1). COD to BOD5 ratio for wastewater experimentally analysed is typical for the food processing industry wastewater according to *(Egyptian Environmental Affairs Agency , 2012)*. Based on comparison of average pH measured upon withdrawal with pH of wastewater sample stored for 3 days at ≈15^{o}C it can be stated that acids formation is considerable and promising for successful anaerobic digestion process, hydrolysis and acetogenesis stages *(Tchobanoglous , et al., 2004).*

Different samples types in biogas potential test have different nature of biogas accumulation: Unfiltered sample with higher COD and BOD has highest amount of biogas accumulation. Culture used in current test is robust - it gave relatively fast response to provided food (substrate). Removal COD efficiency by experimental anaerobic digester is high and equal to 99% for unfiltered sample and 90% for filtered.

Production of biogas from 10 ml of unfiltered wastewater is 47 ml. Approximate biogas volume produced by anaerobic digestion process installed at food processing plant C is $Q_{biogas} = 221\,m^3 / day$. Energy content of biogas is equal to $4{,}7 \cdot 10^6$ kJ/d or 54,4 kW and yearly energy production from biogas is - 476 MWh. With conversion of biogas energy potential to heat with efficiency equal to 50% thermal energy produced is 238 MWh annually.

5.2.3 Wastewater treatment process design

Wastewater treatment plant at the Company C is suggested to consist of following main process stages:

- Preliminary treatment of WW: Grease removal device, equalization basin for raw wastewater;
- Secondary treatment of WW: Anaerobic digester (UASB);
- Biogas furnace (unless it can be used directly in existing boiler)
- Perhaps it is also necessary to purify the gas, have gas storage and delivery systems and heat exchanger to maintenance digester temperature.

Preliminary treatment

There is high fat concentration in Company C effluent wastewater in the range from 25 to 1800 mg/l with average value of 500 mg/l. Ratio of Fat/COD varies from 2 to 15 %.

Grease removal is essential in designing WWTP, to remove the easily separated components - grease, fat and oil in wastewater - which may, in too high concentrations, disturb the following anaerobic treatment process. As stated in (Tchobanoglous , et al., 2004): Granulation of sludge in UASB (suggested used in such cases) is less successful with high concentration of fats, because of scum formation.

Average chemical oxygen demand after grease removal process can be calculated by (5-1)

$$COD_{GT,out} = COD_{GT,in} - \eta \cdot COD_{fat,in} , \qquad (5\text{-}1)$$

where $COD_{GT,out}, COD_{GT,in}$ - COD concentration on inlet and outlet of the grease trap, mgCOD/l;

η - efficiency of fats removal in the grease trap (ARCADIS. Infrastracture. Water. Environment. Buildings., 2013);

$COD_{fat,in}$ - COD of fat on the inlet of the grease trap, mgCOD/l;

Assume that for oxidation of 1 g of fat 2,9 g oxygen is consumed. Fat concentration average value is 500 mg/l. $COD_{fat,in} = 1450\, mg / l$

$$COD_{GT,out} = 10770 - 0,8 \cdot 1450 = 9610\, mgCOD / l$$

$COD_{GT,out}$ is average COD concentration of wastewater after grease and fat removal in preliminary treatment process. This value is used further in estimation of the COD removal efficiency of anaerobic digestion process and is very important in process design and UASB reactor operation.

Upflow anaerobic sludge blanket process design

Determination of upflow anaerobic sludge blanket (UASB) reactor design parameters is based on formulas given in Chapter 2.2.3.

The nominal liquid volume of the reactor is given by (2-1). Average food processing plant (Company C) water load is 47 m^3/d and COD inlet to anaerobic digester is equal to effluent COD from grease removal process - 9610 mg/l.

Average organic loading rate is assumed to be equal to 20 kg COD/m^3 d (for granular sludge with little TSS removal, at 30^{o}C) according to (Tchobanoglous , et al., 2004).

$$V_n = \frac{47 \cdot 9610 \cdot 10^{-3}}{20} = 22{,}6\, m^3 .$$

Total reactor liquid volume can be estimated using (2-2)

$$V_L = \frac{22{,}6}{0{,}9} = 25\, m^3 .$$

Determination of reactor dimensions.

Assume design upflow superficial velocity - 0,5 m/h. Reactor height to accommodate gas collection and storage, equal to 2,5 m.

$$D = \sqrt{\frac{4 \cdot 47}{\pi \cdot 0{,}5 \cdot 24}} = 2{,}23\, m,$$

$$H_T = \frac{25 \cdot 0{,}5 \cdot 24}{47} + 2{,}5 = 8{,}9\, m .$$

Reactor hydraulic retention time (HRT) is calculated by (2-5)

$$\tau = \frac{25}{47} = 0{,}53\, d = 12{,}7\, h .$$

According to (Tchobanoglous , et al., 2004) calculated HRT is applicable 9-m-high UASB for temperature > 26^{o}C. Assume SRT of the reactor to be equal around 40-50 days for temperature > 20 ℃.

Maximum COD concentration at the inlet to anaerobic digester based on historical data is equal to 17000 mg/l. Calculation of reactor volume for this highest value will give ≈ 40 m^3.

Based on calculations construction of PX-100 Biogas Plant, 50 m^3 (Shenzhen Puxin Technology Co., Ltd., 2014) is suggested.

Detailed description of reactor, grease trap and other equipment recommended to install is presented in Appendix H.

5.2.1 COD removal efficiency

To estimate the COD removal efficiency of anaerobic digestion process for wastewater from Company C, COD mass balance around wastewater treatment system can be made (5-2) (Kibiakova, et al., 2013), (Tchobanoglous , et al., 2004).

$$\dot{V}_{AD,in} \cdot COD_{AD,in} = \dot{V}_{AD,out} \cdot COD_{AD,out} + COD^{total}_{methane} \qquad (5\text{-}2)$$

where $\dot{V}_{AD,in}$, $\dot{V}_{AD,out}$ - waste water flow on inlet and outlet of the system, m^3/day;

$COD_{AD,in}$, $COD_{AD,out}$ - COD concentration on inlet and outlet of the system, gCOD/m^3;

Value for $COD_{AD,in}$ was used as estimated $COD_{GT,out}$ (Chapter 5.2.3). Assume that some part of suspended solids is included to $COD_{AD,out}$ and the other part is left in the UASB reactor and is involved in granulation process.

$COD^{total}_{methane}$ - COD of methane, gCOD/day.

$$COD^{total}_{methane} = Q_{biogas} \cdot f_{CH_4} \cdot COD_{methane}, \qquad \textit{(5-3)}$$

where f_{CH_4} - content of methane in produced biogas (Tchobanoglous , et al., 2004), %;

$COD_{methane}$ - amount of COD removed with 1 m^3 methane produced (Tchobanoglous , et al., 2004), gCOD/m^3. Assume that amount of fat in wastewater sample used in experiment (Chapter 4.2.3) was low and has negligible influence on biogas production in this case.

$$COD^{total}{}_{methane} = 221 \cdot 0,65 \cdot 2560 = 367744\,gCOD/day$$

For calculation of COD amount after digester from (5-2):

$$COD_{AD,out} = \frac{\dot{V}_{AD,in} \cdot COD_{AD,in} - COD_{methane}}{\dot{V}_{AD,out}},$$

.

$$COD_{AD,out} = 1785\ gCOD/m^3.$$

Removal COD efficiency is:

$$\eta_{COD} = \frac{COD_{AD,in} - COD_{AD,out}}{COD_{AD,in}} = \frac{9610 - 1785}{9610} = 81\%.$$

Results of investigation of mass balance around anaerobic digester for wastewater from Company C are presented in Table 5-1.

Table 5-1 : Comparison of the effluent with and without implementing local treatment system.

Type	**Average water load (Company C)**	**Current effluent concentration** $COD_C^{current}$		**Effluent concentration after adding the suggested AD** COD_C^{new}		**Expected total removal**
	m^3/day	$gCOD/m^3$	$kg\ COD/day$	$gCOD/m^3$	$kg\ COD/day$	
COD (g/m^3)	47	10770	506	1785	84	81 %

Reduction of the COD at the inlet of Lillevik WWTP can be estimated by (5-4).

$$COD_{reduction} = \frac{COD_C^{current} - COD_C^{new}}{COD_{WWTP}^{current}}, \tag{5-4}$$

Current average daily COD amount at the Lillevik plant inlet is equal to 6000 kg COD/day.

$$\mathrm{COD}_{\mathrm{reduction}} = \frac{506-84}{6000} \approx 7\,\%.$$

As stated in (Larvik Kommune, 2013): Because of high organic matter discharge new purification steps must be built at Lillevik WWTP. With establishment of local waste water treatment at food processing company will reduce the inlet COD to the Lillevik WWTP for 7% per day and respectively decrease total COD discharge to the sea. In addition, fat, BOD concentration will also decrease during local treatment and improve the efficiency of chemical coagulation process at Lillevik WWTP. Therefore, need of new purification step will be avoided.

5.2.2 Cost estimation for anaerobic treatment process

Cost estimation for wastewater treatment process includes calculation of: Investment costs, operation costs and capture costs; and is done based on theoretical information given in Appendix I (Eldrup, 2013).

Calculation of CAPEX for anaerobic digestion at the food processing industry based on process parameters and detailed Factor method is presented in Table 5-2.

Details regarding technical characteristics of the equipment as well as dimensioning are listed in Chapter 5.2.3 and Appendix H, databases and suppliers websites are used for cost estimation.

Table 5-2: CAPEX calculation

Equipment	Details	Parameters	Equipment Cost (currency)	Equipment Cost, kNOK, 2014	Factor (Total Cost)	Total Cost, kNOK
Anaerobic Digester (UASB) with feeding, biogas purify, storage and delivery systems	PX-100, concrete	V = 50 m^3 $H \approx 15$ m $D \approx 3$ m V_G =1.2 m^3	≈ 40 000 (USD, 2014)	≈ 238	7,57	1803
Pumps	Gas pump	1.5 kW 30-50 m^3/h	≈ 3 500 (USD, 2014)	≈ 21	12,883	270
	Water pump	3 kW 40 m3/h				
	Sewage pump	5.5 kW 110 m3/h				
	Circulating pump	1 kW 10 m3/h				
Grease Removal Device	grease trap, stainless steel	$\dot{V}$ = 109 m^3/d	≈ 400 (USD, 2013)	≈ 2,4	26,48	63
Equalization basin for raw wastewater	stainless steel	V = 10 m^3	3 200 (USD, 2006)	22,3	14,02	312,5
Biogas and natural gas boiler	firebox boiler, stainless steel	V_b = 300 m^3/d	20 000 (USD, 2013)	122,5	8,98	1 100
Heat exchanger to maintenance digester temperature	shell/tube, stainless steel	A = 2 m^2 Q =14,8 kW	870 (USD, 2014)	5,3	24,77	131
CAPEX						**3 680**

OPEX refers to the fixed and variable operational costs associated with operation and maintenance (O&M) of anaerobic digestion plant.

Fixed O&M costs can be expressed as a percentage of capital costs. For biogas production plants with anaerobic digestion, they typically range from 2% to 3% of the initial CAPEX per year (International Renewable Energy Agency, 2012). Fixed O&M costs consist of labour, planned maintenance, routine component/equipment replacement, insurance, etc.

Variable O&M costs depend on the output of the system and are usually expressed as a value per unit of output (USD/kWh). They include energy cost (electricity, diesel or natural gas), sludge disposal, unplanned maintenance and equipment replacement. They typically are equal to ≈ 4 USD/MWh (International Renewable Energy Agency, 2012). Assume for suggested system OPEX to be equal to 4-5 % of CAPEX (Eldrup, 2013).

Income from the system with anaerobic digestion can be evaluated as economy from biogas energy usage as heat in the system and for local needs at the plant.

Yearly energy production from biogas is - 476 MWh. With conversion of biogas energy potential to heat with efficiency equal to 50% thermal energy produced is 238 MWh annually. With diesel price 1,72 EUR/litr (Fuel prices: Europe, 2014) usage of diesel instead of biogas to produce the same amount of thermal energy will give 84000 EUR/year or 694 kNOK/year economy with exchange rate: 1 NOK = 8,26 EUR (The European Central Bank, 2014).

The need of thermal energy to heat the AD is 10,6 kW or 96,4 MWh annually. Then, 142 MWh of thermal energy yearly are available for food processing Company C local needs, which is equal to 48910 EUR/year or 404 kNOK/year economy on diesel basis.

Results of the cost estimation for the implementation of anaerobic digestion system with biogas production and conversion into heat are presented in Appendix J.

CAPEX of this project is equal approximately to 3 MNOK, this number is probably considerable for Company C. Approximate payback period for biological wastewater treatment system at the outflow of food processing plant with discount factor = 5% is 25 years. Generally, payback period is the key to the decision making process, and for the case this number is also quite high. However, to reduce the payback period and increase economic feasibility further investigation on possibilities to decrease CAPEX can be done.

Furthermore, if suggested system is found to be profitable by other measures, the payback period can be used as a secondary measure of the financing requirements for a project. Considering this, reduction of fat, COD, BOD and N locally at the Company C leads to loss of necessity to install new purification process (biological treatment process or other measures) at Lillevik WWTP. The consulting COWI on behalf of Larvik considered that the investment in a new purification process will cost > 50 MNOK. Operating costs will increase by approx. 1.3 MNOK/year. (Larvik Kommune, 2013).

Thus, deeper investigation of probability to install local waste water treatment processes at Company C is highly reasonable and recommended. For further analysis of such possibility Companies B and ND1 are suggested too (have low flowrate and relatively high COD discharge (Chapter 4.2.3).

5.3 The Jar Test experiment

Jar test was performed with good precision, e.g. injecting chemicals simultaneously by using different pipettes. (Kibiakova, et al., 2013).

Cleaning efficiency in Jar Test for with different flow regimes: With and without flow in channel simulation are presented in Table 5-3.

Table 5-3 Cleaning efficiency in Jar Test with flow in channel simulation (grey column) and without (white column)

Sample	1	2	3	4	5	6	1	2	3	4
Frequency [rpm]	200	280	360	200	280	360	200	360	200	360
Efficiency of PO_4^{3-} concentration abatement [%]	97,5	97,3	96,1	97,6	97,4	96,9	97,6	96,8	98,0	96,8
Efficiency of Turbidity abatement [%]	97,4	95,2	94,2	97,5	97,3	96,4	96,8	96,9	98,3	98,2

Results from Jar Test experiment performed during this study are compared to previous results from Master Project 2013 and showed on Figure 5-1, Figure 5-2.

The difference in these two analyses is in wastewater dilution characteristics due to amount of precipitations: Wet period (23.11.13 and 14.11.13) and dry period (02.05.14).

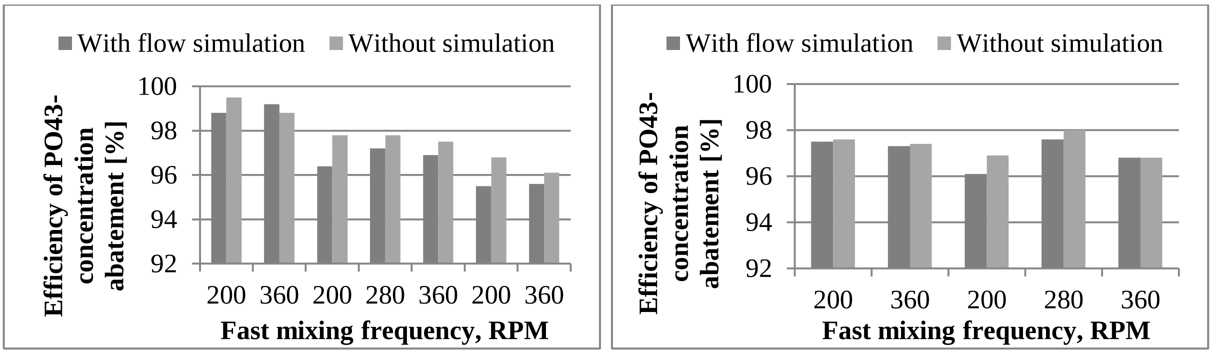
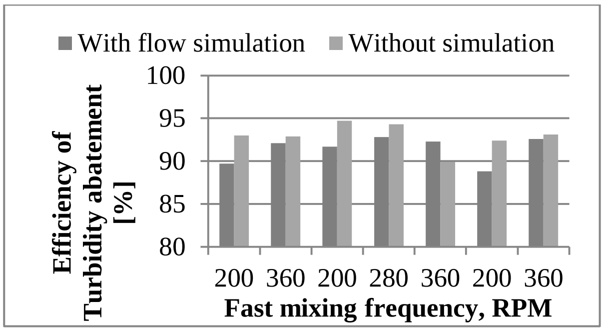


Figure 5-1: Cleaning efficiency of PO_4^{3-} removal versus mixing frequency for Jar Test performed during wet period (left) and dry period (right)

From Figure 5-1 can be observed that the cleaning efficiency of PO_4^{3-} removal is better for the second case (without channel simulation) in general. Results are almost similar for all the parallels. Removal of PO_4^{3-} is relatively higher in case of flow simulation for dry period wastewater than for wet, while for the case without flow simulation – number are almost the same for both – wet and dry periods.



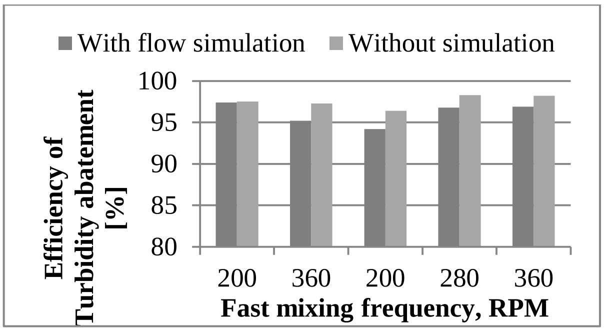


Figure 5-2: Cleaning efficiency of turbidity removal for Jar Test performed during Master Thesis (left) and this study (right)

From Figure 5-2 can be observed that the turbidity cleaning efficiency is better for dry period water in general. Turbidity abatement is relatively better in case without flow simulation.

As a result from experiments for dry weather and wet weather suggestion from (Kibiakova, et al., 2013) can be confirmed: Decrease of coagulation efficiency is result of delay between rapid mixing and flocculation.

6 Conclusion

Based on accomplished research following conclusions can be drawn. A new and very expensive (> 50 MNOK) purification step at Lillevik WWTP to improve treatment can probably be avoided by usage of measures evaluated here. Each one of these measures that can improve treatment process will not give necessary effect alone; however, combining the mentioned improvements will likely provide needed influence.

The recommended measures are:

Plant data analysis: Phosphorus removal at WWTP is efficient. COD and BOD treatment is insufficient. BOD removal depends more than COD on chemicals dosage and temperature. Variations of inlet concentrations and pollutants removal (especially organic matter) are seasonal and probably influenced by operation of food processing industry. Removal of organic material from wastewater locally at these industries is an option to obtain sufficient treatment. Advanced coagulant dosage control may also improve the treatment and the DOSCON system will be installed during year 2014 at Lillevik WWTP.

The Jar Test experiment: Jar test results proved that possible problems of coagulation process can be caused by long distance from chemical addition spot to the flocculation basins. Differences in parameters of wastewater due to precipitations influence removal efficiencies too. Moving of the spot of chemical coagulant adding and mixing closer to the flocculation should help increase the efficiency of treatment.

Optimization of chemical coagulation process: There is wide range of opportunities studied theoretically that could be done for the optimization of chemicals. Various alternative coagulants with various dosage amounts can be tested using jar test in more extensive way to find out optimum coagulant with optimum dosage to be used. Immediate rapid and uniform mixing after addition of chemicals is also important for coagulation process.

Contact stabilization process effects: A contact process where sludge reject water is treated in an aerobic biological process before it is returned to the main wastewater stream can lead to decrease of BOD and COD effluent level.

Decentralized food processing wastewater treatment: Local wastewater treatment is suggested at food processing companies with high COD and P in discharge, that evidently influence treatment at the Lillevik WWTP. COD removal efficiency of suggested local biological wastewater treatment process at analyzed company with low flow rate can be up to 81% causing COD inlet reduction at the Lillevik WWTP around 7%. Such mainly soluble COD removal can give significantly decreased discharge to the sea. The payback period of such local treatment seems reasonable but further investigation is required.

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Appendices

Telemark University College
Faculty of Technology
M.Sc. Programme

MASTER'S THESIS, COURSE CODE FMH606

Student:	**Hanna Kibiakova**
Thesis title:	**Investigation to improve the coagulation process on Lillevik WWTP, Larvik**
Signature:	....
Number of pages:	80
Keywords:	COD, BOD, Removal Efficiency, Jar Test, Biocontactor, Cost Estimation
Supervisor:	Rune Bakke sign.: ....
Censor:	sign.: ....
External partner:	Lillevik WWTP, Larvik sign.: ....
Availability:	Open

Archive approval (supervisor signature): sign.: .... **Date :** 2/6 - 14

Abstract:

Investigation to improve the wastewater treatment, focusing on the coagulation process, at Lillevik WWTP has been performed. Four activities were carried out for this purpose:

1. Investigate variations and correlations for all plant process data. 2. Study coagulation process in Jar test experiment. 3. Analysis of decentralized food processing wastewater treatment possibility theoretically and experimentally with biogas potential test and by economic feasibility estimation. 4. Theoretically evaluate the option of adding a biological contact process to the main treatment process.

The existing data from the full scale plant since January 2012 show insufficient organics removal (measured as BOD and COD). It is seasonal and related to food processing wastewater, so local treatment of such was investigated. Local biological wastewater treatment can be efficient at a few companies to reduce COD inlet at Lillevik WWTP. Economic feasibility estimation suggests it as a reasonable solution.

Jar tests using the coagulants presently in use gave consistent results showing that the method can be used to investigate chemical coagulation process improvements such as using different coagulants. The coagulation efficiency was reduced by the long distance from rapid mixing to flocculation. The chemical addition spot should therefore be moved closer to the flocculation.

Adding a biological contact process to the main treatment process by aerobic treatment of the sludge reject water before it is returned to the coagulation appears to be an efficient measure. It can be a good way to improve the coagulations since active biomass can absorb dissolved organics before they are removed as sludge by coagulation.

Since none of above mentioned measures alone is expected to enhance wastewater treatment as needed to always fulfil discharge requirement, integration of some of these solutions can be sufficient and should be further investigated.

Appendix B Task Description

Telemark University College
Faculty of Technology

FMH606 Master's Thesis

Title: Investigation to improve the Lillevik WWTP performance

TUC supervisors: Rune Bakke

External partner: Lillevik WWTP, Larvik

Task description:
The plan is to make experimental and theoretical investigations of the possible measures identified to improve the Lillevik WWTP performance. The study involves:
- Investigate inlet wastewater composition variations
- Check the location of the dosage of chemical coagulants
- Study control of dosage of chemical coagulants
- Discuss the possibility of alternative chemical coagulants usage
- Study and simulate biological contactor process effects
- Simulate decentralized food processing wastewater treatment
- Literature review

Task background:
A variety of factors, probably including climate change, make it increasingly challenging to comply with discharge limits at Lillevik WWTP, Larvik. An MSc student project has extracted information from existing data to identify bottlenecks for treatment performance. The investigation shows that organic matter (COD, BOD) removal is the main challenge and that it is especially hard to meet the discharge limits during the seasons when receiving wastewater from commercial food processing. Improved chemical coagulation, adding a biological contactor process and decentralized food processing wastewater treatment are measures that can be implemented to meet the challenge. The aim is to help establish efficient solutions to the challenges of Lillevik WWTP.

Student category:
EET student

Practical arrangements:
Work will be carried out both at TUC and at Lillevik WWTP, Larvik.

Signatures:

Student (date and signature): 05.05.14

Supervisor (date and signature): 05.05.14

Adress: Kjølnes ring 56, NO-3918 Porsgrunn, Norway. **Phone:** 35 57 50 00. **Fax:** 35 55 75 47.

Appendix C Keywords and definitions for coagulation process

Colloidal Particles: Microscopic solid particles suspended in liquid that range in size from 10 nm to several microns. Their extremely small size possesses problem in water treatment because of very slow settling time and easy passage through screens and filters.

Turbidity: It is the measure of cloudiness or haziness in a fluid caused due to the suspended solid particles which are not visible by naked eyes. It is a key measure to determine the water quality.

Coagulation: Thickening of liquid into curd like insoluble state due to some chemical reaction is known as coagulation.

Flocculation: It is a process of formation of larger lumps of the colloidal particles. Slow agitation of water results into bumping of the suspended particles and in turn agglomeration to form heavier flocs.

Coagulant: Chemicals added to the water to facilitate agglomeration of colloidal particles to form heavier flocs**.**

Coagulant Aid: It is a substance or process which helps a liquid to coagulate.

Jar Test: It is a setup containing small containers which is used to evaluate best coagulant, coagulant aid, optimum coagulant dose, mixing speed and flocculation time for multiple samples. (Wan, et al., 2011)

Appendix D Contact stabilization process

Following calculation of removed BOD values were estimated and discussed in (Kibiakova, et al., 2013).

Values of soluble BOD that were obtained after two dewatering steps, were found experimentally in the project of Knardalstrand wastewater treatment plant.

$$BOD_{Thick,out} = 300\ g/m^3$$
$$BOD_{Centr,out} = 150\ g/m^3$$

Total number of these BOD values gives soluble BOD that can be removed in nitrification reactor. Assume 0,9 of this BOD removed

$$BOD_{recycle} = \frac{Q_A \cdot BOD_{Thick,out} + Q_B \cdot BOD_{Centr,out}}{Q_{recycle}}$$

$$BOD_{recycle} = \frac{3,56 \cdot 300 + 79,04 \cdot 150}{82,6} = 156,5\ g/m^3$$

$$BOD_{removed1} = 0,9 \cdot BOD_{recycle} = 140,8\ g/m^3$$

Also some BOD will be removed by activated solids that return with recycle. MLSS is responsible for removing BOD and reach the value of 4000-6000 g/m3 in stabilization chamber. Contact stabilization has the highest F:M ratio (typically 0,05-0,6 g/g·d). (Tchobanoglous , et al., 2004)

Assume concentration MLVSS in recycle water equal to 4000 g/m3

Assume F:M is equal to 0,325. Though worst and best cases will be also considered and summed in the Table D-1.

$$BOD_{removed2} = \frac{MLVSS \cdot Q_{recycle} \cdot (F:M)}{Q_{tot}}$$

$$BOD_{removed2} = \frac{4000 \cdot 82,6 \cdot 0,325}{19427,8} = 5,5\ g/m^3$$

Considering removal BOD during contact of activated sludge and incoming organic matter, we obtain

$$Q_{out} \cdot BOD_{out,modified} = Q_{out} \cdot BOD_{out} - Q_{recycle} \cdot BOD_{removed1} - Q_{tot} \cdot BOD_{removed2}$$

$$BOD_{out,modified} = \frac{19363,5 \cdot 25,6 - 82,6 \cdot 140,8 - 19427,8 \cdot 5,5}{19363,5} = 19,4\ g/m^3$$

Considering the same amount of MLVSS and F:M ratio equal to 0,06 and 0,6 removal efficiencies for them are presented in Table D-1.

Table D-1: Comparison of BOD removal due to stabilization contact process with different F:M ratios.

F:M ratio, g/(g·d)	BOD removed in contact process, g/m3	BOD out modified, g/m3	Efficiency of removal, %
0,06	1	23,9	74,2
0,325	5,5	19,4	79,1
0,6	10,2	14,8	84,1

Appendix E Wastewater treatment process parameters correlation

Detailed analysis of the wastewater treatment based on the following factors influencing the process:

1. Water plant load, m^3/d. Is measured at the outlet of wastewater treatment plant.
2. Dosages of chemical coagulants: Polyaluminum chloride (PAX 18) and ferric chloride sulphate (PIX 318), $ltr/m^3 \cdot d$, are dependent on water plant load.
3. Average temperature, K, and pH of wastewater, precipitations, mm

Firstly, correlation analysis for these factors was performed using daily measured data from 01.01.12 to 01.03.14; results are presented in Table E-1.

Table E-1: Correlation dependences for various parameters of process

	Water Load	PAX	PIX	Precipi-tations	Tempera-ture	Outlet pH	Season
Water Load	100%						
PAX	82%	100%					
PIX	53%	64%	100%				
Precipitations	33%	32%	15%	100%			
Temperature	-24%	-23%	-15%	-2%	100%		
Outlet pH	-9%	-25%	-43%	-17%	-52,63%	100%	
Season	10%	5%	5%	4%	77%	-41%	100%

Parameters described have correlations with nutrients removal efficiency, which are calculated for data from 01.01.12 to 01.03.14 and presented in Table E-2.

Table E-2*: Correlation dependencies of P, COD and BOD on various parameters of process*

	Water Load	PAX	PIX	Preci-pitations	Tempe-rature	Inlet pH	Outlet pH	Season	BOD	COD
BOD	17%	-9%	-18%	2%	21%	5%	3%	18%	100%	30%
COD	-28%	5%	2%	-36%	-12%	9%	15%	-22%	30%	100%
Tot-P	-3%	33%	29%	-15%	27%	-16%	-16%	28%	-	-

Appendix F Food processing industries analysis

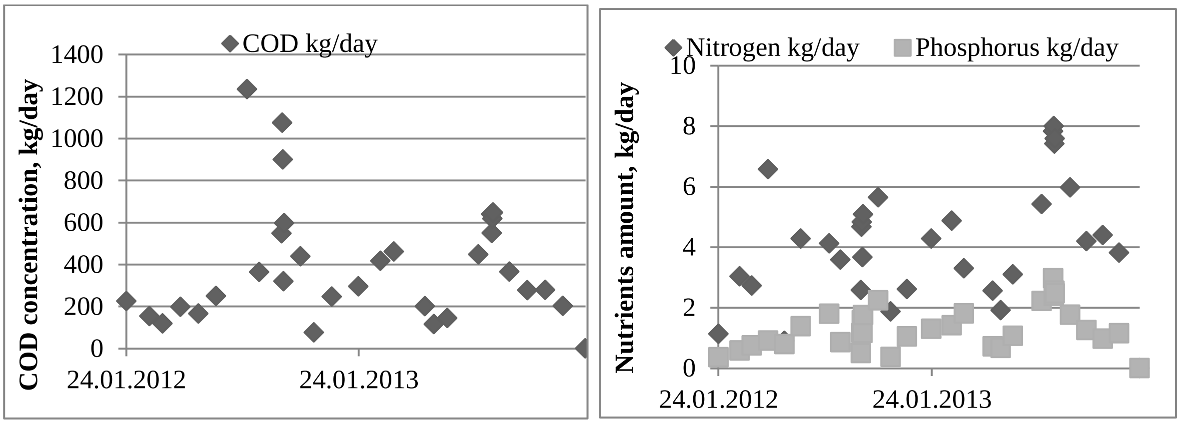

Figure F-1: Nutrients content in wastewater from Company A (2013-2014)

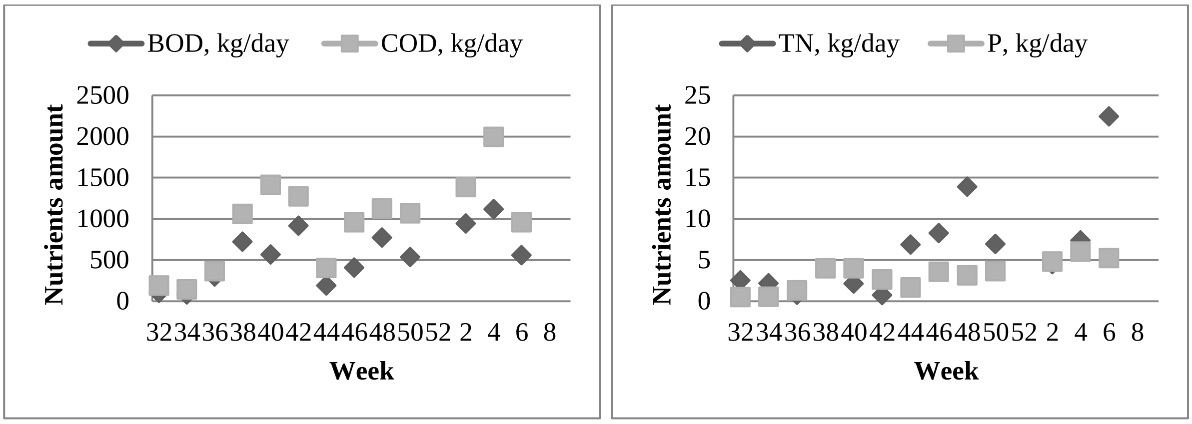

Figure F-2: Nutrients content in wastewater from Company B (2012-2014)

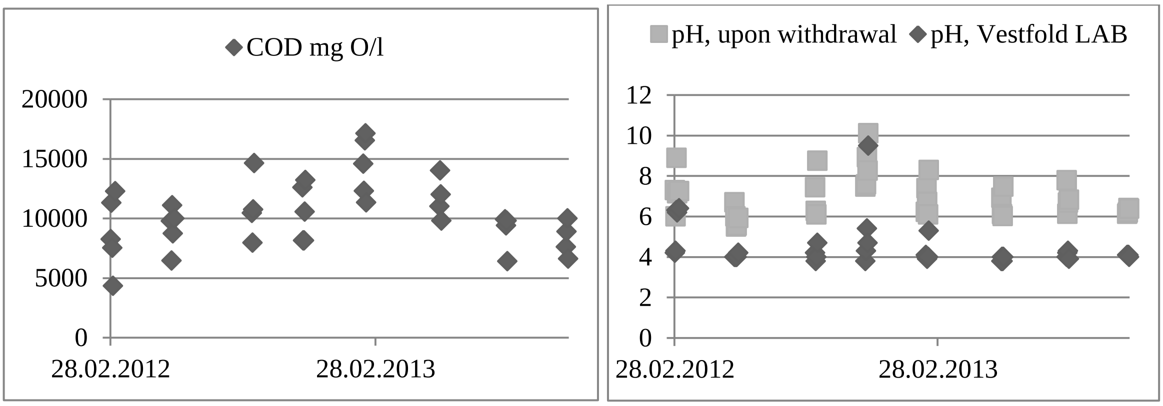

Figure F-3: Nutrients content in wastewater from Company C (2012-2013)

Appendix G Jar Test Results

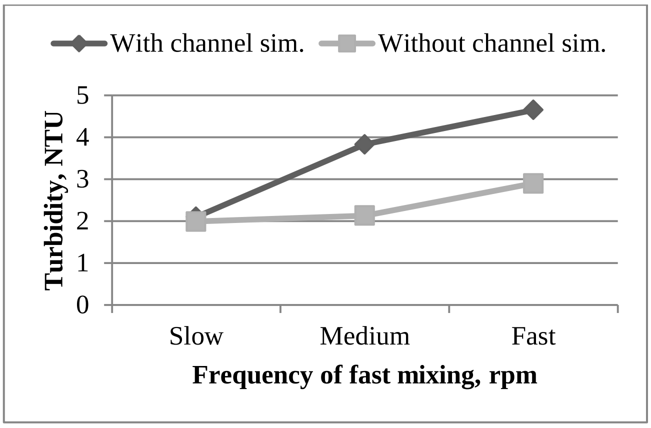

Figure G-1: Turbidity for the different frequencies with and without channel flow simulation, 1st parallel.

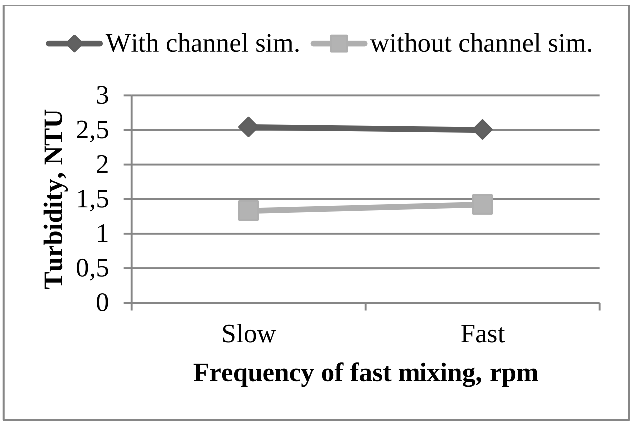

Figure G-2: Turbidity for the different frequencies with and without channel flow simulation, 2nd parallel.

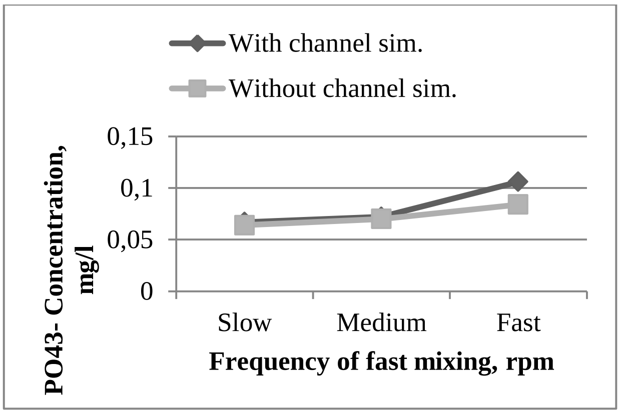

Figure G-3: Phosphate concentrations for different frequencies, 1st parallel.

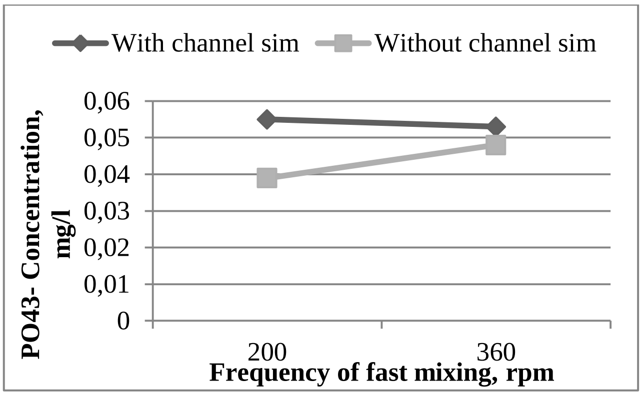

Figure G-4: Phosphate concentrations for different frequencies with and without channel flow simulation, 2nd parallel.

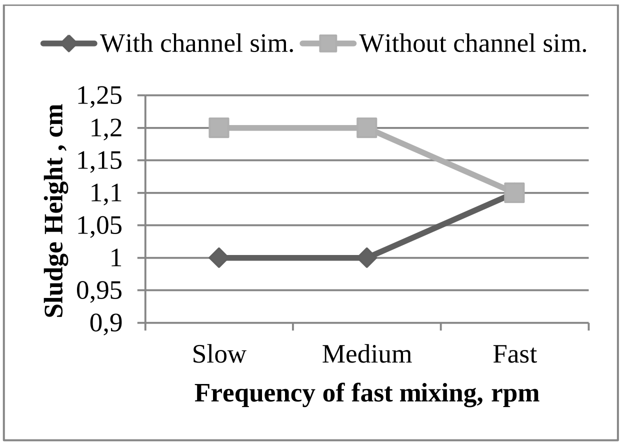

Figure G-5: Sludge height for different frequencies with and without channel flow simulation, 1st parallel.

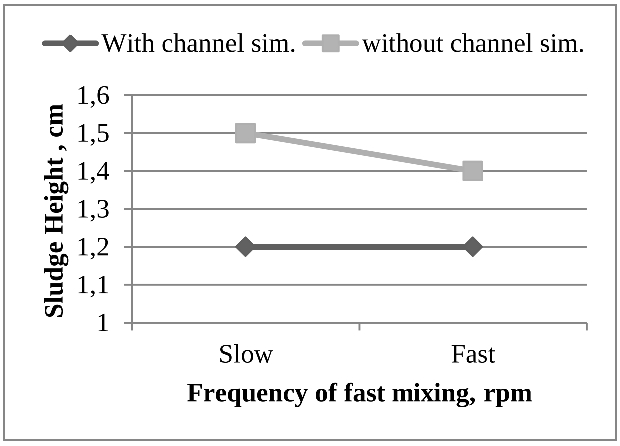

Figure G-6: Sludge height for different frequencies with and without channel flow simulation, 2nd parallel.

Appendix H Equipment parameters and dimensions

Anaerobic Digester process design

PX-100 Biogas Plant is composed of a concrete digester and several glass fibre reinforced plastic gasholders. The digester is 75 m^3 of capacity. The gasholder is 1.6 m of diameter, 0.75 m of height and 1.2 m3 of capacity. The feeding system, the biogas purify system (the desulphurization tower and the dehydration tower), the biogas storage and delivery system, biogas appliances or generators are included.

Features:

(1) High reliable: no mechanic movement, no mechanic failures.

(2) Wide range of application. The plant can be built both under and above ground. The plant is suitable to handle both liquids (sewage, human and animal manure) and solids (grass, straw, and food waste).

(3) Low maintenance cost: very few workers are needed, almost no maintenance for rust prevention and mechanic repair are needed.

(4) Durable: The concrete digester which can stand strong acid and alkali can last over 40 years, the glass fibre gas holder can last over 10 years and it is replaceable when it is worn out or broken.

Range of Apply:

(1) Disposal of sewage sludge for waste water disposal stations

(2) Disposal of wastes for medium size livestock farms

(3) Disposal of sewage and food waste for departments, factories and schools etc.

(4) Disposal of waste water and solid waste for food processing plants and brewing plants.

Pumps

Description of pumps characteristics is given in Table H-1 (Shenzhen Puxin Technology Co., Ltd., 2014)

Table H-1:Pumps

Product	Description&specification
GAS PUMP (1.5KW, 30-50M3/H)	380V, 1.5KW, 30M3/H 10KPA
WATER PUMP 3KW	Flow: 40M3/h, head: 13meters, Power:3KW
SEWAGE PUMP 5.5KW	Flow: 110M3/h, head: 10meters, Power:5.5KW

Grease removal devise

The type of grease removal device selected is grease trap. Ratio of FOG/COD in the wastewater from Company C estimated as average value using historical data is 0 - 15 % with average concentration 300 – 8000 mg/l, min – 20 mg/l, max – 2000 mg/l.

Grease trap capacity was estimated to be 18 kg with flow rate – 100 m^3/day. Cost and technical parameters were evaluated based on (ARCADIS. Infrastracture. Water. Environment. Buildings., 2013)

Equalization basin for raw wastewater

Dimensions of equalization basin for raw wastewater was calculated according to (Christian & Karia, 2006): for the given flow data prepare a graph of time vs cumulative flow and draw the tangents, the sum of maximum vertical distances from tangency to average flow line will give the total volume required.

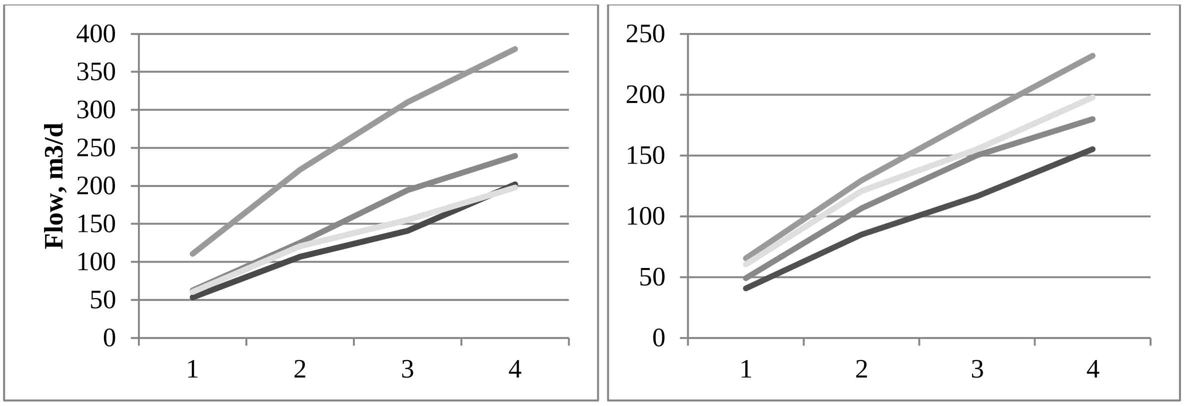

Figure H-1: Flow lines for Company C during 4 different measurements for 2012 (left) and 2013 (right).

Equalization basin capacity was estimated to be 10 m^3. Cost and technical parameters were evaluated based on (Williams, 2006)

Biogas and natural gas boiler

Boiler volume flow rate was evaluated to be V_b = 300 m^3/d. Based on this, cost and parameters were found using (City of Klamath Falls, Spring Street Sewage Treatment Plant, 2010).

Heat exchanger

Estimation of digester heating requirements. (Tchobanoglous , et al., 2004)

Concrete digester dimensions: Diameter - D = 2,23 m; Height - H_T = 9 m.

Temperatures: Average air T = 15^{o}C; Earth below floor T = 10 ^{o}C; Incoming wastewater and sludge = 20 ^{o}C; Digester content T = 30 ^{o}C.

Table H-2: Required heat-exchanger capacity

Heat requirement for digester content		$q_R = 47\, m^3/d \cdot 0{,}6346\, kg/m^3 \left[(30-20)\ {}^oC\right]\left(4200\ J/kg\cdot {}^oC\right) = $ $= 1{,}25\cdot 10^6\ J/d$
Heat losses	walls	$q_W = \left(4\, W/m^2\cdot {}^oC\right)\cdot\left(\pi\cdot 3\cdot 15\ \ m^2\right)\cdot\left(30-15\ {}^oC\right)\cdot 3600\cdot 24 = $ $= 7{,}28\times 10^8\ J/d$
Heat losses	floor	$q_F = \left(1{,}4\ \ W/m^2\cdot {}^oC\right)\cdot\left(0{,}25\cdot\pi\cdot(3)^2\ m^2\right)\cdot\left(30-10\ {}^oC\right)\cdot 3600\cdot 24 = $ $= 0{,}168\times 10^8\ J/d$
Heat losses	roof	$q_r = \left(4\, W/m^2\cdot {}^oC\right)\cdot\left(0{,}25\cdot\pi\cdot(3)^2\ m^2\right)\cdot\left(30-15\ {}^oC\right)\cdot 3600\cdot 24 = $ $= 1{,}71\times 10^8\ J/d$
Required heat-exchanger capacity		Q = $9{,}17\times 10^8\ J/d = 10613\, W$

Necessary heat exchanger area can be estimated by (G-1)

$$A = \frac{Q}{LMTD\cdot U}, \qquad \textit{(H-1)}$$

where LMTD - the logarithmic mean temperature difference, K;

U - heat transfer coefficient, W/m^2K.

The LMTD formula for a countercurrent heat exchanger is given by (H-2)

$$LMTD = \frac{(T_{H2} - T_{C1}) - (T_{H1} - T_{C2})}{ln\left(\frac{T_{H2} - T_{C1}}{T_{H1} - T_{C2}}\right)}, \tag{H-2}$$

where T_{H1} and T_{H2} - temperature of hot water before and after the boiler, 60 and 70 ^{o}C;

T_{C1} and T_{C2} - temperature of wastewater before and after the HE, 10 and 30 ^{o}C.

$$LMTD = 45^{o}C\,.$$

Heat transfer coefficient U is assumed to be equal to 200 W/m^{2}K for liquid-liquid heat transfer in a shell-and-tube heat exchanger (Beardmore, 2013).

$$A = \frac{10613}{45 \cdot 200} = 1{,}18\,m^2$$

Based on this cost and parameters were found using (Matches, 2014).

Appendix I CAPEX estimation

Cost estimation for wastewater treatment process includes calculation of: investment costs, operation costs and capture costs. Calculations are based on the process parameters, equipment dimensions calculated (Chapter 5.2.3 and Appendix H) and theoretical information given in (Eldrup, 2013).

Full operational time of the plant is assumed to be 8760 hours uptime per year.

Investment Cost

In the current project investment cost or CAPEX, is the cost of production and installation for process equipment necessary for wastewater treatment plant.

There are several ways to find the total investment cost. The detailed factor method chosen in this study includes both: direct costs and indirect and is the most advanced method that gives the best accuracy, because the factors used take into account all details needed to install the equipment (direct, engineering, administration, commissioning, contingency costs, etc.).

Equipment Cost Estimation

The equipment cost can be found using dimensions calculations via sellers websites, databases, books or by direct contact with the seller. In case of this research first three methods were used as described in Appendix H.

Power Law of Capacity

The power law of capacity is used to make the result valid for any other equipment specification. The power law formula is given in (I-1) (Eldrup, 2013).

$$Cost\ B = Cost\ A \cdot \left(\frac{Cap\ B}{Cap\ \mathrm{A}} \right)^{e}, \qquad (I\text{-}1)$$

where Cost B, Cap B - the cost and capacity of the facility being estimated;

Cost A, Cap A - the known cost and capacity of a similar facility;

e - the exponent or proration factor, typically lies between 0.5 and 0.85.

This value of Cost B will give rough estimate of the new equipment cost easily and quite accurately.

Cost Conversion

To update the equipment cost to the current year and convert the currency from USD to NOK, the exchange rates and consumer price indexes are used according to (I-2) (Eldrup, 2013).

$$Cost_{kNOK,2013} = Cost_{USD,year} \cdot ER_{NOK/USD,year} \cdot \frac{CPI_{2013}}{CPI_{year}}, \qquad (I\text{-}2)$$

Where $Cost_{kNOK,2013}$ - cost of equipment in kNOK in 2013 year;

$Cost_{USD,year}$ - cost of equipment in USD in known cost year;

$ER_{NOK/USD,year}$ - exchange rate from USD to kNOK in known cost year (DNB Bank ASA, 2013);

CPI_{2013} - consumer price index for 2013 year (SENTRALBYRÅ, STATISTISK, 2013);

CPI_{year} - consumer price index for known cost year (SENTRALBYRÅ, STATISTISK, 2013).

Detailed Factor Method

The detailed factor method is used to take factors such as piping, insulation, engineering, administration among others to the equipment price and include it in CAPEX.

According to this method, cost of equipment installed is based on cost factors given in Table I-1 based on estimated equipment cost in carbon steel (CS) given in kNOK for 2013/2014.

Equipment made of stainless steel have to be calculated using material factors: Welded -1.75, Machined -1.3. Total installation cost factor can be calculated by (I-3):

$$F_{TC}{}^{SS} = F_{TC}{}^{CS} + (F_M - 1) \cdot (F_E + F_P), \qquad \text{(I-3)}$$

where $F_{TC}{}^{SS}$ - total cost factor for equipment in stainless steel;

$F_{TC}{}^{CS}$ - total cost factor for equipment in carbon steel;

F_M - material factor for equipment;

F_E, F_P - equipment and piping factor.

Total cost for each type of equipment (I-4):

$$TC = F_{TC} \cdot COST_{kNOK,2013}. \qquad \text{(I-4)}$$

The total investment cost, CAPEX, for the whole process is the sum of the total cost for all the equipment.

Table I-1: Cost factors *(Eldrup, 2013)*

Cost of equipment in Carbon Steel (CS) (kNOK)	Fluid								Solid						
	0-20	20-100	100-500	500-1000	1000-2000	2000-5000	5000-15000	>15000	0-20	20-100	100-500	500-1000	1000-2000	2000-5000	>5000
Equipment	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Erection	0,70	0,37	0,20	0,14	0,11	0,09	0,08	0,06	1,55	0,82	0,48	0,34	0,28	0,20	0,17
Piping	2,80	1,61	0,88	0,65	0,51	0,38	0,32	0,23	0,67	0,31	0,17	0,13	0,10	0,08	0,07
Electric	0,81	0,56	0,38	0,32	0,27	0,22	0,20	0,14	1,37	0,86	0,57	0,44	0,37	0,31	0,26
Instrument	2,80	1,51	0,88	0,65	0,51	0,38	0,32	0,23	1,11	0,61	0,36	0,26	0,21	0,14	0,12
Civil work	0,43	0,28	0,20	0,16	0,13	0,11	0,10	0,07	0,99	0,59	0,38	0,29	0,23	0,19	0,16
Steel & concrete	1,41	0,92	0,62	0,50	0,43	0,34	0,31	0,22	1,97	1,22	0,80	0,62	0,52	0,41	0,37
Insulation	0,53	0,27	0,14	0,11	0,09	0,07	0,04	0,03	0,53	0,27	0,14	0,11	0,09	0,07	0,04
Direct Cost	**10,60**	**6,53**	**4,43**	**3,65**	**3,17**	**2,69**	**2,47**	**2,09**	**9,20**	**5,79**	**4,00**	**3,33**	**2,90**	**2,50**	**2,29**
Engineering Process	0,97	0,34	0,19	0,14	0,12	0,10	0,09	0,07	0,97	0,34	0,19	0,14	0,12	0,10	0,09
Engineering Mechanical	0,77	0,19	0,08	0,04	0,03	0,02	0,01	0,01	0,97	0,29	0,13	0,09	0,07	0,04	0,03
Engineering Piping	0,85	0,46	0,27	0,20	0,14	0,11	0,10	0,07	0,17	0,09	0,04	0,03	0,02	0,02	0,02
Engineering Electric	0,82	0,24	0,12	0,09	0,08	0,07	0,04	0,03	0,96	0,32	0,16	0,12	0,10	0,08	0,07
Engineering Instrument	1,46	0,57	0,28	0,20	0,16	0,11	0,10	0,07	0,95	0,28	0,12	0,09	0,07	0,04	0,03
Engineering Civil	0,31	0,09	0,03	0,02	0,02	0,01	0,01	0,01	0,39	0,13	0,07	0,04	0,03	0,02	0,02
Engineering Steel & Concrete	0,46	0,19	0,10	0,08	0,07	0,04	0,04	0,03	0,63	0,22	0,12	0,10	0,09	0,07	0,07
Engineering Insulation	0,21	0,07	0,02	0,01	0,01	0,01	0,01	0,01	0,21	0,07	0,02	0,01	0,01	0,01	0,01
Engineering Cost	**5,83**	**2,11**	**1,09**	**0,78**	**0,63**	**0,48**	**0,41**	**0,30**	**5,14**	**1,73**	**0,86**	**0,63**	**0,50**	**0,39**	**0,34**
Procurement	1,22	0,41	0,16	0,10	0,07	0,03	0,02	0,02	1,22	0,41	0,16	0,10	0,07	0,03	0,02
Project Control	0,29	0,11	0,04	0,03	0,03	0,02	0,02	0,02	0,26	0,09	0,04	0,03	0,02	0,02	0,01
Site Management	0,52	0,33	0,22	0,19	0,16	0,13	0,12	0,09	0,44	0,28	0,20	0,16	0,14	0,12	0,12
Project management	0,70	0,38	0,23	0,19	0,16	0,13	0,12	0,09	0,60	0,31	0,20	0,16	0,13	0,12	0,11
Administration Cost	**2,74**	**1,21**	**0,66**	**0,50**	**0,41**	**0,33**	**0,29**	**0,21**	**2,52**	**1,09**	**0,60**	**0,46**	**0,37**	**0,31**	**0,27**
Commissioning	0,57	0,26	0,13	0,08	0,08	0,04	0,04	0,03	0,49	0,23	0,12	0,09	0,07	0,04	0,03
Total Known Cost	**19,72**	**10,12**	**6,31**	**5,00**	**4,29**	**3,55**	**3,23**	**2,64**	**17,35**	**8,85**	**5,58**	**4,49**	**3,84**	**3,25**	**2,94**
Contingency	3,91	2,02	1,27	1,01	0,87	0,73	0,66	0,48	3,39	1,73	1,11	0,89	0,77	0,66	0,60
Total Cost	**23,63**	**12,13**	**7,57**	**6,02**	**5,16**	**4,28**	**3,89**	**3,11**	**20,73**	**10,59**	**6,69**	**5,38**	**4,60**	**3,90**	**3,54**

Appendix J : COST estimation results

Table J-1: Cost Estimation for biological treatment system

	Years of operation												
	0	1	2	3	4	5	6	7	8	9	10	11	12
Economy, kNOK	-	404	404	404	404	404	404	404	404	404	404	404	404
CAPEX, kNOK	-3680	0	0	0	0	0	0	0	0	0	0	0	0
OPEX (FC+VC), kNOK	-	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2
Cash Flow, kNOK	-3680	256,8	256,8	256,8	256,8	256,8	256,8	256,8	256,8	256,8	256,8	256,8	256,8
F, 5 %	1	0,95	0,91	0,86	0,82	0,78	0,75	0,71	0,68	0,64	0,61	0,58	0,56
NPV, kNOK	-3680	244,6	232,9	221,8	211,3	201,2	191,6	182,5	173,8	165,5	157,7	150,1	143,0
Σ NPV, kNOK		-3435,4	-3202,5	-2980,7	-2769,4	-2568,2	-2376,6	-2194,1	-2020,2	-1854,7	-1697,1	-1546,9	-1403,9

	Years of operation													
	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Economy, kNOK	404	404	404	404	404	404	404	404	404	405	406	406	406	406
CAPEX, kNOK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEX (FC+VC), kNOK	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2	147,2
Cash Flow, kNOK	256,8	256,8	256,8	256,8	256,8	256,8	256,8	256,8	256,8	257,8	258,8	258,8	258,8	258,8
F, 5%	0,53	0,51	0,48	0,46	0,44	0,42	0,40	0,38	0,36	0,34	0,33	0,31	0,30	0,28
NPV, kNOK	136,2	129,7	123,5	117,6	112,0	106,7	101,6	96,8	92,2	88,1	84,3	80,2	76,4	72,8
Σ NPV, kNOK	-1267,7	-1138,0	-1014,5	-896,9	-784,8	-678,1	-576,5	-479,7	-387,5	-299,4	-215,1	-134,9	-58,5	14,3

Appendix K Risk analysis

The main risks studying the Master research were performed during Jar test, biological potential test. Any risk carrying out this laboratory experiments shall be evaluated to decrease and liquidate possible consequences.

Jar Test

Figure K-1 represent main step of Jar test.

Figure K-1: Main step of jar test

Short description

Influent wastewater was poured to six cylinders 1 litre volume each. Then chemicals (PIX 18, PAX 318) are added to samples, while the first mixing stage starts. After the experiment pH , turbidity and phosphorus concentrations were measured.

Possible accidents

Jar test is that kind of experiment that has very low risk of accident happening. Hence the consequences can be pretty high around medium level according to riskmatrix.

1. Spilled raw wastewater, risk to be infected by different pathogens.
2. Spilled chemicals (PIX 18, PAX 318). Can affect when it is inhaled. Contact with it can severely irritate and burn the skin and eyes with possible damage.

Measures

- Gloves, glasses and laboratory coat should be used. According to laboratory procedure.
- Proper utilization of applied chemicals should be
- Vaccination to prevent hepatitis A, hepatitis B and tetanus.

Biological potential test

Figure K-2 represent main step of biogas potential test, determination of biological oxygen demand, BOD5, chemical oxygen demand COD.

Figure K-2 : Main step of biogas potential test, BOD and COD measurements

Short description

- Measurement of pH and turbidity.

- Determination of biological oxygen demand, BOD5 with WTW OxiTop Control 12.
Effluent wastewater from food processing company which is specialized on production of salads, brines, etc. is poured to graduated flask for sample dilution with distilled water. After estimation of the necessary volume based on chosen BOD-range samples are filled into BOD bottle. Then nitrification inhibitor and sodium hydroxide are added. Insert the rubber sleeve, close the BOD bottle with OxiTop measuring head, place the bottle on the stirrer, start the measurement with controller.

- Determination of chemical oxygen demand, COD with Spectroquant Pharo 300.

Effluent wastewater from food processing company which is specialized on production of salads, brines, etc. is poured to graduated flask for sample dilution with distilled water. After estimation of the necessary dilution based on chosen COD-range samples are filled into reaction cell in volume of 2 ml. Bottom sediment in the reaction cell should be swirled before. Tightly attach screw cap to the cell. The cell must be held only by screw cap and vigorously mixed. The cell should be heated at 148 ^{o}C for 120 min and cooled down during 40 minutes after heating. The cell is placed into photometer and COD is measured.

- Biogas potential test.
The experiment is performed in series of 100 ml medical syringes which are used as small anaerobic digesters. Sludge from wood processing wastewater is used as inoculum. Each syringe is connected to a needle blocked by a small rubber stopper to prevent gas and liquid leakage. No chemicals are added.

Possible accidents

Determination of biological oxygen demand, chemical oxygen demand, biogas potential test are the experiments with low risk of accident happening.

1. Spilled raw wastewater, with low risk to be infected by different pathogens since both inoculum and samples come from industrial wastewater with no known risk of pathogens.
2. Spilled chemicals, BOD5 (nitrification inhibitor). Toxic if swallowed. Irritating to eyes, respiratory system and skin.
3. Spilled chemicals, COD (solution in reaction cells). Very toxic if swallowed. Irritating to eyes, respiratory system and skin, can cause cancer.

The consequences may be high with low probability to occur according to risk matrix.

Measures

- Gloves, glasses and laboratory coat should be used. According to laboratory procedure.
- Proper usage of the chemicals should be applied.