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STUDIES OF GREASE SLUDGE AND LABORATORY
ANALYSES OF WATER SEPARATED FROM GREASE SLUDGE

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The main purpose of this thesis was to make analysis for water separated from grease sludge. Lassila Tikanoja Oyj (L&T) is collecting grease sludge, also called fat oil and grease (FOG), from interceptors of restaurants and hospitals and transporting it to further treatment to biogas facility. Distances are long and transportation costs are very high because of small loads. L&T is aiming to decrease the expenses, hence they built a separation tank as a temporary storage. In the separation tank water and grease sludge are being separated. After the separation grease sludge is transported to Biogas facility and the separated water to waste water treatment plant (WWTP). WWTP has limits for the waste water they receive with certain boundary values determined in industrial waste water guide. The main task of this thesis was to analyse the separated water and clarify the suitability of separated water for WWTP. Following analysis for separated water were made; pH, BOD_{7au}, COD_{mn}, total nitrogen, total phosphorus, suspended solids and grease content.

Interception of fat oil and grease was examined in general level. Also recyclability and future potential was discussed.

In this work it was found that separation was successful when it comes to grease. Grease value of separated grease sludge matched with the boundary value of WWTP. In other analyses it was determined that separated grease sludge has low pH, high values of COD, total nitrogen and total phosphorus. Especially concentration of organic matter consuming oxygen from the water was very high compared to boundary values of WWTP. Value of suspended solids was also very high when sediment was included.

RASVALIETTEEN TUTKIMUS SEKÄ RASVALIETTEESTÄ EROTETUN VEDEN LABORATORIO ANALYYSIT

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Tämän opinnäytetyön tarkoituksena oli analysoida rasvalietteestä erotettua vettä. Lasila & Tikanoja Oyj kuljettaa rasvalietettä mm ravintoloiden, sekä sairaaloiden rasvanerottimista jatkokäsittelyyn biokaasunpolttolaitokselle. Kuljetusmatkat ovat pitkiä ja kuormamäärät pieniä, mikä aiheuttaa suuret kuljetuskustannukset. L&T haluaa vähentää kuljetuskustannuksia rakentamalla rasvanerotussäiliön Nakkilan toimipisteeseen väliaikaisvarastoksi. Erotussäiliössä rasva nousee pinnalle ja vesi jää pohjalle. Pinnalle kertynyt rasva kuljetetaan biokaasulaitokselle ja erottunut vesi jätevedenpuhdistamolle. Jäteveden puhdistamoilla on tiettyjä raja-arvoja laitokselle tulevalle jätevedelle, jotka on määritelty teollisuusjätevesioppaassa. Opinnäytetyön päätehtävä on selvittää erotetun veden kelpaavuus Porin Veden Luotsinmäen jätevedenpuhdistamolle. Erotetulle vedelle tehtiin seuraavat analyysit: pH, BOD_{7atu}, COD_{mn}, kokonaisytyppi, kokonaisfosfori, kiintoaine ja rasvapitoisuus.

Opinnäytetyössä käsiteltiin myös rasvalietteen erotusta yleisesti. Lisäksi opinnäytetyössä käsiteltiin rasvalietteen kierrätyskelpoisuutta, sekä tulevaisuuden mahdollisuuksia.

Työssä saatiin selville että rasvanerotus oli varsin onnistunut juuri rasvapitoisuuden osalta. Rasvalietteestä erotetun veden rasvapitoisuus osui jätevesilaitoksen raja-arvoihin. Muissa analyyseissä selvisi, että kyseisellä lietteellä on matala pH, korkeat COD-, typpi-, fosfori-, sekä kiintoainearvot. Erityisesti kemiallinen hapenkulutus oli korkea verrattuna jätevesilaitoksen raja-arvoihin. Myös kiintoainepitoisuus oli korkea kun pohjasakka oli huomioitu mukaan analyysiin.

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Terms and definitions

BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
CHP	Combined heat and power production
FOG	Fat oil and grease
Grease interceptor	Piece of equipment used to separate grease from waste water
L&T	Lassila & Tikanoja Oyj (the customer of the thesis)
N_{tot}	Total nitrogen concentration
P_{tot}	Total phosphorus concentration
Sediment	Solid matter found in the bottom of a liquid
SS	Suspended solids
Titration	Reaction based on analysed sample and titrant, observed with indicator or measuring device
WWTP	waste water treatment plant

1 INTRODUCTION

"The worst part is located in Kluuvinkatu where 50 m³ of grease is collected monthly" states Sami Sillstén from Helsinki Region Environmental Services Authority, HSY. "It corresponds 40 tonnes in kilos." he clarifies the amount. These paragraphs are part of the tidings published in Helsingin Sanomat newspaper in 8th of August 2013. The tidings dealt with the growing grease sludge problem in Helsinki sanitary sewer system. Fat oil and grease (FOG) passes the sewer from restaurants which should have proper grease interceptors to prevent the grease flows to enter the sewer. "The emptying is not our business but someone has to do it" states Sillstén. If emptying was stopped, there would be a blockage in sewer and the waste water would find its way on the street and interiors. Every emptying costs 2 000 euros. HSY has a deal with hotel Kämppe that emptying will not be done when important guest are present. Sillstén continues; "I've been there once during the emptying, the smell was awful." Sillstén states that grease problem is getting worse all the time, hence HSY has founded a grease team dealing with this problem (Lontoon ihravuori kalpenee....2011).

A Couple of days before there was a tidings in the Guardian with a topic; "Fatbearg a head". A Team of sewerage workers were working for three weeks to clear a fatbearg size of a bus that was about to enter the streets with sewage. "Kingston came very close to being flooded with sewage. We have recorded greater volumes of fat in the past but we don't believe there's ever been a single congealed lump of lard matching this one", stated Simon Evans, the spokesman of Thames Water. (Fatbearg ahead... 2013)

These tidings describe well the problem of FOG in sanitary systems. In this thesis FOG problem was discussed in general and also the separation of grease from the FOG loaded sludge was examined. The main task of this thesis was to make laboratory analyses for water separated from FOG. Analyses include pH, COD, BOD, total grease content, total phosphorus, orthophosphate, total nitrogen and suspended solids.

2 LASSILA & TIKANOJA OYJ

The customer of this final thesis was company Lassila & Tikanoja Oyj. L&T is a service company dealing i.e. with waste management, recycling, process cleaning and sewer maintenance. The company has a history for over 100 years and it operates in Finland, Sweden, Latvia and Russia. (Lassila & Tikanoja, 2013).

L&T has a very diverse history and it has operated in many different fields. L&T was founded in 1905 as a wholesale business company by Josef Lassila and Frithjof Tikanoja. During the first years L&T became the biggest wholesale company in the Nordic countries. In 1923 L&T started to operate in cloth industry by side of the wholesale business and it was a major manufacturer of clothes in Finland until 1980's. In 1960 L&T expanded its activity to European countries. L&T was listed first time in the stock market of Helsinki in 1961. (Lassila & Tikanoja, 2013)

In 80's L&T expanded the business more. L&T acquired company called J.W Suominen Oy, which was manufacturing fabrics. Another company was called Amerplast Oy, which manufactured flexible packaging. In 1989 the company turned more into environmental business when it bought a big share of a company called Säkkiväline Oy. Säkkiväline manufactured waste bags but later on made firm acquisitions and expanded its business to waste management and cleaning. Also damage repair and property maintenance became part of the business (Lassila & Tikanoja, 2013)

In 90's L&T was conglomerate Company dealing with fabrics, flexible packaging, service industry, and shoe and cloth industry. Environmental business became the biggest part of company's market share along Säkkiväline. Recycling and waste utilization started to play an important role. Also cleaning services were developed and hazardous waste reception became part of the business. (Lassila & Tikanoja, 2013)

Säkkiväline was the biggest company working in the environmental business after buying WM ympäristöpalvelut Oy in 2000 and it was growing its market share continuously. Säkkiväline merged with L&T and achieved its current form in the early

2000's. Today L&T works in the fields of environmental management, support services of properties and facilities. L&T is also investing a lot in supplying wood-based biofuels, recycled raw materials and recovered fuels. (Lassila & Tikanoja, 2013)

3 FAT OIL AND GREASE

Fat oil and grease, commonly known as FOG, is a byproduct from cooking, and cleaning activities. The source of FOG is meat, sauces, shortening, butter, solid food waste, and dairy product etc. used in cooking. Residues of these products are flushed to the drainage through sink and floor drains. Restaurants are the major source of FOG but in a minor scale it ends up to the sewage system also from private houses (Website of New Castle County 2013.) The average concentration of FOG in domestic wastewater is 30-50 mg/l (Website of WE&T 2011). FOG has very strong unpleasant odor because of its decomposing fatty acids reacting with spoiled fats and oils (Coker, 2006, 27).

Fats	=	Solid
Oils	=	Liquid
Grease	=	Viscous, but not capable of flow

FOG ends up to the drainage mostly in liquid form; however, temperature drop causes it to congeal and harden very easily. This makes FOG very unwanted substance in the drainage because it accumulates inside of the walls of the pipes. Accumulation causes pressure drop in pipelines which affects reduced fluid flow and further on can lead to sanitary sewer overflows SSOs (Website of New Castle County 2013.) It is very much the same kind of effect that cholesterol narrowing blood veins (Coker 2006, 27). FOG is the cause for 40-50 percent of all sanitary overflows (Ducoste, J., Kreener, K., Groninger, J., Holt, L. 2008. Chp 1.1). These overflows have many risks; they can damage property and health. In worst cases there is also a risk for pollution of drinking water lines and waterways if FOG releases occur (Website of New Castle County 2013.)

Different FOG's are classified according to the level of degradation by biofuel industry:

- virgin / neat /refined which contains less than 1.5 % Free fatty acids (FFA)
- High quality yellow grease which contains less than 5 % FFA
- Low quality yellow grease, 5 -10 % FFA
- Brown grease 20-100 % FFA

(Partanen, 2008. 8)

Most of the different FOG types can be recycled for different purposes. Yellow grease is FOG collected straight from dry filter hoods, fryers and grills. It has not been in contact with water. Yellow grease can be reused as biodiesel and for human contact. Yellow grease is used as a raw material for as soaps and other cosmetics which might be reason a definition "high quality". Before it was used also as additional nourishment for animals but nowadays it is not recommended. Brown grease in turn is the kind of FOG that can be found in interceptors. Brown grease has been in contact with drain water thus recycling is restricted to the non-human contact area such as methane production. Brown grease is too contaminated for biodiesel production (Weiss 2007. 34-39.)

In table 1 it can be seen different volumes of the FOG flows from various facilities. In the table it can be seen that restaurants produce a lot more waste water per meal compared with canteens. This can be explained by different ratio of prepared food. Restaurants prepare smaller amounts of food less efficiently which increases the amount of water used in cooking.

Table 3-1 Volume flow per meal and peak flow. (Suomen rakentamismääräyskokoelma, D1, 2007, 55)

Kitchen	Volume of the Wastewater V, dm³ / meal	Peak flow factor F
Hotel	100	5,0
Restaurant	50	8,5
Hospital	20	13,0
Catering	10	22,0
Canteen(office, factory)	5	20,0

Table 3-2 Volume of the waste water per kg of meat product, peak flow f and the amount of meat product per day in different facilities. (Suomen rakentamismääräyskokoelma, D1, 2007, 55)

LU = Livestock Unit = 1 bovine or 2,5 pigs

Size of slaughter house or meat processing facility	Volume of the waste water	Peak Flow	Complete meat products , kg/ d
Small, not more than 5 LU/wk.	20	30	If unknow, assumed 100 kg / d / LU
medium size, 6-10 LU/wk.	15	35	
Big 11-40 LU/wk.	10	40	

In Finland wastewater flows are cool, so grease will solidify easily. Mostly the grease will accumulate to the places where flow is at its lowest, as it is in pumping stations. The formation of floating grease occurs and it needs to be removed periodically. Finnish Water Utilities Association (FIWA) sent an inquiry for 50 waste water treatment plants (WWTP) in September of 2013 (Toivikko 2014, 38). 68 % of the respondents announced that grease is causing problems, as blockages or the need for periodical removal in certain areas. In turn 32 % of respondents answered that none of these problems occur. 82 % of the respondents reported that grease is accumulated to pumping stations so that it needs purification. 51 % of respondents reported that there are blockages in sewer system caused by grease. 24 % reported of odor nuisances and 24 % reported of disadvantages for wastewater purification (Toivikko 2014, 38).

45 % of the respondents reported that problems occurred in the centers of the cities, 35 % in residential areas and 29 % reported the problems occurring the most in industrial areas. 24 % of the respondents answered that problems occurred in other areas in the proximity of restaurants (Toivikko 2014, 38). The cause of grease to enter the sewer sanitary system was inquired too. Insufficient grease interceptor was reported to be the cause by 39 % of respondents, 27% lack of interceptor, 22 % the emission of a food company, 14 % private households (Toivikko 2014, 38).

3.1 Characteristics of Fat Oil and Grease

Grease interceptor waste consist mainly fats and oils (called as well lipids), but there are also grease, water, food particles and contaminants. Total solid content is usually around 5-6 percent. Fats and oil consist of chemical compounds called triglycerides. 1/3 from triglycerides is glycerol and 2/3 are fatty acids. The most common fatty acids found in grease interceptors are: lauric (C₁₈H₃₆O₂), myristic (C₁₄H₂₈O₂), palmitic (C₁₆H₃₂O₂), stearic (C₁₈H₃₆O₂), oleic (C₁₈H₃₄O₂), linoleic (C₁₈H₃₂O₂) (Coger 2006, 27).

Grease is “substances of vegetable and /or animal origin, of a density less than 0,95 g/cm³, which are partially or totally insoluble in water” (SFS-EN 1825-1, 15). FOG is a general term for a myriad of organic compounds that exhibit hydrophobic properties. Hydrophobic means basically water resistant. FOG liquefies when heated and gasifies into methane when digested anaerobically (Forbes, B. Jonson, T., Shea Tim. No date. 2).

Usually 80 to 90 % of the FOG is water. Water content varies a lot depending on how often the interceptor is emptied and the grease has had time to dry out.

Table 3-3 Typical characteristics of FOG (Forbes, B. Jonson, T., Shea Tim. No date)

Component	Restaurant Interceptor FOG Waste	Biodiesel glycerin	Polymer Dewatered FOG	Lime Dewatered FOG
Total Solids, %TS	1.8-21.9	14.7	42.4	49.1
Volatile Solids/Total Solids, %	88.9-98.6	95.2	96.5	76.5
Chemical oxygen demand, g/L		1,160	1,211	1,030
Total nitrogen, g/L			5.4	
Total phosphorus, g/L		0.128	0.67	
pH	4.3-4.8	8.4	4.0	6.5
Volatile solids destruction potential ¹ , %			70.8	78.3
Methane content of generated gas, %			75.0	74.6
Methane (CH ₄) potential yield ² , m ³ /kg (scf/lb) feedstock volatile solids			1.048 (16.8)	0.927 (14.8)
Biogas potential yield ² , m ³ /kg (scf/lb) feedstock volatile solids			1.398 (22.4)	1.242 (19.9)
¹ Maximum potential volatile solids destruction and yield based on long-term (120 days batch)				
² At 60°F and 1 atm				
³ From Bailey (2007); Parry et al. (2009); Kabouris et al. (2007)				

3.2 Preventing the FOG from entering sanitary system

There are ways to prevent sanitary overflows caused by FOG. The first step is to try to avoid discharges entering the sinks and floor drains at all. Although it is impossible avoid all the discharge of FOG, education of people can help to reduce the problems. People need to be informed of the negative effects when dumping grease down the drain. Public education, advertisements and signs above the sinks is one way to prevent grease discharges into sewer systems.

Second step is to collect the FOG once it has entered the sanitary system. For larger contributors, FOG can be removed periodically by grease interceptors. There are regulations considering the need of a company to install an interceptor and what kind of an interceptor which vary nationally. These things will be discussed more in chapter 4.

The third step is to ensure that the disposal of FOG is done properly. Big part of FOG ends up to landfills although it has a high potential in energy and methane production. These issues will be discussed more in chapter 8.1.

4 GREASE INTERCEPTOR

A Grease interceptor is “a unit or assembly of units to separate grease from wastewater and retain the separated grease within the unit, normally comprising a sludge trap, a grease separation chamber and, if necessary, a sampling point” (SFS-EN 1825-1, 15.)

Grease interceptors, also called grease separators or grease traps, are devices constructed as a purpose to prevent FOG entering the city’s sanitary sewer system. Grease interceptors receive waste water from pot sinks, dishwashers and floor drains.

The first patented passive grease interceptor was introduced in the late 1800’s and it has remained almost unchanged until these days. Function of a grease interceptor is based on gravity and coalescence. A typical grease interceptor can be seen in figure 4.1. Waste water laden with fog is discharged from flow inlet into the device. Fats oils and greases are about 10 % lighter than water so they rise up to the upper level of the grease interceptor. Separated water is in the lower part of interceptor and further on continues flowing towards the outlet (Whitehead W 2008, 1).

European standard SFS-EN 1825 is a standard dealing with grease interceptors which considers interceptors based on gravimetric separation without any external energy. It consist two sections;

- basics of designing, implementation, testing, marking and quality control
 - decision of nominal size, installation, operation and maintenance
- (SFS-EN 1825-1, 25)

Grease interceptors constructed according to this standard can be made of following materials:

- Unreinforced or reinforced concrete, fiber reinforced concrete
 - Metal materials: cast iron, stainless steel, steel
 - Plastic materials: fiberglass reinforced plastics, polyethene
 - vitrified clay
- (SFS-EN 1825-1, 17)

All the parts of a grease interceptor such as joints, seals, connections and partitions need to be watertight. The Grease interceptor needs to be ventilated and extension shafts need to be tested. The storage capacity of the grease collection area needs to be at least 40 x NS in liters. (SFS-EN 1825-1, 27). Nominal size or dimension is “an approximate or rough-cut dimension by which a material is generally called or sold in trade, but which differs from the actual dimension” (website of Business dictionary). 2014). All of the components of grease interceptor need to be accessible for inspection and emptying. If nominal size of the grease interceptor is more than 4 there must be at least one access point into the grease interceptor. In order to avoid waste water from flowing upstream the total fall through interceptor, the grease separation chamber and the sludge trap need to be accurate. Also the level between the bottom of the outlet and the bottom of the inlet is important factor for the proper function of the interceptor. (SFS-EN 1825-1, 25).

The size of the interceptor is determined by the rated flow, which is calculated based on quality and volume of waste water. The rated flow consists of parameters; design discharge, maximum temperature, density of grease and detergent/softener content. (Suomen rakentamismääräyskokoelma D1) The standard nominal sizes of grease interceptors are 1, 2, 4, 7, 10, 15, 20 ja 25. Other nominal sizes are also allowed to be used. (SFS-EN 1825-1, 16)

4.1 Function of an grease interceptor

The function of gravity based grease interceptor is rather simple. FOG loaded wastewater enters interceptor from the inlet. Grease has a smaller density than water so grease will ascent to the surface and food solids and debris will sink to the bottom. Inlet is above the surface of the water. Outlet is on the opposite of the interceptor and

near the bottom. This way FOG will stay in separation chamber and purified water continues to the sewage system as can be seen from figure 4.1.

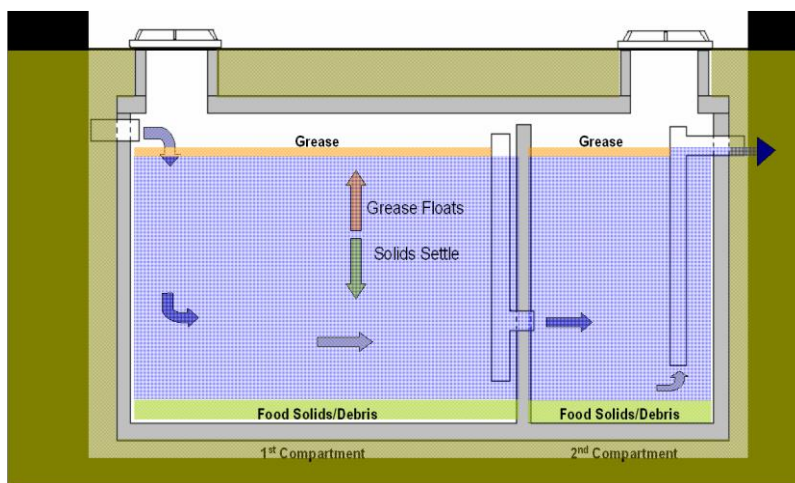


Figure 4-1 Function of grease interceptor Standard Configuration of Grease Interceptor. (Ducoste, Kreener, Groninger, Holt, 2008, 1-1)

4.2 Regulations considering interceptors

There are restrictions in Finnish legislation considering conveying FOG to sewer sanitary system. In the regulation of environmental protection of Finland (36 §) it is stated that waste water from industry and other waste water containing harmful substances need proper pretreatment in order to avoid damage of the environment, disadvantages for purification process, or damages for sewer sanitary system or purification equipment. WWTP can refuse receiving wastewater if requirements above are not met.

In building code of Finland it is stated that wastewater system needs to be equipped with proper interceptor and treatment systems if waste water is containing grease with a harmful volume. Restaurants producing more than 50 meals per day are required to install grease interceptor (Teollisuusjätevesiopas, 2013, 68). Also slaughterhouses and meat processing facilities etc. need to have interceptors. It is not allowed to convey any other kind of wastewater into the interceptor. This considers only new properties. (Suomen rakentamismääräyskokoelma, D1 2007).

In general waste management regulation is stated that oil, sand and grease interceptors need to be emptied at least once a year. Documentation of emptying needs to be implemented and shown for supervisory authority if necessary. (General waste management regulation of Pori.2010. 60/18)

5 ELIGIBILITY OF THE WASTEWATER TO WWTP

The quality of waste water conveyed to sanitary sewer system is important to measure for several reasons. It has an effect on employee safety, condition of sewage drainage and refinery equipment. Quality of wastewater effects also the refining process itself and the condition of waterways that receive the treated waste water.

It is not allowed to transport to refinery waste water or waste material that can cause damage or danger. Materials and substances such as objects, textiles, plastic, metals, sand, glass plastic, rubber, and grease are prohibited. In general, every kind of community- and industrial waste that can cause blockages or complicate the treatment process or cause danger to employees are not allowed to be transported. The Entrance of material which can react with sewage water needs to be rejected. Reactions can cause significant temperature rise of sewage water, they can corrode pipelines, cause blockages or form poisonous compounds or gases. The pH-value of wastewater needs to be more than 6 but less than 11. Temperature of waste water cannot exceed over 40 °C if transported as high amounts. High temperature in drainage causes increase of processes with high oxygen consumption, corrosion and odor nuisance. High temperature also harms the function of grease interceptor system of refinery. Cold temperatures instead slow down microbe activity and decrease the efficiency of refinery's processes. Especially bacteria used to refine nitrogen are very sensitive to low temperatures. Concrete and plastic pipelines are not designed to stand high temperature differences. (Teollisuusjätevesiöpas. 2003)

6 SEPARATION TANK OF L&T

Grease is separated in a horizontal tank with the volume of 20 m³. It is an old oil tank which is renovated particularly for grease separation purposes. The system is very simple and it is based on gravity separation. Tank is outdoors isolated with urethane which is made water resistant with paint. It has an additional heating system to keep up the proper temperature for separation.



Figure 6-1 Separation tank of Lassila & Tikanoja Oyj

Hauling truck discharges FOG contaminated wastewater into the tank with a high pressure through inlet tub. The inlet tub is welded into the hatch of the tank. Sludge settles so that the FOG rise on the top and the clear water rest on the bottom. Separated water will be vacuumed from the bottom of the tank with a hauling truck through a transparent outlet tube. Outlet tube reaches 10 cm above the bottom of the tank in order to let the water flow freely. The color of the water can be observed from transparent outlet tube so that the loading can be stopped before FOG sludge enters the hauling truck. Separated water will be transported to WWTP Porin Vesi and this is the water that should have values under all the requirements i.e. with grease content 150-200 mg/l. The separation is assumed to be effective enough with gravitational separation. There

are two main variable factors which can be adjusted to improve the efficiency of the separation: emptying periods, and the temperature of the tank.

The FOG will be loaded into the hauling truck through the hatch of the tank. FOG needs to be removed so often that it still flows and there is no need for additional water. The assumed time period needed for FOG removal is 2 months. "All interceptors containing excessive amounts of FOG and aged FOG will demonstrate dramatic reduction in separation and retention efficiency" (Weiss, 2007, 37). Thus, the efficiency of the separation in the tank is dependent of the maintenance and performance of interceptors from which the FOG is collected.

A typical myth is that the grease is separated the best in cool and non-turbulent condition but that is not the truth. American petroleum institute has discovered about 50 years ago that "a less dense, viscous substance rises faster in warm water than cool water and that turbulence can cause either a reduction in separation time or an increase in separation time depending on the presence, absence, and orientation of deflection." There will be periodical turbulence in the tank because of loading but the settling time will be days or weeks so it will have no major positive or negative effect on separation. (Weiss, 2007, 35)

L&T collects FOG to the tank periodically from the same customers and locations so the sludge will be quite uniform. There are still always some variables which affect the efficiency of the separation such as: presence of detergents, globule size, FOG viscosity, age and amount of FOG (Weiss, 2007)

For non-emulsified FOG between globule size 30-100 μm it takes time 15 to 25 minutes to rise 7,6 cm in 26 °C based on application of Stokes' law. (Weiss, 2007). The diameter of the separation tank is 2 m so it takes time approximately one hour to grease reach the surface.

7 ANALYSES OF SEPARATED WATER

7.1 Sampling of separated water

One cubic meter of separated water was removed from the separation tank with a low pressure into cleaned tank of a hauling truck. Further on separated water was poured into two 10 liters canister through the sea valve of the hauling truck. These canisters can be assumed to contain a lot of solid matter compared to average concentration because this one cubic meter was removed from the bottom of the separation tank. Outlet is placed 10 cm above the bottom of separation tank and upper layers of separated water contain much less solid matter in words; sedimentation. Thus most of the analyses are made with two types of sample; well mixed and unmixed canister.

Following analyses were made of separated water: pH, BOD_{7atu}, COD_{mn}, total nitrogen, total phosphorus, orthophosphate, total solids and grease content. The limit values were found in industrial waste water guide (Teollisuusjätevesiopus 2003) which is commonly used in WWTPs.

7.2 The pH-value analysis

The pH-value is the measure of acidity, in other words measure of hydrogen concentration. Pure water has almost the same amount of H⁺ and hydroxyl OH⁻ ions. (Weiner & Mathews 2003, 93). In refinery point of view, pH has essential role in biological processes. Rapid changes in pH cause disorder in the activity of micro-organisms. Biological process work best when pH is 7-8. (Teollisuusjätevesiopus 2003)

The pH value was determined with calibrated 827 pH Lab Metronome indicator. In table 6-1 can be seen the results of mixed and unmixed sample.

Table 7-1 Results of pH

Sample	pH	Limit
1. Unmixed	3,84	6-7
2. Mixed	3,84	

Separated water had a low pH-value. The most probable reason for that might be fatty acids which lowers the pH. This can be assumed to be the case for FOG sludge in general. The pH might be even lower when there is more FOG present.

7.3 Analysis of biochemical oxygen demand

The biochemical oxygen demand analysis (BOD) was done according to standard SFS-EN 1899-1. BOD was implemented to discover the amount of oxygen required by bacteria and other microorganisms in waste water. High BOD level indicates decrease of dissolved oxygen and high amount of micro-organisms oxidizing organic matter. Low BOD indicates clean water or water polluted with toxic or no degradable pollutant. (Weiner & Mathews 2003, 85). In drainage high BOD concentration can promote methane production and further on cause danger of explosion. High BOD concentration can also cause odor nuisances and corrosion. The load of organic waste need to be restricted by following the efficiency of refinery's oxidizing equipment (Teollisuusjätevesiöpas. 2003. 32).

Waste water sample was pretreated and diluted with various volumes of enriched dilution. Dilution was enriched with dissolved oxygen, nutrients and wastewater including a lot of micro-organisms. (SFS-EN 1899-1) The pretreated sample was stored in the dark in full and well-sealed glass bottle in temperature of 20 °C for 7 days. Dissolved oxygen was measured both before and after the storage. All the dilutions and samples had reference bottles.

Table 7-2 Oxygen concentrations before and after the storage

Sample number	O ₂ conc. before [mg/l]	O ₂ conc. after 7 days. [mg/l]	O ₂ conc. after 7 days. (reference bottle) [mg/l]	Average O ₂ Conc. after 7 days [mg/l]
1. Zero sample	8.99	3.80	4.41	4.105
2. Replicate solution	8.88	1.78	1.69	1.735
3. Dilution 1:99	8.73	0.14	0.11	0.135
4. Dilution 1:999	8.96	0.18	0.13	0.155

Biological oxygen demand of the samples were calculated from the equation:

$$BOD_7 = [(c_1 - c_2) - \frac{V_t - V_e}{V_t} \times c_3 - c_4] \times \frac{V_t}{V_e}$$

Where;

c_1 = the concentration of dissolved oxygen of the sample in the beginning, mg/l

c_2 = the concentration of dissolved oxygen of the sample after 7 days, mg/l

c_3 = the concentration of dissolved oxygen of the zero sample in the beginning, mg/l

c_4 = the concentration of dissolved oxygen of the zero sample after 7 days, mg/l

v_e = Volume of the sample taken for dilution, l

V_t = Total Volume of the solution, l

Example of the calculations: $BOD_{7\text{atu}}$ of sample number 3

$$= \left[(8.73 - 0.14) \text{ mg/l} - \frac{1000 \text{ ml} - 100 \text{ ml}}{1000 \text{ ml}} \times (8.99 - 4.105) \text{ mg/l} \right] \times \frac{1000}{100}$$

$$= 41.935 \text{ mg/l}$$

Sample 3 was diluted with ratio 1:99, so the result needs to be multiplied by 100.

$$BOD_{7\text{atu}}(3) = 41.935 \text{ mg/l} \times 100 = \mathbf{4193.5 \text{ mg/l}}$$

Table 7-3 results of BOD_{7atu}

Sample	BOD _{7atu} [mg/l]
2. Replicate solution	117.89
3. Dilution 1:99	4193.5
4. Dilution 1:999	43 835

All the oxygen concentrations were very low after the storage, even zero sample had very low oxygen concentrations after the storage. According to standard zero sample should not consume more than 1,5 mg/l oxygen in order the analyze to be reliable. BOD_{7atu} analyze was done twice in order to achieve reliable results but the situation was the same with the other analyze too. Oxygen concentrations were very low after the storage in every bottle. Thus, BOD_{7atu} measurement was not successful. Reason for that might be contaminants in nutrients which consumed all of the oxygen of the samples. In both analyses same nutrients in enriched dilution water were used. In any case BOD values can be assumed to be rather high because of high COD results.

7.4 Analysis of chemical oxygen demand

Chemical oxygen demand (COD) analyze was done by following standard SFS 3036. COD_{mn} stands for chemical oxygen demand which is determined by oxidizing the sample with permanganate. This method is used usually for clean water. Permanganate is a weaker oxidizer than dichromate which is another method used for analyzing of COD. For this reason COD_{cr} values are commonly higher than COD_{mn} values. COD_{cr} method is used usually when it comes to contaminated water but in this case COD_{mn} was the method used because of the familiarity of the method. High dilution factors were used in order to achieve reliable results. (SFS 3020 2013, 1)

BOD analyze takes a lot of time because organic matter oxidized biologically. Chemical oxygen demand (COD) analyze can be done faster because of the chemicals used. COD has always higher results than BOD because chemical compounds can oxidize almost all organic organisms, whereas BOD can oxidize only part of them. Cellulose

is an example of substance oxidized very fast with COD measurement but takes a lot of time to decompose biologically (Weiner & Mathews 2003, 91).

A known volume of potassium permanganate was added into the samples which gave the samples a violet color. The sample was also made acid with sulfuric acid. The sample was kept 20 minutes in boiling water. The oxidizing part of the sample oxidized permanganate and the consumption of permanganate is determined by titration with thiosulfate. Consumption of titrant is used in calculation of COD value. (SFS 3036, 2013, 2)

Three different dilution factors were used; 1:9, 1:99 and 1:999. Also zero sample was measured. All of the samples had replicates so all together there were 8 test tubes.



Figure 7-1 Test tubes before boiling

Table 7-4 thiosulfate consumption of the samples

Sample number	dilution factor	NaS ₂ O ₃ Consump. [ml]
1.	1:9	no result
2.	1:9	no result
3.	1:99	no result
4.	1:99	no result
5.	1:999	1.28
6.	1:999	1.41
7.	Zero sample	1.86
8.	Zero sample	1.95

Permanganate was consumed immediately in sample number 1 and during the boiling the samples. There was no permanganate left for titration in sample number 1 and 2. Thus, it was not possible to get any results for those dilutions. Sample number 5 and 6 gave thiosulfate consumptions 1,28 and 1,41 ml. It was possible to calculate COD-value from these samples by using equation:

$$COD_{mn} = (V_0 - V_1)c \cdot 800 \cdot f$$

Where;

- V_0 = Consumption of thiosulphate of the blank test, mg/l
- V_1 = Consumption of thiosulphate of the wastewater sample
(average of sample 5 and 6)
- c = Concentration of thiosulphate in mol/l
- f = Dilution factor

$$COD_{mn} = 1,905 - 1.345 \times 0,01 \frac{mol}{l} \times 800 \times 100 = 4480 \frac{mg}{l}$$

Table 7-5 Results of COD_{mn}

Sample (dilution factor)	COD _{mn}	Limit
1.Mixed (1/999)	4480 mg/l	483-805 mg/l

The result is very high compared to boundary values used in WWTP with COD_{cr} value of 438-805 mg/l for incoming waste water. Although it is possible to have this high values in case of COD. For instance in Fish Port of Reposaari, Pori Finland, have been measured COD values as high as 25000 mg/l. (Mäkiranta 2011,34)

7.5 Analysis of total phosphorus

Though phosphorus and nitrogen are crucial nutrients in nature, they can cause eutrophication or fast biological aging of streams, lakes and estuaries. Phosphorus and nitrogen end up to waters mainly from agricultural, residential activities and municipal wastewater discharges (Weiner & Mathews 2003, 91). In refinery, nitrogen and phosphorus are needed for production of activated wastewater sludge so they are not harmful in that sense. The problem is that there are so many nutrients available in municipal waste water so they give too much load for refinery's oxidation system. Phosphorus is removed usually chemically which increases expenses of chemicals and may lead to increased discharge costs. Nitrogen is removed biologically but this requires a lot of space for treatment pools. (Teollisuusjätevesiöpas 2003. 32).

Total Phosphorus concentration was determined according to standard SFS 3026. Phosphorus was determined from an unfiltered sample. Method is based on peroxide sulfate decomposition where organic phosphate compounds and organically bounded phosphorus are changed into orthophosphate under high pressure and acid circumstances. Calibration curve with different concentrations of phosphates was prepared. Calibration solutions was analyzed by using Fennolab UV-visible spectrophotometer. Figures 7-2 and 7-3 reveal that calibration curve was very successful. Only the last and strongest calibration solution was ignored from the curve because it was not following the curve at all. It had too minor color change

compared to the concentration of phosphorus. Probably something went wrong when preparing the solution.



Figure 7-2 Calibration solutions before analysing with spectrophotometer

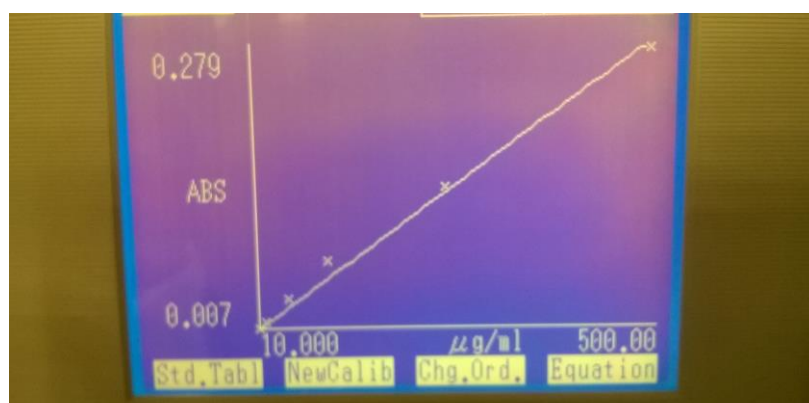


Figure 7-3 Calibration curve after analyzing the calibration solutions

Table 7-6 Results of total phosphorus

Sample (dilution factor)	P_{tot}	Limit
1. mixed (1/9)	29,798 mg/l	8,1-13 mg/l
2. unmixed (1/9)	28,14 mg/l	
3. mixed (1/99)	51,535 mg/l	
4. unmixed (1/ 99)	48,194 mg/l	

From table 7-6 can be seen the results of total phosphorus concentrations. From samples dilutions 1:9 and 1:99 were made and results were compared to absorbance values of calibration curve. Spectrometer gave absorbance numbers 0,007-0,279 for calibration curve. Sample number 4 hit very well the absorbance values with value 0,276 which corresponded 481,94 $\mu\text{g/l}$ which is 0,48194 mg/l. Further on the result was multiplied with dilution factor of 100 which gave 48,194 mg/l. Also sample 3 was very close the calibration curve. Results of sample number 3 and 4 are reliable estimations of the amount of total phosphorus in the waste water. It can be seen from the table 7-6 that phosphorus concentrations run over the common limits used in WWTPs.

7.6 Analysis of orthophosphate

Orthophosphate concentration was determined by following the standard EN ISO 6878. The principle of the method is basically the same as SFS 3036. It just doesn't include heating under pressure. Orthophosphate concentrations are usually less than total phosphorus concentrations because phosphorus is not transformed to phosphates.

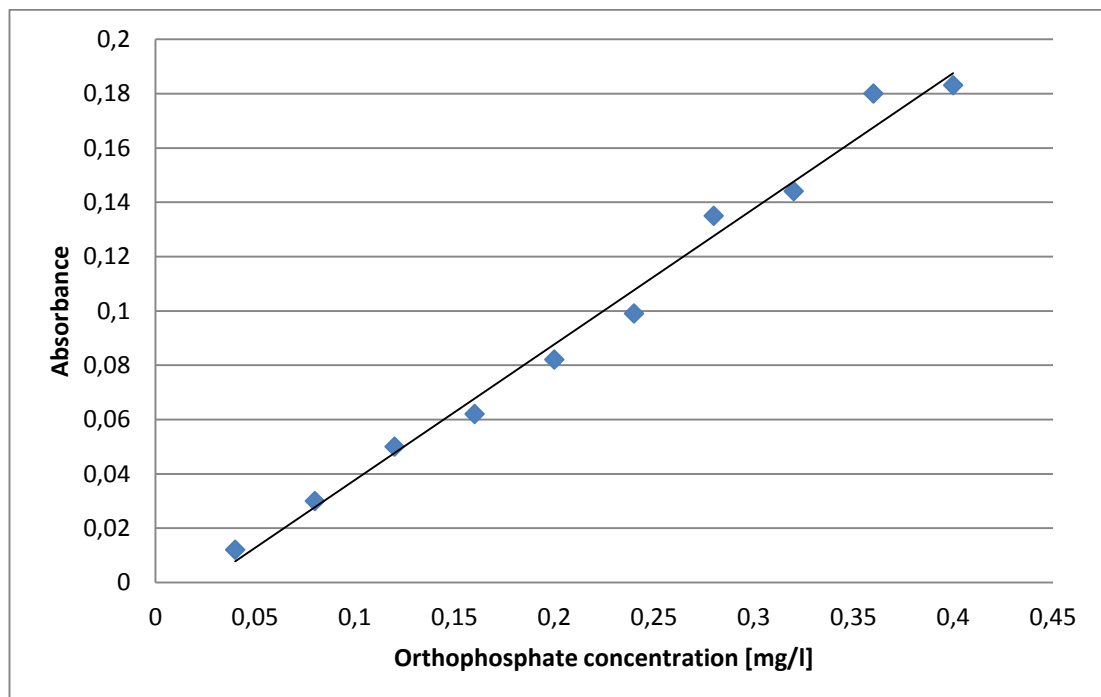


Figure 7-2 calibration curve prepared for orthophosphate concentration

Table 7-7 Results of orthophosphate

Sample number	dilution factor	ABS	Conc	conc x f
1. unmixed	1/9	0.036	0.0798	0.798 mg / l
2. unmixed	1/99	0.003	0.0072	0.720 mg / l
3. mixed	1/9	0.292	0.6408	2.920 mg / l
4. mixed	1/99	0.014	0.0310	3.100 mg / l
5. unmixed	not diluted	0.105	0.2313	0.231 mg / l

The color change of the samples and calibration curve was not as clear as it was in total phosphorus concentration analyze. Solutions changed the color into blue very little and it also can be seen from the results of orthophosphate. As it was said earlier orthophosphate concentrates should be less than phosphorus concentration but the difference seems to be very radical. Phosphorus occurs the most in the form of phosphates in the nature so the difference should be less. Some of the samples were turbid which might have and distort the results. Thus, total phosphorus analyze gave more reliable results.

7.7 Analysis of total nitrogen

The amount of total nitrogen was determined with Kjeldahl-method. Principle of the method is to burn organic matter and change organic nitrogen into the form of ammonium nitrogen. Samples, zero samples and glycine test solution were heated in specific machine in temperature of 400-450 °C for two hours. After this samples were removed to Kjeltex b 100 nitrogen indicator. In the machine ammoniac was released from ammonium sulfate with sodium hydroxide and bounded into a receiver containing boric acid. After this sample was titrated with automatic pipette which included hydrochloric acid (website of opetushallitus 2014.)

Results Table 7-8 consumption of HCL titrant

Sample number	consumption of HCL [ml]
1. Zero sample	0.09
2. Zero sample	0.09
3. Not mixed	13.43
4. Not mixed	12.71
5. Mixed	20.18
6. Mixed	15.88

$$gN/Liter \frac{(T - B) \times N \times 14.007}{Volume\ of\ the\ sample}$$

T = Consumption of titrant in sample [ml]

B = Consumption of titrant in zero sample [ml]

N = Normality of titrant

$$\begin{aligned}
 gN/Liter(1) & \frac{(13,43 - 0,09) \times 0,01 \times 14.007}{50ml} \\
 & = 0.03737 \frac{g}{l} \\
 & = 37,37 \frac{mg}{l}
 \end{aligned}$$

$$\begin{aligned}
 gN/Liter(6) & \frac{(15.88 - 0,09) \times 0,01 \times 14.007}{50ml} \\
 & = 0.04423 \frac{g}{l} \\
 & = 44,23 \frac{mg}{l}
 \end{aligned}$$

Table 7-9 Results of total nitrogen

Sample	Concentration of N [mg/l]	Limit
3. Not mixed	374 mg /l	48-72 mg/l
4. Replicate	354 mg/l	
5. Mixed	563 mg /l	
6. Replicate	442 mg/l	

Greenish color of the samples after burning was a good sign of a successful nitrogen analysis. Values are about ten times higher than boundary values used in WWTPs.

7.8 Analysis of total grease content

Grease blocks pipelines and consumes oxygen which harms biological purification processes. Grease also may promote increase of filamentous bacteria. Limit for grease content of wastewater is commonly 150-200 mg/l. In nearly every case, grease sludge from industry needs pretreatment before discharge to purification plant (Teollisuusjätevesiöpas. 2003. 33).

In the beginning there was struggling how to measure the grease content of grease sludge. Turbidity analyze was made to determine the congruence between turbidity and grease content. Relation between turbidity and grease content showed up as very proportional. The problem was that vegetable oil did not work the same way than butter which is originated from animals. Vegetable oil is more transparent, hence turbidity measurement is not reliable option to analyze grease concentration. Below can be seen relation between turbidity and butter concentration of the water.

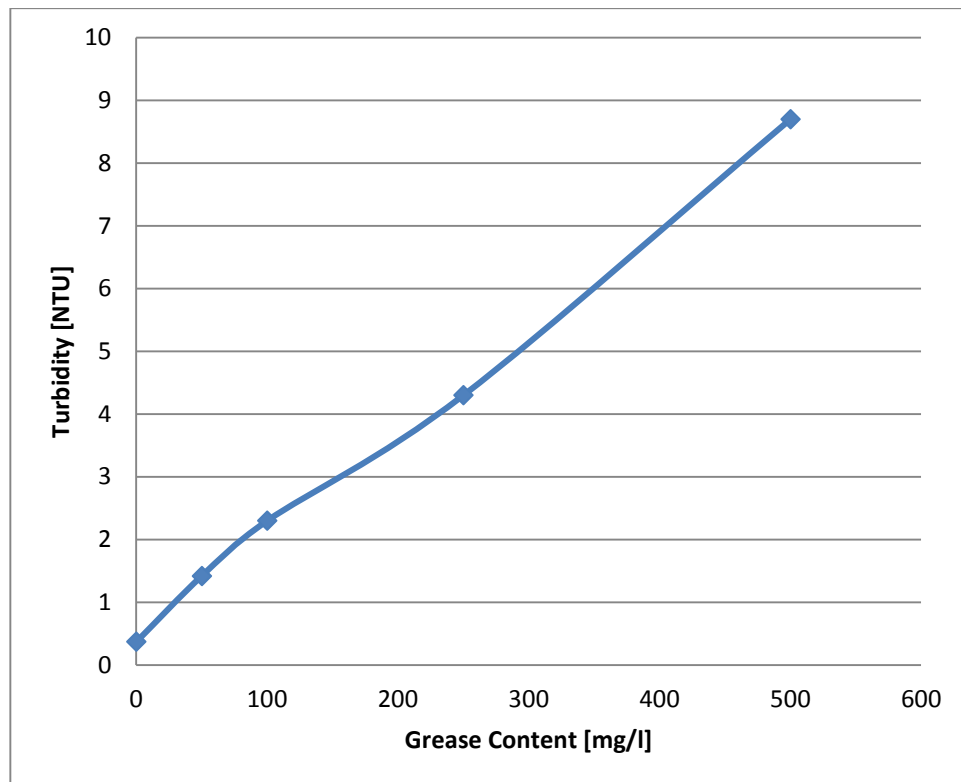


Figure 7-3 Grease content vs turbidity

Grease content was finally analyzed in accredited laboratory of Pori Lab. Analyze was made by Mojonnier method. The method is based on acid hydrolysis and gravimetric extraction of ether and petrol-ether.

Table 7-10 Result of the grease content

Sample	Grease content	Limit
1. Not Mixed	200 mg /l	100-200 mg/l

From the result can be seen that the separation of grease from the FOG sludge is successful.

7.9 Analysis of suspended solids

Separation of solids is one of the main objectives in waste water treatment. Depending on the size, total solids can be divided into categories; total suspended solids and total dissolved solids. (Weiner & Mathews 2003, 91). Solid material accumulates in pipelines and dwells of refinery which reduces the fluid flow of waste water. Characteristics of solid material defines its effect on the purification process. The composition of solid material needs to be analyzed also in biological decomposition point of view also. If solid material didn't decompose biologically it might affect sedimentation of activated sludge, drying of the sludge or utilization of the sludge. (Teollisuusjätevesiopus, 2003, 33).

Typical values for suspended solids (SS) in wastewater vary from 190-438 mg/l and boundary values 300-800 mg/l are commonly used. (Teollisuusjätevesiopus, 2003, 33).

The analysis was made according to standard SFSF-EN 872. Principle of the method was to use vacuum pressure filtration apparatus, where the sample was filtered through standardized glass fiber filter. After the filtration the filter and the solid residues were dried in the oven for at least one hour in order to vaporize all the water from the sample. Filter was weighted before and after the filtration. The difference is the weight of suspended solids. Two homogenous and mixed samples with different volumes, 100 ml and 200 ml was used. Also 100ml of the unmixed sample was analyzed. The content of suspended solids was calculated from the equation:

$$\rho = (1000 \times b - a) / V$$

Where

ρ is the content of suspended solids in milligrams per liter, mg/l

b is the mass of the filter after the filtration, mg

a is the mass of the filter after the filtration in milligrams, mg

V is the volume of the sample, in milliliters, ml. If the sample has been weighed, consider 1 g as equivalent to 1 ml.

Table 7-11 Result of SS

Sample number	volume of the sample	content of SS in mg/l	Limit
1	200 ml (mixed)	4461,5 mg / l	190-438 mg/l
2	100 ml (mixed)	4429,0 mg /l	
3	100 ml (not mixed)	441,0 mg / l	
(4)	Zero sample	- 2,6 mg / l	

Results in the case of samples 1 and 2 are very high. The results seem to be reliable because first two samples have almost the same value. Zero sample has negative value most likely because of pieces of filter stuck in the bottom of the filtering cup. Ion exchanged water from the water tap of laboratory was used as zero sample.

The sample canister included a lot of solids in the bottom. It can be assumed that unmixed water might include less SS when transporting bigger loads of separated waste water. This is because the sample was taken from the bottom of the separation tank which includes the biggest volume of SS. Upper layers below the floating grease can be assumed to contain less SS than the bottom of the tank.

8 RECYCLING OF FOG

Diversion of waste to energy is common trend these days. Hence, anaerobic digestion (AD) of organic waste is a growing field. It is a process where organic matter is broke down by bacterial activity in the absence of oxygen. Typical organic matter i.e. in agriculture is manure. Anaerobic digestion process forms biogas which consists mostly of CH₄ but also CO₂. (AEBIOM. 2009, 8).

There are different substrates which can be used in AD processes and also different ways to improve the process. Co-digestion is one option to do so. It is an AD process

boosted with two or more substrates in order to increase methane production. Re-

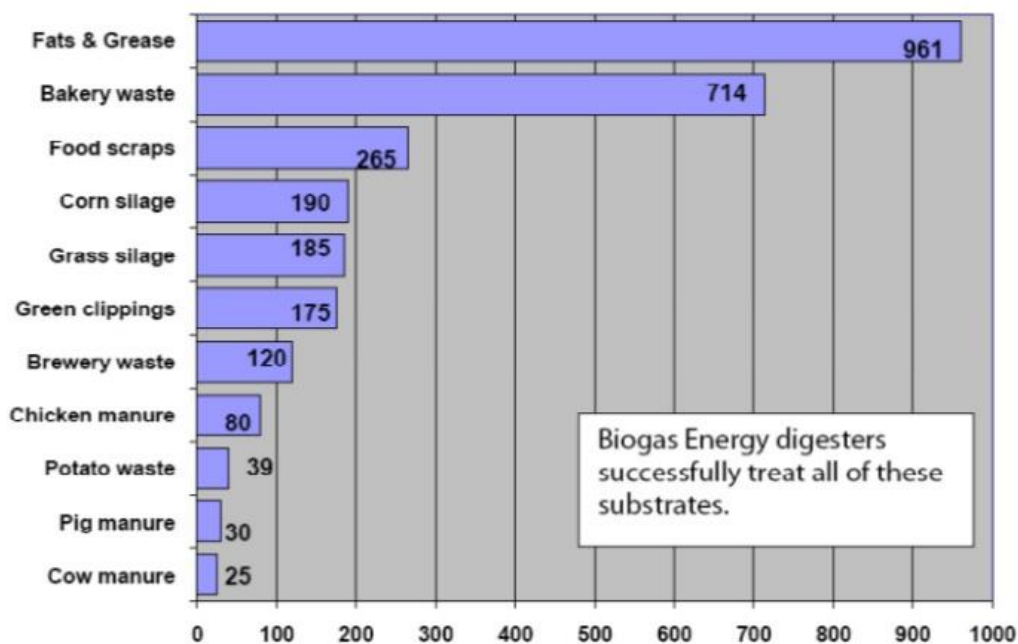


Figure 8-1 CO-digestion substrates

cently it has been noticed that the process is more stable when several substrates are added. There are following options for co-digestion substrates; food wastes from restaurants and cafeterias etc. energy crops, crop residues and FOG (Website of EPA 2014). In figure 1 below can be seen comparison between different Co-digestion substrates. FOG is the most efficient substrate with 961 m³/ton.

FOG has a substantial amount of energy and it is considered as a typical high strength organic waste and it a good substrate for co-digestion. There are several benefits in recycling of FOG. Technical benefit is simply to remove FOG from sewer collection systems are prevent SSOs. Economic benefit is that FOG can be used in biogas production. Typical efficient way to treat FOG among other organic waste is done by codigestion. Environmental benefit is that recycling of FOG reduces land filling with high-strength wastes hence, reducing emission of greenhouse gases. FOG breaks down into methane. Challenge of co-digestion of FOG is that it usually requires upgrades for biogas plants. It also might have a negative impact on anaerobic digester performance and potential increase in nutrient concentration in side streams. (Dale Gabel 2012.) Under anaerobic digestion 70 % of FOG turns into of methane and 30 % to carbon dioxide. Under STP conditions 1 mole of FOG produces 948 liter of methane (Sidhoum, Mohammed Dr. May 2013).

Produced methane can be used for several purposes:

- Production of heat and/or steam
- Electricity production / combined heat and power production (CHP)
- Industrial energy source for heat, steam and/or electricity and cooling
Injection into the gas grid
- Vehicle fuel
- Production of Chemicals
- Combustible for fuel cells

In the end of the year 2012 there were 85 biogas facilities in Finland and in 2013 there were built 10 facilities more. 42 of them were landfill facilities and 53 reactor facilities (website of Vambio Oy, 2014).

L&T transports the separated grease to biogas facility Vambio Oy. The company was founded in 2009. Vambio produce biogas and fertilizers. As raw material they use sludge hauled from food industry, sludge from primary production and WWTPs. The facility has built local energy grid where bioenergy is delivered to local industry, primary production and regional electricity company (website of Vambio Oy, 2014).

9 CONCLUSIONS

“The problem is not getting any easier – vice versa” Sillstén continues. According to Sillsten the amount of blockages caused by FOG is increasing all the time. “There are people on the field that doesn’t care” he says. “We (HSY) cannot do anything”. “Authorities should be involved” Sillstén states (Lontoon ihravuori kalpenee....2011.) FOG is smelly and harmful substance not only in drainage and in WWTPs but also in landfills where it releases methane emissions. On the other hand FOG could be very useful if recycled more efficiently. Regulations already exists, in order to make the situation better authorities should be more involved with this issue.

In laboratory analyses it was seen that separated water had low pH, high concentrations of COD, SS, P_{tot} and N_{tot} and P_{tot} . In order to decrease the concentration of SS, the outlet tube of the separation tank will be cut a bit higher from the bottom, so the sediment stays better in the tank during the emptying of separated water. Separation of grease turned out to be successful because of grease content matched with the boundary value set by WWTP. L&T got the permission to transport the separated water to WWTP Porin Vesi. Decision was made during the meeting kept in 22th of May 2014 where the results of laboratory analyses were discussed. Although many of the concentrations of the analysis run over the boundary values, the volume of transported waste water will be very small compared to total incoming waste water flow to Pori Vesi.

I found that the subject of the thesis was very interesting and useful. Selection of the subject was successful but the workload was massive compared to assumptions I had before starting the work. If I started the work again I would concentrate only in laboratory analysis because they took so big part the whole work. Standardized laboratory analyses required very much time and focusing. I did most of the analysis for the first time, without continuous guidance. Thus, results should be used only as an estimations. On the other hand I learned a lot about water analysis and I believe it will turn out to be useful in the future. I also got a lot of help from Porilab, from Porin Vesi and from the teachers involved of which I'm very grateful for.

I also made an inquiry for some of local restaurants considering their interceptor situation in the area of Pori. I visited and emailed a few restaurants and got a few answers. It was hard to find a person responsible for grease interceptors. Part of the restaurants were very up to date with this issue but others were not. This part of the thesis was left stub because of lack of time and it was also important to delimit the area of the thesis in order to decrease the workload. It was quite easy to find information about grease interceptors and recycling of FOG and it seems that it really has a potential role in green energy production.

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