FLOTATION AS PRE-TREATMENT FOR MIXED DAIRY AND MUNICIPAL WASTEWATER IN A MUNICIPAL WASTEWATER TREATMENT PLANT

Lappeenranta–Lahti University of Technology LUT

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ABSTRACT

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Flotation as pre-treatment for mixed dairy and municipal wastewater in municipal wastewater treatment plant

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Examiner(s): Professor Susana Rodríguez-Couto and Associate Professor Ritva Tuunila,

Keywords: Wastewater treatment, flotation, dairy wastewater, fats oils and grease.

Heavily loaded and rich in fats, oils and grease dairy wastewater has been treated in municipal wastewater treatment plant without sufficient pre-treatment. This has caused problems by clogging devices and accumulation of greasy sludge to aeration and clarifier surfaces and decreasing settling properties in the wastewater treatment process that relies on gravitational separation. For Solving this problem, a flotation unit was implemented in wastewater treatment plant to pre-treat the dairy wastewater.

In this thesis a middle size municipal wastewater treatment plant environmental permit regulations and limit values for different wastewater parameters concentrations and reduction efficiencies are described. In the thesis wastewater parameters and their relation in wastewater treatment have been thoroughly reviewed. Unit operations of normal middle-sized wastewater treatment plant are explained. The problems fats, oils and grease caused in the treatment process were reviewed. It was also discussed how Turenki wastewater treatment plant has met the environmental permit and Government agreement limits.

Dissolved air flotation process theory and the implementation of dissolved air flotation unit to Turenki wastewater treatment plant are explained. Flotation process separation efficiency in Turenki WWTP has been studied and reported in the thesis. Also, the evaluation of flotation process influence to biological process has been performed.

Studies in this thesis showed that dissolved air flotation separate efficiently fats, oils and grease from mixture of dairy and municipal wastewater. It was also shown that implemented flotation unit in Turenki WWTP did not compromise denitrification in biological process and decreased clogging problems.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUTin insinööritieteiden tiedekunta

Kemiantekniikka

Markku Koivula

Flotaatio esikäsittelynä sekoittuneille meijeri- ja kunnallisjätevesille kunnallisella jätevedenpuhdistamolla

Diplomityö

2025

86 sivua, 31 kuvaa, 17 taulukkoa and 1 liite

Tarkastaja(t): Professori Susana Rodríguez-Couto ja tutkijaopettaja Ritva Tuunila,

Avainsanat: Jätevedenkäsittely, flotaatio, meijerijätevesi, öljyt ja rasvat.

Kunnallisella jätevedenpuhdistamolla on käsitelty paljon rasvoja ja öljyjä sisältävää suurikuormituksellista meijerijätevettä ilman kunnollista esikäsittelyä. Tämä on aiheuttanut puhdistamolla ongelmia kuten laitteiden tukkeutumista, rasvaisen lietteen kertymistä prosessin, kuten ilmastusaltaiden ja selkeyttämöiden pinnoille ja heikentänyt lietteen laskeutuvuutta, joka heikentää painovoimaiseen erotukseen perustuvaa erotusprosessia. Ongelman ratkaisemiseksi flotaatio yksikkö on asennettu esikäsittely-yksiköksi meijerijätevesille.

Tässä diplomityössä selvitetään keskikokoisen kunnallisen jätevedenpuhdistamon ympäristöluvan mukaiset pitoisuuden ja käsittelytehon raja-arvot käsitellylle jätevedelle. Käydään läpi jäteveden ominaisuuksien merkitys jätevedenpuhdistuksessa. Esitetään normaalit keskikokoisen jätevedenpuhdistamon yksikköprosessit. Diplomityössä kuvataan myös rasvojen ja öljyjen aiheuttamat ongelmat jätevedenpuhdistamolla. Lisäksi käydään läpi miten puhdistamo on saavuttanut ympäristöluvan ja valtioneuvoston asetuksen (888/2006) mukaiset raja-arvot.

Diplomityössä esitetään flotaatio prosessin teoria ja miten flotaatio prosessi on Turengin puhdistamolle asennettu. Työssä tutkitaan ja raportoidaan asennetun flotaation erotuskykyä ja vaikutuksia puhdistamon prosessiin.

Diplomityön tutkimus osoitti, että flotaatio erottaa tehokkaasti rasvoja ja öljyjä kunnalliseen jäteveteen sekoittuneesta meijerijätevedestä. Tutkimus myös osoitti, että Turengin puhdistamolle asennettu flotaatioyksikkö ei vaarantanut puhdistamon biologista prosessia ja vähensi laitteiden tukkeutumista huomattavasti.

ACKNOWLEDGEMENTS

Special thanks to Turenki WWTP operators!

SYMBOLS AND ABBREVIATIONS

Roman characters

D	effective diameter of the cluster	cm
p	pressure	bar, Pa
Q	flow	m^3/d
q	flow	m^3/h
R	gas constant	J/kg K
T	temperature	ºC, K
V	volume	m^3
v_t	terminal rise velocity of the cluster	cm/s

Greek characters

ρ_a	density of the cluster	g/cm^3
ρ_o	density of the liquid	g/cm^3
μ	viscosity of the liquid	kg/(m•s)

Constants

g	gravitational acceleration	9,81 m/s

Abbreviations

a.a.	Annual average
ADT	Air dissolving tube
ASP	Activated sludge process
BOD	Biological oxygen demand

$BOD_{7\text{-}ATU}$	Biological oxygen demand with 7 days incubation time and allylthiourea solution addition to prevent NH_4 nitrification in sample
BOD:N	Ratio between BOD and N
BOD:N:P	Ratio between BOD,N and P
CIP	Cleaning in place
CLD	Chemiluminescence detector
COD	Chemical oxygen demand
COD_{Cr}	COD where dichromate is used as oxidiser
COD:BOD	Ratio between COD and BOD
C/N	Carbon/nitrogen ratio
DAF	Dissolved air flotation
DN	Denitrification
DNb	Dissolved bound nitrogen
DO	Dissolved oxygen
DP	Dissolved phosphorus
FEC	Flotation enhancement cells
F/M	Food to microorganism ratio
FOG	Fats, oils and grease
HLR	Hydraulic loading rate
HRT	Hydraulic retention time
ICP	Inductively coupled plasma
LCFA	Long-chain fatty acids
LOI	Loss of ignition
MLSS	Mixed liquor suspended solids

MLVSS	Mixed liquor volatile suspended solids
NH_4-N	Ammonium
P	Phosphorus
PAC	Polyaluminum chloride
PE	People equivalent number
PE_{BOD}	PE calculated based on BOD load
PE90	90^{th} percentile PE, describes maximum load situation in WWTP
RAS	Return activated sludge
RS	Recycle sludge
SLR	Surface loading rate
SRT	Solid retention time
s.s.	Single sample
SS	Suspended solids
SVI	Sludge volume index
TC	Total carbon
TCP	Three phase contact
TLF	Thin liquid film
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TNb	Total bound nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TSS	Total suspended solids
WWTP	Wastewater treatment plant

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Appendices

Appendix 1. Calculated effects to discharged concentrations and treatment efficiencies

DECLARATIONS

Turnitin

The originality of this thesis has been reviewed with the Turnitin similarity checking service.

AI usage

The author of the thesis, Markku Koivula, used the following AI-tools during the preparation of the thesis:

1. Google translator
    a. Purpose of use: Language translator
    b. Explanation of the use of the tool: To translate words or sentences when reading source material and to check correct spelling for some words.
2. ChatGPT
    a. Purpose of use: Language translator
    b. Explanation of the use of the tool: To translate words or sentences when reading source material and to check correct spelling for some words.

Responsibility

The author, Markku Koivula, takes full responsibility for the content of this thesis and has reviewed and edited the content generated by the possible use of AI tools.

1 Introduction

Municipal wastewater treatment plants (WWTP) treat household and municipal services like schools and offices sanitation wastewater and small business, like stores and restaurants wastewaters. Large industry facilities usually have their own wastewater treatment plants. In some cases, usually with smaller industry, industry wastewater is discharged to municipal WWTP. In those cases, wastewater treatment agreement is drafted in which sufficient pre-treatment is required before industry wastewater is discharged to municipal WWTP. That is because municipal WWTP usually can't treat large quantities heavily loaded wastewater that industry often produces. (Finnish Water Utilities Association (FIWA) 2018) Treating industry wastewater before it is mixed with municipal wastewater may be more cost-effective (Stasinakis et. al. 2022).

In Turenki local dairy industry wastewaters are treated in Turenki municipal WWTP. Local dairies don't have any wastewater treatment in factories site besides pH adjustment in equalisation tank before discharging to sewer. Dairy wastewaters are pumped from equalization tanks to Turenki municipal sewer and to WWTP. The dairy wastewaters are heavily loaded with biological oxygen demand (BOD), chemical oxygen demand and fats, oils and grease (FOG) and the concentrations in the wastewater are constantly changing, which makes operating the WWTP more difficult. Turenki WWTP is a biological-chemical co-precipitation facility and there hasn't been suitable pre-treatment process for dairy wastewater. Turenki WWTP wastewater is unique and the composition of the influent varies along with dairy production. Industrial wastewater contains large amounts of fats, oils and grease which increases the organic load to the plant, prohibits settling of solids and causes fouling of instrument. Dairy wastewaters are commonly treated in situ by dairy factories themselves (Stasinakis et. al. 2022), but in the Turenki all treatment is placed in Turenki municipal WWTP. To overcome the problems caused by the dairy wastewater, a flotation process as pre-treatment is built to Turenki WWTP. Flotation is a commonly used technique to treat suspended solids and FOG containing wastewater due to their inherently poor settling or even natural floating characteristics on water surface (Shammas et al. 2010). Turenki WWTP has enhanced the treatment process by installing a dissolved air flotation unit, DAF, in parallel with the existing pre-treatment. Even though flotation is a common pre-treatment

process in dairies own WWTP (Stasinakis et. al. 2022) no studies were found where flotation would have been implemented in municipal WWTPs to pre-treat mixture dairy and municipal wastewater. In this work the DAF process efficiency to separate FOG, (BOD) and Total suspended solids (TSS) from dairy wastewater mixed with municipal wastewater is studied. Also, the affects to biological process, nitrogen removal, device clocking and sludge settling properties in Turenki WWTP is studied and reported. The first objective of this thesis is to research the reductions of FOG, BOD and TSS in the implemented flotation process and to have answer to question how these reductions affect to biological proses i.e. when BOD load is predicted to decrease thus changing the BOD:N ratio in biological process. The second objective is to assess the decreased hydraulic capacity role in the environmental permit limit exceeding's and asses if the flotation has improved the solids settling properties and thus normalised the lowered hydraulic capacity.

2 Wastewater treatment plant

In wastewater treatment the municipal wastewater treatment plant (WWTP) incoming wastewater is a composition off different waters from different sources like restroom usage, cooking, bathing and laundry. Wastewater is generated in normal households as well as in commercial and municipal facilities. Also, pre-treated industrial wastewater can be discharged to municipal WWTP based on agreements between the industry and the WWTP, but often industry has own WWTP for treating its own wastewaters (Stasinakis et. al. 2022).

Typical WWTP process consist of sub-processes like preliminary treatment, primary treatment and secondary treatment. Today more often also tertiary treatment is applied to polish the treated water further (Qambar et al. 2022). Below in Figure 1, is presented a typical WWTP is process.

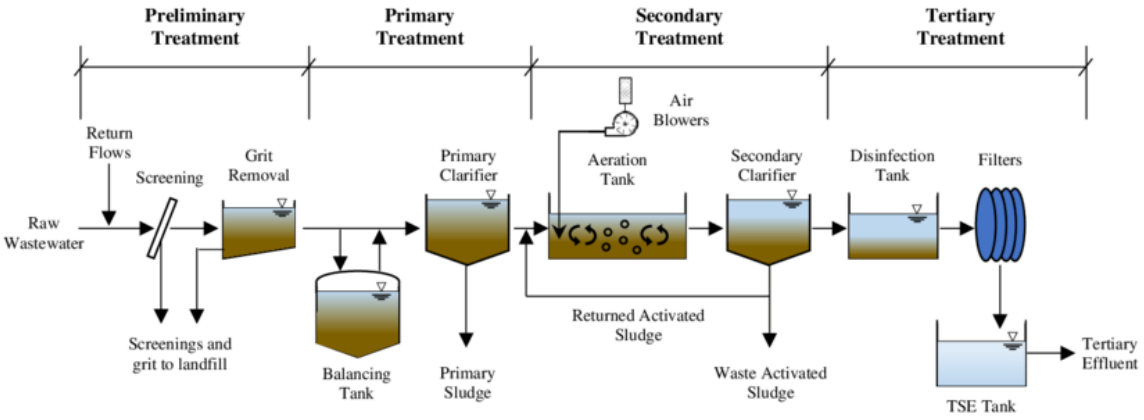

Figure 1. A flow diagram of a typical WWTP process. (Metcalf & Eddy, 2015)

Incoming wastewater or raw wastewater to WWTP is called influent. The term 'influent' is well established in the field of wastewater engineering to describe the incoming sewage water.

2.1 Preliminary treatment

First the influent is screened in fine screens to separate solids like rags, plastic pieces, and larger organic particles. Screened solids are washed in a washer to avoid organic material

ending up in screening solids disposal. After screening is grit removal. Removed grit is also washed in a sand washer before disposal.

Precipitation/coagulant chemical is added to influent in the grit removal phase where influent flow and grit removal aeration mixes coagulant to effluent properly. The main target of coagulation is to neutralize the effect of particle surface charges that prevents particles to gather and form flocs. In the coagulation process small particles make bigger masses. This is due to the influence of physical and chemical phenomena where due decreasing the repulsing electrical potentials in colloids, colloids can make bigger aggregates that can then form even larger aggregates or flocs (Sillanpää et al 2018). The typical coagulation chemical used in chemical coagulation is ferrous or ferric sulphates or chlorides. Fe is able to make good performing polyvalent ions (Fe^{2+} and Fe^{3+}) that form metal hydroxides in solution. In this process (forming metal hydroxides) charged hydroxyl ions (OH^-) make complexes with the contaminant colloid in water and destabilizes them by neutralizing surface charges. Surface charge neutralization decreases or even eliminates repulsive forces that prevents contaminant colloid particles precipitate and form bigger flocs that are possible to be removed in a gravitational separation process i.e. settling (Tahreen et al. 2020). Coagulation is a very important process and must be performed successfully in order to other separation processes succeed. Dissolved phosphorus (DP) is precipitated from dissolution to precipitate i.e. to solid phase as iron phosphate $FePO_4$ that is then further intact to sludge and removed from process in excess sludge.

After screening, grit removal and adding precipitation/coagulation chemical total suspended solids (TSS) are removed from wastewater in primary clarification. Clarification is typically done by a gravitational separation method where separation occurs due to density difference, meaning that heavier i.e. more dense particles than water sink to the bottom of the clarifier where they are removed from process as primary sludge.

2.2 Biological treatment

Preliminary treatment is followed by secondary treatment, where the influent is usually entering to the activated sludge process (ASP) that is a biological treatment process. In ASP there are aerated tanks where sludge is aerated so that activated sludge containing different micro-organisms, bacteria, protozoa and fungi can consume organic matter from sludge and

form bigger and more settable flocs. Flocs are formed by different bacteria, from which the most important ones in activated sludge are flock forming bacteria and filamentous bacteria. Besides bacteria, flocs include different organic and inorganic material and biopolymer produced by floc forming bacteria. Biopolymer is the floc forming bacteria way to store nutrients. Biopolymer also binds floc structures together. Filamentous bacteria are also essential for floc formation. Filamentous bacteria provide support structure for floc to form on. Floc forming bacteria and filamentous bacteria ratio must be well balanced in order to have sludge that forms firm, stable and settleable flocs. (Manninen & Haapea, 2019)

For nitrogen removal in the biological process stage there are anoxic denitrification tanks where heterotrophic bacteria use nitrates as electron acceptors and thus producing dinitrogen, in other words nitrogen gas. Nitrogen gas will separate to atmosphere from water surface. In the denitrification stage the heterotrophic bacteria consume organic material and are able in absence of free oxygen to use nitrate as source of oxygen. To grow optimally and to produce good biomass, sufficient amount of food, i.e. carbon is needed in the process for the microbes. If the influent contains insufficient amount of carbon, an excess carbon source is needed. If the process includes denitrification tanks before aeration and there is a first anoxic denitrification stage, an excess carbon source is usually not needed. (Mulder et al. 1995)

To have successful nitrogen removal, the process also includes recycling sludge that is aerated sludge where ammonia is oxidized to nitrate, taken from the end of the aeration stage and pumped to the anoxic part where nitrate is converted to nitrogen gas in anoxic conditions. Excess sludge is removed from aeration tanks to dewatering process.

After ASP and nitrogen removal, sludge is directed to secondary settling i.e. clarification where flocculated sludge is separated gravitationally from water. Flocculation is usually enhanced by polymer addition. Sludge is returned from the settler's bottom to the biological process. This return activated sludge (RAS) flow rate is to be one of the key parameters in operation of WWTP.

Excess sludge is removed from aeration tanks or from secondary clarification to dewatering and disposal. The amount of excess sludge is calculated based on the wanted sludge age that usually is between 7 to 20 days. Normally during winter longer sludge age is needed because of the colder water that inhibits microbial growth in activated sludge processes. Also,

different wastewater types need different sludge ages in order to get the process work properly. For example, lipids rich dairy wastewater requires typically longer sludge age than plain municipal wastewater (Chipasa and Mędrzycka 2006).

Treated water from settling is discharged after quantity and quality measurement. Typically performed online quality measurements include temperature, pH, TSS, NH_4, total phosphorus (TP) and dissolved phosphorus (DP). Sufficient measurements are presented in environmental permit.

2.3 Tertiary treatment

Tertiary treatment is the next phase after secondary treatment i.e. typically after the biological process. Tertiary treatment is typically implemented to remove more phosphorus, nitrogen and oxygen demanding substances, to improve microbiological quality and in some cases, even micro contaminants like drug residues and herbicides and pesticides. Tertiary treatment may be some sort of filtering like nanofiltration membrane, gravitational separation like flotation, activated carbon adsorption. Conventional tertiary treatments are sand filtration and UV-densification. Tertiary treatment is commonly implanted only in bigger WWTP. (Metcalf & Eddy, 2015)

2.4 Influent characteristics

WWTP influent concentration and load measurements are usually done from samples taken according on Government Decree on Urban Wastewater Treatment (888/2006) and environmental permit. Minimum number of samples for Government decree and permit is set in decree. In the European Union larger WWTPs are required to take more samples per year than smaller WWTPs. All samples used in decree or permit limits evaluation are analysed by standardised analyse methods in an Accredited and Certified laboratory, but WWTPs may also have their own laboratories that make analyses for operational purposes. In this chapter basic influent parameters are explained.

2.4.1 Influent Flow

WWTP influent flow is the flow of incoming wastewater measured as online measurement. In practise only, effluent flow may be measured, because the effluent flow measure is mandatory based on decree and permit so that the discharged wastewater load to environment can be calculated. In the case that the influent flow is not measured the influent flow is assumed to be the same as the effluent flow. From an operational point of view, it would be desirable that influent is measured as independent to make operating the plant smoother. When only effluent flow is measured in case of bypass, the bypass water flow is also measured and added to the calculation of the total influent flow. Besides operational needs, influent and effluent flows are needed in order to calculate influent and effluent loads and WWTP efficiencies and reductions. Sewer network infiltration coefficient is also calculated annually based on the inflow to WWTP. The infiltration coefficient indicates the leakage of the network, i.e., how much stormwater and rainwater enter the wastewater network. High variation in influent flow i.e. variation in diurnal flow over 250% causes great threads to the process due to the loss of activated sludge in settling phase (Samer M. 2015). In Finland during the spring time simultaneous rain with snow melt increases the infiltration flow to sewers. Infiltration water causes problems on WWTP by increasing the flow and thus, hydraulic capacity may exceed and also wastewater temperature decreases inhibiting the biological treatment. Infiltration water sources are leakages in sewer network and unauthorised couplings of rainwater pipes to wastewater sewer system. Infiltration water amount decrease is priority in almost every municipal sever network. Large amounts of infiltration waters cause permit limit exceeding and forces WWTP operators to bypass wastewater in WWPT to avoid activated sludge to wash of from biological process. Continuous sewer network repair and renovation is important to decrease infiltration water floods in WWTPs.

2.4.2 Temperature, pH, alkalinity and conductivity

Temperature affects to microbial growth and it is an important parameter for WWTP operator and also important in calculations like the determination of dissolved oxygen. Water pH is determined as the negative logarithm of hydrogen-ion activity in water. pH affects

largely water physical and chemical properties thus making it important to measure and control. Alkalinity describes the water resistance to pH change. It is essential for microbes to sustain more stable pH conditions. Alkalinity is consumed by nitrification and coagulation chemicals. Conductivity measures the water capability to carry electrical current and it is related to ionized substances in water. Dissolved organic materials in water are typically in ionic form thus increasing conductivity. (Kaul & Gautam 2021, 31-34, 50-51) Temperature is measured in sample collection and pH is determined based on the standard SFS 3021:1979 where the pH value is determined potentiometrically using a pH meter. Alkalinity measurement is based on standard SFS-EN ISO 9963-1:1996, that is titrimetric method to determine alkalinity in natural and treated waters and wastewaters in an alkalinity range from 0.4 to 20 mmol/L. Conductivity is measured as soon as possible after sample collection to avoid changes in sample. Conductivity measure is done at 25 °C or temperature correction coefficients are used. Measure is done with certain distance placed electrodes in measured solution based on conductivity measurement standard SFS-EN 27888:1994.

2.4.3 Biochemical oxygen demand (BOD)

Biochemical oxygen demand is determined as $BOD_{7\text{-}ATU}$ in Finland. BOD tells how much organic matter in water consumes oxygen. It is calculated from one litre water sample as the difference between the oxygen amount mgO_2/L when the sample is taken and after 5 or 7 incubation days. In Finland 7 incubation days is used. The difference between these measurements at the beginning and after incubation days is the BOD mg/L. In case of wastewaters sample is diluted and the dilution ratio is taken account in calculations. ATU stands for allylthiourea. ATU in the index of BOD means that the effect of NH_4 nitrification that consumes oxygen must be excluded using allylthiourea solution addition to the sample before incubation. Method is based on standard SFS-EN ISO 5815-1:2019. (Kaul & Gautam 2021, 98; ISO 5815-1)

2.4.4 Chemical oxygen demand (COD)

Chemical oxygen demand (COD) describes the amount of oxygen needed to chemically oxidise organic material in the sample. The higher the COD the higher is the wastewater

pollution potential (Valdez & Maradona, 2013, 251). Excess oxidiser is used in laboratory test and after certain reaction time unreacted oxidiser agent concentration is measured by redox back-titration and oxidiser consumption is calculated by difference to initial oxidiser concentration. With wastewater dichromate is used as oxidiser and it is expressed as COD_{Cr}. Result is given in mg/L. (Radojevic & Bashkin, 2006, 196; ISO 15705.)

COD to BOD ratio in wastewater treatment describes how easily wastewater is treated in normal WWTP process, meaning activated sludge process. It has been determined that wastewater is readily biodegradable if COD:BOD ratio is <3,3 and not biodegradable if this ratio is >5 (Bouknana et al. 2014).

2.4.5 Total Suspended solids (TSS)

Total suspended solids (TSS) describe the amount of solid particles in water that can be minerals or organic compounds, bacteria, clay, sand, sediment, algae etc. High TSS content proposes high pollution potential and also can be related to eutrophication, because solid particles often bound nutrients phosphorus or nitrogen that causes eutrophication in water sheds. (Castillo et al. 2022, Valdez & Maradona, 2013) TSS is determined according to standard SFS-EN 872:2005. Sample is preferable examined in four hours after collection and stored in dark under 6 °C, but not more than 24 hours or results won't be reliable because microbial decomposition of solids may occur. Preservation liquid use is forbidden. Sample is filtered through a glass fibre filter and the dried filter is measured and the weight of solid residue is calculated. TSS result is given in mg/L. (SFS-EN 872:2005; Radojevic & Bashkin, 2006, 163)

2.4.6 Total phosphorus (TP) and dissolved phosphorus (DP)

Thought phosphate is an essential nutrient, it is also causing eutrophication in discharge receiving water body. TP is measured by inductively coupled plasma optical emission spectrometry. Sample is sprayed to aerosol fog that is transported to plasma torch. Plasma torch causes excitation and inductively coupled plasma (ICP) produces emission spectra characteristics to species that is then dispersed by grading spectrometer and the intensities of the spectra lines are monitored with detector. Detector signals are processed by computer

and transferred to measurement data. To determine the dissolved fraction sample is filtered by membrane filter pore size 0.45 µm. Total and dissolved phosphorus in presented as mg/L. (Kaul & Gautam 2021, 120; ISO 11885)

2.4.7 Total Nitrogen (TN) and Ammonium (NH_4-N)

Total nitrogen measurement is included in normal environmental permit sampling. Ammonium nitrogen is may also be measured as online measure from influent as in Turenki WWTP. Nitrogen is a necessary nutrient in biological treatment, but in the environment excess nitrogen causes eutrophication and also the ammonium form of nitrogen is toxic to aquatic life. Nitrogen ratio in biological process should be expressed BOD:N:P ratio where optimum ratio would be 100:5:1. Too low nitrogen concentration in activated sludge process causes changes in microbial population and filamentous bacteria over growth that decreases the sludge settling properties. Nitrogen is presented as [mg/l]. (Slade et al. 2011, 627-632; Kaul & Gautam 2021, 107 -110)

Nitrogen is measured according to standard SFS-EN ISO 20236:2024. In ISO 20236 standard Thermal catalytic combustion inorganic and organic nitrogen in an oxygen-containing atmosphere is done at ≥720 °C temperature to determine total nitrogen organic or inorganic bound (TNb) or dissolved bound nitrogen (DNb). Inorganic or organic nitrogen in sample is converted to nitrogen monoxide and then oxidised with ozone. In oxidation nitrogen dioxide molecules are formed which are first in excited state and emit measurable light when returning to normal energy state that is detected by chemiluminescence detector (CLD). (Avramidis et al. 2015, SFS-EN ISO 20236:2024)

2.4.8 Fats, oil and grease (FOG)

Fats, oil and grease (FOG) are emerging in normal municipal wastewater due to being discharged to sewer by normal households. FOGs from industry and food premises must be separated before discharging to sewer (Environmental Protection Act 2014). Suitable limit for FOG discharge is in the range of 100-200 mg/L FOG, but also the FOG cannot be discharged in loads kg/d so that it compromises the WWTP process (Finnish Water Utilities Association (FIWA) 2018). When FOG is discharged to WWTP it can cause overflow,

blockages, disturbs to settling process and lead to FOG and solids discharge to receiving water basin. (Wallace et al. 2017) FOG also fouls sensors and other equipment and increases needs for maintenance. FOG entering the WWTP process should be prevented.

FOG load from households has not been widely studied, but Collings et al. (2022) studied in Britain that average FOG produced per capita per year was 0.8 kg. That can be calculated as 19.2 mg/L by the information that 3-person household produces wastewater 124.9 m^3/a (Collings et al. 2022, Southern Water Services 2024).

Oils, fats, fatty acids and grease can also be referred as lipids in wastewater. Suspended lipids can be removed from wastewater in a physical process, but stabilized lipid-water emulsion is harder to separate. Emulsion lipids can be removed in a biological process, but they are affecting negatively to floc formation and settling properties thus inhibiting the biological process. Also, growth of filamentous bacteria and foaming may occur. (Chipasa and Mędrzycka 2006)

In anaerobic conditions long-chain fatty acids (LCFAs) are produced due to oils and fats hydrolysis. LCFAs are toxic to anaerobic microbes and inhibit microbial activity. LCFAs also degrades slowly (Lalman and Bagley 2001). LCFA toxicity also aligns to flotation sludge treatment. According to Harris et al. (2018) LCFA inhibits the anaerobic digester process and same kind reports of LCFA inhibition and toxicity have been reported by other researchers earlier (Cramer et al. 2010, Pitk et al. 2012).

Activated sludge where microbes have been adapted to lipid rich wastewater has better performance in removing lipids than in sludge where microbes are not adapted to lipids. That is due to specialized microbe behaviour of producing enzyme systems that improve lipid degradation. (Wakelin and Forster 1997). But also, high concentrations of lipids in activated sludge leads to higher growth of filamentous bacteria in aerobic and anoxic stages. (Andreasen and Nielsen 1997). *Microthrix parvicella (M.parvicella)* is a bacterium that can take up and storage LCFAs in anaerobic conditions and metabolize them i.e. use them as food in aerobic conditions. Because of these abilities *M. parvicella* is advantageous and can be more successful than other bacteria in wastewater rich with insoluble fats and lipids. Due *to M. parvicella* fairly hydrophobicity cell walls and filamentous bacteria structure it is easily attached to gas bubbles ending up in surface of tanks forming fairly stable surface foam. The foam consists of gas bubbles bind to filaments and it can be broken by physically shaking

the foam when gas bubbles are released and foam collapses. (Ganidi et al. 2009, Nielsen et al. 2002, Westlund et al. 1998)

FOG determination from wastewaters is based on ISO 11349:2010 standard about determination of low volatile lipophilic substances by gravimetric methods. Determination can be done for suspended, dissolved or emulsified animal oils, vegetable oils, fats, greases, mineral oils, waxes, and non-ionic surfactants in concentration from 10 to 500mg/L.

2.4.9 Process parameters

Typical process parameters in activated sludge based WWTP is presented in this chapter. Process parameters are essential for WWTP operators and designers to control the complex process.

- Mixed liquor suspended solids (MLSS) are the solids amount in the aeration tank. MLSS unit is typically presented as concentration g/L. (Gerardi M.H. 2003) It can be measured as online measurement by TSS meter.

- Food to microorganisms -ratio (F/M) is the ratio between food entering to aeration process and the microorganism mass in the aeration process. It is simply calculated by dividing aeration influent $BOD_{7\text{-}ATU}$ kg/d by mass of mixed liquor volatile suspended solids (MLVSS) in aeration, equation (1). Typically, MLVSS concentration is 70-80% from mixed liquor suspended solids MLSS concentration (g/L) in aeration. In conventional activated sludge process F/M ratio is 0.2-0.5, in extended aeration process where aeration time is longer and F/M ratio can be 0.05-0.15. (Gerardi M.H. 2003)

$$F/M = \frac{BOD_{7-ATU}[\frac{kg}{d}]}{MLVSS[kg]} \quad (1)$$

Where $BOD_{7\text{-}ATU}$ is aeration influent $BOD_{7\text{-}ATU}$ [kg/d], MLVSS is mass of mixed liquor volatile suspended solids in aeration [kg], F/M is food to microorganism ratio

- Hydraulic retention time (HRT) is the time wastewater takes time to pass through the aeration tank. Too little HRT leads to too low contact time between wastewater and activated sludge and thus decreases process deficiency. Longer HRT increase BOD reduction and nitrification rate. HRT is calculated by equation (2) below. (Gerardi M.H. 2003)

$$HRT = \frac{Volume\ of\ aeration\ [m^3]}{Flow\ rate\ to\ aeration\ [^{m^3}/_{h}]} \quad (2)$$

Where HRT is hydraulic retention time

- Solid retention time (SRT) is the time that microbes are maintained in the whole activated sludge process. SRT is used more for design purposes than for operational purposes. SRT is presented as days and calculated by dividing aeration and secondary clarification MLSS mass (kg) by sludge exiting the process. Normally the very small amount of solids exiting via WWTP effluent are neglected and only excess sludge amount removed from the process (kg/d) is used, equation (3). MLSS mass (kg) is calculated by equation (4). (Gerardi M.H. 2003)

$$SRT = \frac{MLSS_{mass}\ [kg]}{Exces\ sludge\ [\frac{kg}{d}]} \quad (3)$$

Where SRT is solid retention time, MLSSmass is mixed liquor suspended solids in aeration and secondary clarification [kg]

$$MLSS_{mass}\ [kg] = (Aeration + sec.clarifier)vol.[m^3] \times MLSS_{con}[\frac{kg}{m^3}] \quad (4)$$

Where $MLSS_{mass}$ is mass mixed liquor suspended solids in aeration and secondary clarification [kg], $MLSS_{con}$ is concentration of mixed liquor suspended solids in aeration and secondary clarification [kg/m^3]

- Sludge age is similar to SRT, but it describes the time microbes are in activated sludge in anoxic and aerobic zones of the aeration basin and it is used by operators to control the sufficient amount of activated sludge in the aeration process. When calculating sludge age, instead of combined aeration and secondary clarifier volume

only aeration volume is used in calculation of MLSS. To simplify, MLSS and excess sludge concentration (g/L) can be neglected from the equation and use only aeration volume (m^3) and excess sludge volume per day (m^3/d) to calculation of sludge age if it is presumed that the concentrations are the same in MLSS and excess sludge. Sludge age is calculated by equation (5). (Karttunen et.al.2004)

$$Sludge\ age = \frac{MLSS_{Aeration}\left[\frac{g}{L}\right] \times Aeration\ tank\ volume\ [m^3]}{MLSS_{excess\ sludge}\left[\frac{g}{L}\right] \times Excess\ sludge\ removed\left[\frac{m^3}{d}\right]} \quad (5)$$

Where $MLSS_{aeration}$ [g/L] is concentration of mixed liquor suspended solids in aeration, $MLSS_{excess\ sludge}$ [g/L] is concentration of mixed liquor suspended solids of excess sludge

- Sludge volume index (SVI) describes the settling properties of sludge. It is calculated by dividing MLSS volume (mL) by density of the MLSS. In practice first is conducted 30 min settling ability test in 1000-mL graduated cylinder and measured the settled solids amount (mL) after 30 min settling. This volume is then divided by the MLSS concentration g/L. SVI unit is mL/g, equation (6). (Gerardi M.H. 2003) SVI should be under 150 mL/g so that the settling process can work (Karttunen et al. 2004). If SVI is over 200 mL/g is talked about bulking sludge. Bulking sludge is the result of filamentous bacteria overgrowth, too low F/M ratio, too low DO or too long SRT. (von Sperling & Fróes 1999)

$$SVI = \frac{MLSS\ volume\ [ml]}{MLSS\ concentration\ [g/L]} \quad (6)$$

Where SVI is sludge volume index, MLSS volume is amount of solids in 30 min settling ability test [mL], MLSS concentration is concentration of mixed liquor suspended solids in aeration [g/L]

- Surface loading rate (SLR) or also hydraulic loading rate (HLR) is used is the amount of water overflowing from clarifiers per clarifier area. Unit of SLR is $m^3/(m^2h)$ or it can be expressed more shortly as m/h. SLR is calculated by equation (7). For conventional activated sludge process SLR average flow is in the range of 0.67-1.2

and in extended aeration 0.33-0.67. Maximum SLR flows would be 1.7-2.7 for conventional activated sludge processes and 1-1.3 for extended aeration processes. (von Sperling & Fróes 1999)

$$SLR = \frac{Owerflow\ rate\ m^3/h}{Surface\ area\ m^2} \quad (7)$$

- Solids loading rate is the ratio between the solids load from the influent and RAS (kg/h) to surface area (m^2). Solid loading rate unit is kg/(m^2h) and it is calculated based on equation (8). (von Sperling & Fróes 1999)

$$Solids\ loading\ rate\ [\frac{kg}{h}] = \frac{Q_{influent} \times SS_{influent} + Q_{RAS} \times SS_{RAS}}{Clarification\ surface\ area\ [m^2]} \quad (8)$$

Where $Q_{influent}$ is influent flow to clarifier [m^3/h], Q_{RAS} is return activated sludge flow [m^3/h], $SS_{influent}$ is suspended solids concentration in clarifier influent [kg/m^3], SS_{RAS} is suspended solids concentration in return activated sludge [kg/m^3]

3 Flotation process theory

In flotation air is introduced to influent so that bubbles are formed. Bubbles cling to colloidal particles reducing gravitational forces and letting particles to float to surface of the flotation tank. The scum from the surfaces is skimmed by skimmers and disposed. (Pirzadeh, B. 2022) Shammas & Bennett (2010) have presented the principle of flotation in four basic steps:

1. Bubble generation in the wastewater
2. Contact between the gas bubble and the particle or oil droplet suspended in the water
3. Attachment of the particle or oil droplet to the gas bubble
4. Rise of the air/solids combination to the surface where the floated material is skimmed off

Flotation has many implements like:

- Included air flotation where air is mechanically mixed to water and rather large air bubbles is formed
- Froth flotation where gas is sprayed or sparged to water
- Electrolytic flotation where electrolysis produces bubbles to water
- Vacuum flotation where supersaturation is produced in negative pressure

In this thesis I concentrate to Dissolved air flotation (DAF) where air is introduced to water under pressure and then released to normal pressure leading to formation of fine bubbles. (Shammas & Bennett 2010, 2)

3.1 Pre-treatment of flotation

Raw wastewater must be pre-treated before actual flotation to separate larger particles rags, plastics and to remove sand and grit. Coagulation and flocculation are also usually necessary to improve the separation process. (Samer M. 2015)

3.1.1 Screening and grit removal

Before actual flotation process DAF or other flotation method, the influent must be pre-treated by screening and grid removal to remove large particles and sand. Pre-treatment is constructed in the same way as in normal wastewater treatment presented in chapter 2. First stage is screening with fine screens followed by sand removal and in addition typically with grease trap. Removal of the sand and grit and large particles like plastics and rags improves the coagulation flocculation process and prevents blockages in the flotation process. (Valdez & Maradona, 2013, 254)

3.1.2 Coagulation and flocculation

Principles of coagulation and flocculation are explained in chapter 2.8. Gravitational separation processes require usually coagulation and flocculation in order to accomplish the separation process and DAF is no exception. (Pankivskyi & Wang 2021, 246) However, gravitational removal of grease may not need coagulant or flocculant at all. (Shammas et al. 2010, 538) But on the other hand, emulsified oils and grease always needs chemical conditioning to break the emulsion. Separation efficiencies of food industry wastewater oils and grease had been increased when coagulant is used. (Shammas et al. 2010, 25, 541) Coagulation is always done before flocculation. In coagulation main target is to neutralize particles surface charge so that small particles in suspension can be drawn and make flocks. Also, entrapment of dissolved contaminants occurs. In flocculation these neutralized particles and flocs are bound together by a flocculation agent, like a long-chained polymer that binds these flocs more together and also keeps the flocs more staple by surrounding one or more flocs together with filament strings. Metal salt coagulants and cationic polymers are usually used together in water treatment for the benefit of significantly less coagulant requirement that further decreases the need of alkalinity adjustment. (Howe et al. 2012) When coagulation and flocculation are combined in wastewater treatment process very good separation efficiencies are achieved. (Tahreen et al. 2020,37)

3.2 Dissolved air flotation (DAF)

DAF has been used in water treatment since 1920's. DAF removes FOG, BOD and suspended solids. (Arnold et al. 1995) DAF is an extremely efficient method to separate solids from liquid (Pankivskyi & Wang 2021, 246). Especially separation of light particles in flotation is efficient and all particles that stick to bubbles can be floated from liquid phase to surface. Oil emulsion should be broken before emulsion oil can be removed from wastewater in the flotation process. (Shammas et al. 2010, 1)

In DAF process air is introduced to flotation influent under 4.5 – 6.5 bar pressure so that air is dissolving to water. This water may be called as "white water" or "pressurised air-water" and it is produced from recycled water from flotation. After pressure released through pressure release valve in laminar conditions water becomes supersaturated by extremely fine bubbles with size range of 20-80 µm. These micro bubbles clinch with colloid in water and increase lift to water surface by decreasing the particles specific gravity. The micro bubbles attachment to particles may be result of several different phenomena like physical entrapment, electrochemical attraction, surface adsorption, and gas stripping. (Pankivskyi & Wang 2021, 246, Shammas et al. 2010, 20)

There are different approaches in the pressurization. The whole influent water volume or part of it can be air-pressurised or then can be used recycled water from the flotation effluent that is air-pressurised. Recycle water use is preferable since it is already purified in flotation and thus, it contains less solids. Down side is that it increases the flotation tank size, because the recycled water amount must be added to full water flow. Used recycle water amount is 20-50% of the flotation influent flow. However, in the field of flotation technology, it has been widely understood that the best option of these approaches is the use of recycle water (Shammas et al. 2010, 21-23).

Because in flotation it is usually treated large volumes of water the detention time in flotation tanks is an important design and operating parameter. Retention time, meaning the air bubbles retention in flotation, depends on the air bubbles rising rate that can be calculated by Stokes law by Equation (9).

$$V_t = \frac{gD^2(\rho_a - \rho_o)}{18\mu} \quad (9)$$

Where V_t is the terminal rise velocity of the cluster [m/s], g is the gravitational constant [980 m/s^2], D is the effective diameter of the cluster [m], ρ_a is the density of the cluster [kg/m^3], ρ_o is the density of the liquid [kg/m^3] and μ is the viscosity of the liquid [kg/(m•s)].

3.2.1 Air bubble attachment to particles or flocks

When gas bubble and solid particle collision occurs in water solution, a thin liquid film (TLF) forms between these two entities and must be broken in order to have the solid particle to adhere to gas bubble. Solid particle to bubble attachment can be presented in three stages (Kruszelnikci et al. 2024:

1. Drainage: → Thin film thickness decreases until critical stage where the film rupture begins
2. Rupture: → Thin film breaks and gas-water-solid, i.e. three phase contact (TCP) forms with critical radius
3. Expansion: → TCP-line expands from critical radius to radius of a stable surface contact area

Solid particle attachment to air bubble depends on of the TLF drainage kinetics and contact time in particle-bubble collisions. The drainage depends on of the treated water (liquid) properties like, viscosity and surface tension and also surface properties of the solid particle e.g. wettability, charge, topography, size, and shape. So, it is important to create a stable TCP in a very short collision time, because of the turbulent environment in the DAF process where contact time for air bubbles and solid particles is very short. The efficiency of the particle-bubble attachment depends on how quickly and effectively the liquid film between the particle and the bubble drains away, i.e. drainage kinetics. If the liquid film drains quickly, the particle and bubble can make contact and attach. If it drains slowly, the attachment is less likely to occur. (Stechemesser & Nguyen 1999, Kruszelnikci et al. 2024)

Solid particles/flocs and air bubbles adherence or permanent contact depends on the forces effecting on gas, water and solids interfaces that are resulting from physical attraction and physicochemical- repulsion forces. Surface properties of solid particles and affinity to the surrounding solution has very big effect on successful gas bubble adherence to solid particle. Solid particle affinity i.e. wettability and hydrophilicity decrease the solid particle adherence

to gas bubble. Contact angle is used to describe this phenomenon. It describes the properties of three phases gas, solid and water interreference that are crucial to gas bubbles and solid particles surfaces permanent aggregation. The hydrophilicity-hydrophobicity of solid particles effects on the contact angle and thus the formation of stable gas bubble-floc structure. Contact angle is one of basic parameters in flotation research and the most important parameter in the determination of the optimal bubble size. When contact angle is reduced, smaller bubbles must be used to form stable gas bubble-floc structures. Typically, in wastewater treatment contact angle is 40-50° which requires very fine bubble under 100 μm size. (Kruszelnikci et al. 2024, Shammas et al. 2010, 128)

Based on Shammas et al. (2010, 4-5) the basic steps of air bubble-solid particle-Flock attachment in dissolved air flotation processes are:

1. Bubble generation through a pressurized air-water tank, which is then released into the flotation tank.
2. Collisions between gas bubbles and suspended matter in the flotation tank.
3. Attachment of microbubbles to suspended matter in the flotation tank.
4. Collisions between bubble-attached suspended matter and thus, bigger cluster formation
5. Entrapment of more gas bubbles to clusters
6. Upward rise of floc structures in sweep action where smaller contaminants are trapped in big floc structures, “sweep flocculation”.

It is shown in Figure 2. how air bubbles and oil droplets or solid particles interfere in DAF process and form clusters. Small gas-bubble nucleation is stuck to solid particle in early stage of flotation. The gas-bubble nucleation grows in size when pressure decreases. Rising air bubble adhering to solid particle depends on the contact angle when rising bubble and solid particle or droplet are colliding. Gas bubbles may also get trapped inside floc structure or floc surface irregularities.

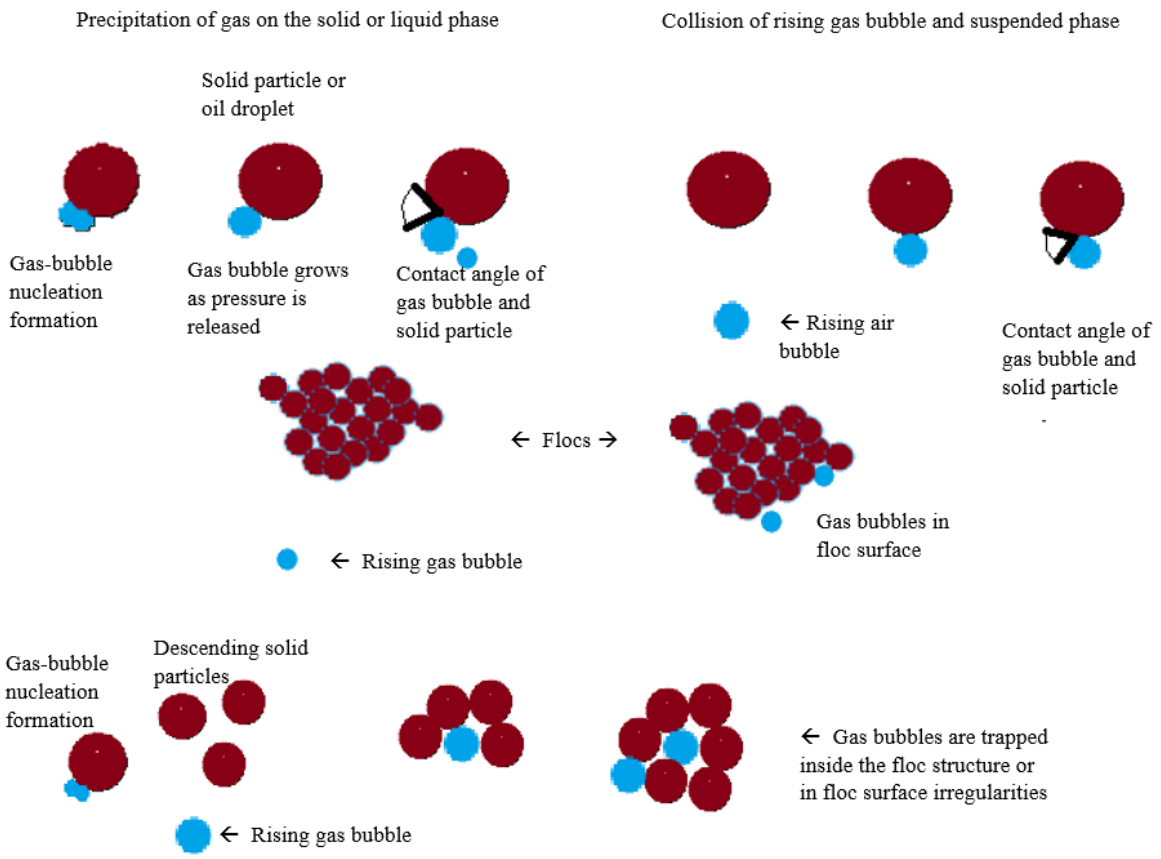

Figure 2. Mechanisms of air-droplet or air-solid particle/floc formation via air bubbles and solids interfering in the DAF process, (Shammas et al. 2010 s.4).

Calculated and in real process observed rising rate varies because the bubbles are interacting with particles and flocs in water and also having collisions to one on other. (Shammas et al. 2010, 3-4) Hydraulic surface loading rate (SRL) is an important design parameter for flotation. SRL is usually represented as $m^3/(m^2h)$ (equation 7), that can be transformed to $m^3/(m^2min)$ and further to m/min that is the same unit as in bubble rising velocity and is equivalent to the rising rate. That can be used in the design phase to size the process unit. (Shammas et al. 2010, 13-14)

3.2.2 Important design and process parameters for DAF

Important design and operation parameters in DAF are the dissolved air volume and rate to water flow rate. Increase of the air amount in flotation increases also the rising rate. Bubble size distribution and degree of dispersion effects to rising rate. Bigger bubbles rising velocity is higher, supported by the Stokes' law, but attachment properties to fine colloids is increased

with small bubbles. Small bubbles also have bigger specific surface area that increases the flotation efficiency, which is important to remember and compare bubble size to contact angle i.e. solid particle properties. Concentration and properties of the suspended and dissolved matter that is supposed to separate in flotation is crucial to know. The shape, geometry and hydraulic design of the flotation tank affects the flotation process separation efficiency and must be taken in to account when one is designing flotation device. Retention time, 10-60 minutes is average retention time in flotation process. Recycle water amount 20-50% is normally used as discussed in chapter 3.2. Coagulant, flocculation and other chemicals that may be used must be taken account and devices like pumps and measurement instruments suitability for used chemicals must be checked. Influent temperature and pH are also important because they affect to coagulation and flocculation process. The most important design parameter is the air/solid ratio that is ratio between the mass of air entering the treated water when pressure is released per mass of the solids in treated water. If ratio is too low, it means that too little air is produced and the removal efficiency decreases. When ratio is too high and air is introduced too much it means excess compressed air is produced compared to mass of solids to be separate. Too much air may lead to unwanted air bursts that breaks scum planked on flotation tanks. The excess air production may also lead to a situation where energy is wasted and operation costs are increased. (Shammas et al. 2010, 9, 14, 26) Optimizing the pressure and the white-water flow may be difficult since compressor energy consumption increases as pressure increases, but at the same time white water i.e. recycle water flow decreases and smaller size equipment is needed which decreases also the capital costs. The power demand of recycle pump increases directly with the same rate as the pressure increases and decreases when the flow decreases. So, dissolving more air to certain quantity of flow or dissolving certain quantity of air to decreased flow increases the power demand, but at the same time less flow demands less power due the smaller need for pressurised water. The solid content determines the required air volume in flotation and it is not related to pressure. Higher pressures lead to heavier, more expensive equipment and increases compressors energy demand. For these reasons it is not simple to design perfect white-water apparatus in energy wise. Taken account the above-mentioned factors the used pressure has usually been set between 4-8 bar for flotation white-water. (Woodard & Curran, 2007)

Overall, it is mentioned that according to DAF process all parameter are not known and cannot be precisely foreseen and for that reason it is important to conduct a pilot scale test to ensure the process suitability for certain influents. (Shammas et al. 2010, 5)

3.2.3 Examples of DAF utilizations in literature

DAF is a process that can efficiently separate oil, grease and suspended solids from water. DAF is in history utilised for oil separation in petroleum industry and fats, oils and grease in food processing industry for plant and animal wastes. (Shammas et al. 2010, 200, 538)

As an example, Ekolat plant in Vipava, Slovenia that is part of Italian Sabelli group, constructed a DAF process to separate COD and FOG from dairy wastewater. Ekolat dairy in Vipava uses milk 130 000 L/w in production, Ekolat plant effluent concentrations were COD 3220 mg/L, TSS 710 mg/L, TN 71 mg/L FOG: 580 mg/L. Wastewater treatment costs were very high and that lead to decision of building wastewater treatment process in-house to reduce wastewater treatment costs. Solution was 25m^3/h DAF process that removes 70% of COD and basically all FOG is removed. (Fluence Corporation 2024)

DAF is proposed to use in-house treatment in dairy industry to recovery of valuable material from waste streams. For example, Ryder et al. (2018) proposed a DAF process to separate caseins from dairy effluent streams and reuse it as protein source in other applications.

Shammas et al. (2010) reported a 76% reduction of BOD for slaughterhouse wastewater, 92% reduction of SS for Margarine factory, 98% of SS reduction for Car factory, 96% of SS reduction for Paper mill and 75% of SS and 58% of BOD reduction for cannery. For flotation process efficiency in municipal wastewater treatment Shammas et al. (2010) reported TSS reduction of 50-60% for TSS and 98% for Settleable solids without coagulants and 85-90% and 100% with coagulants respectively.

In one wastewater treatment facility of vegetable food industry flotation was used to treat 1000-2000mg/L of SS. SS reduction was 60-90% and BOD reductions 50-70% and hydraulic load is average 5m^3/(m^2h) (Viitasaari et al. 1995). In Norway smaller, up to 40m^3/h, flotation units as municipal wastewater pre-treatment has been used. Coagulation by ferric chloride and polymer flocculation addition have been used. Overflow rates from 1.9 m^2/h to 5 have been achieved 91,7% to 98% removal of phosphorus (mg/L) and from

69,9% to 91,8% of COD (Ødegaard, H. 2001). In another study, dairy industry flotation process as pre-treatment unit was suggested to cease the use of chemical before flotation in order to preserve nutrients in flotation effluent that was further treated in biological stage. (Ambrosova & Kruglikova 2021) Wang et al. (2021) reported for municipal wastewater with concentrations TSS 325 mg/L, COD 251 mg/L, BOD 116 mg/L, TP 1.6 mg/L and TKN 25 mg/L, average removal of 76.6% TSS, 48% COD, 49% BOD, TP 25% and TKN 20% in a pilot scale experiment of 9 m^3/h flow and hydraulic loading rate 2.4 $m^3/m^2/h$.

Laeva Dairy of Valio Eesti AS located in Valmaotsa Village in Tartu rural municipality in Estonia and Võru Cheese Plant in Võru Southern Estonia rely on DAF as a pre-treatment in dairies wastewater treatment. Laeva Dairy, production includes fresh dairy products: milk, cream, kephir, yoghurt, curd creams and cottage cheese. Production in Laeva dairy is 7 000 tonnes per month. Võru Cheese Plant manufactures hard cheese products with production of 900 tonnes per month. Võru and Laeva dairies WWTP:s flotation influents and effluents and calculated reduction percentages are presented below in Table 1 and 2. Data were provided by the companies.

Table 1. pH, BOD_7, COD_{Cr}, Turbidity, TN and TP of Võru Cheese Plant flotation unit influent and effluent and flotation reduction percentages of four different sample analyses.

Flotation influent	pH	BOD_7	COD_{Cr}	Turbidity	TN	TP
1	6,7	830	1100	240	38,1	12,9
2	7	650	850	220	39,8	8,17
3	6,6	1060	1330	360	51	11,7
4	6,4	1250	1570	300	47,8	14,2

Flotation effluent	pH	BOD_7	COD_{Cr}	Turbidity	TN	TP
1	6,1	600	760	120	21,4	3,4
2	6,4	610	800	80	28,8	3,8
3	6,4	650	830	60	27	3,73
4	6,3	900	1170	220	39,8	5

Reductions		BOD_7	COD_{Cr}	Turbidity	TN	TP
1		28 %	31 %	50 %	44 %	74 %
2		6 %	6 %	64 %	28 %	53 %
3		39 %	38 %	83 %	47 %	68 %
4		28 %	25 %	27 %	17 %	65 %

If DAF process in Valio's Laeva Dairy WWTP is not working properly and high COD concentrations occur DAF effluent is pumped to ring canal tank before biological process because too high COD inhibits the biological process.

Table 2. BOD_7, COD_{Cr}, Turbidity, TN and TP of Laeva dairy WWTP flotation unit influent and effluent sample analyses average, maximum and minimum concentrations and reductions in flotation unit from year 2021.

Influent	BOD_7	Turbidity	COD_{Cr}	TP	TN
Average	1477	666	2631	13	79
Max	1900	1000	3100	18	100
Min	1200	270	2000	5	6

Effleuent	BOD_7	Turbidity	COD_{Cr}	TP	TN
Average	553	238	947	7	30
Max	1100	670	1700	13	61
Min	340	18	440	2	11

Reductions	BOD_7	Turbidity	COD_{Cr}	TP	TN
Average	62 %	64 %	64 %	52 %	64 %
Max	80 %	97 %	84 %	82 %	87 %
Min	42 %	26 %	43 %	15 %	39 %

DAF can also be used as bypass water treatment for primary treated municipal wastewater. Separation efficiency of 90%, 47% and 70% of P, COD and SS, respectively, and very good microbial removal of 98-99,8% have been reported. (Koivunen et al. 2008)

4 Turenki wastewater treatment plant

Turenki Wastewater Treatment Plant (WWTP) treats municipal wastewaters from Janakkala build-up areas and also from dairy industry factories in Turenki. Dairy industry represents in average 30% load of influent to Turenki WWTP.

WWTP:s capacity is measured as people equivalent (PE), that is calculated from the BOD_7 load in WWTP. According to Finnish Government degree on Urban Wastewater, one human produces BOD_7 70 g per day (2006). In year 2023 people equivalent (PE) in Turenki WWTP calculated based on BOD_7 was 25 700 and based on the last five years average the 90th percentile population equivalent (PE90) was 35 400. PE90 describes the maximum load situation in WWTP (KVVY Tutkimus Oy 2024).

4.1 Process design parameters

Turenki WWTP is a traditional biological-chemical activated sludge process with nitrogen removal. Design capacity people equivalent of Turenki WWTP is 39 000. Design parameters are presented on Table 3. below.

Table 3. Design parameters of Turenki WWTP (Airix, 2007) Average values for example $Q_{average}$ is the average flow that is it supposed to go through WWTP process. Maximum values, for example Q_{max} is the maximum water flow that can go through process. Maximum values are values can be hold only for short period of time.

Parameter	Value	Unit
$Q_{average}$	4 100	m^3/d
q_{desing}	360	m^3/h
Q_{max}	12 200	m^3/d
q_{max}	720	m^3/h
$BOD_{7\_average}$	2 700	kg/d
BOD_{7_max}	3 400	kg/d
$TP_{average}$	40	kg/d
TP_{max}	55	kg/d
$TN_{average}$	230	kg/d
TN_{max}	270	kg/d
$SS_{average}$	1 800	kg/d
SS_{max}	2 500	kg/d
PE_{BOD}	39 000	

4.2 Process description

Treatment process in Turenki WWTP is based on biological activated sludge process with nitrogen removal and chemical precipitation. Excess sludge treatment is outsourced after dewatering. Experimental site permission for wetland and for constructed basin for bypass waters is ongoing as improvement experiment to effluent treatment. Turenki WWTP process diagram is presented in Figure 3 below.

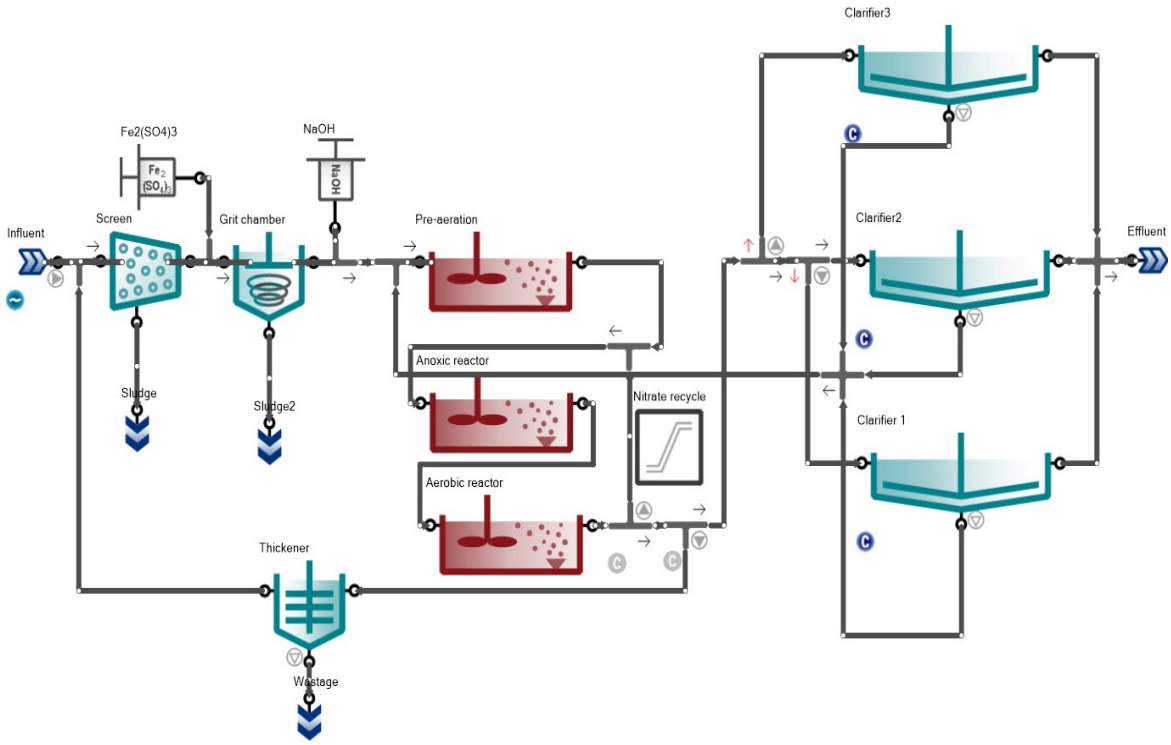

Figure 3. PFD diagram of Turenki WWTP before flotation unit.

4.2.1 Preliminary treatment

First the influent is screened with 3 mm opening fine screens to separate solids like rags, plastic pieces, and larger organic particles. Screened solids are washed in a washer to avoid organic material ending up in screening solids disposal. After screening is grit removal. Removed grit is also washed in a sand washer before disposal.

Precipitation/coagulant chemical, ferric salt, is added to the influent in the grit removal phase where influent flow and grit removal aeration mixes coagulant to effluent properly. In

Turenki WWTP coagulation chemical used in chemical coagulation is ferric sulphate or chloride.

After screening, grit removal and adding precipitation/coagulation chemical wastewater is referred as pre-treated wastewater. In Turenki WWTP there is no primary clarification which is a typical process stage after screening and grid removal in most WWTP's.

4.2.2 Biological treatment

After preliminary treatment in Turenki WWTP is pre-aeration tank, size 330 m^3 where influent to biological treatment is slightly aerated before entering the three-line activated sludge process (ASP) with total size of 3 000 m^3. Every line in ASP there is first anoxic denitrification tank, á 500 m^3 and in the second stage consist of á 500 m^3 aerated tanks. Excess sludge is removed from aeration tanks, to dewatering. Below is presented basic parameters of Turenki WWTP biological treatment.

- Size of the whole ASP is 3 000 m^3 where 50% is for the denitrification (DN) and 50% for the nitrification (N) process
- Sludge concentration in aeration is 5 kg/m^3 (in practice max 7 kg/m^3)
- Food-to-microorganisms (F/M) ratio is 0.15 kg $BOD_{7\text{-}ATU}$/kg MLSS*d
- Volumetric load 0.75 kg $BOD_{7\text{-}ATU}/m^3$
- Recycle sludge (RS) ration in ASP 150%
- Return sludge 140 - 180%
- Excess sludge is removed 200-250 m3/d from aeration so that sludge age is average 14 days

After ASP and nitrogen removal, sludge is directed to secondary settling i.e. clarification where flocculated sludge is separated gravitationally from water. Flocculation is enhanced by polymer addition. Sludge is returned from the settler's bottom to the pre-aeration tank. This return activated sludge (RAS) can also be pumped straight to ASP if necessary. Below are presented secondary settling phase parameters in Turenki WWTP.

- Total secondary settling area is 716 m^2
- Designed surface loading rate (SLR) 0.5 m/h, (max 0.69 m/h)
- Solids loading rate 2.5 kg SS/m^2h
- Sludge volume index (SVI) is 150 mL/g
- Hydraulic loading rate 0.45m^3/m^2/h

Treated water from settling is discharged after quantity and quality measurement. Performed online quality measurements include Temperature, pH, TSS, NH^4, TP and DP.

4.2.3 Experimental site permission, Wetland and Constructed Basin

At the moment there is a study is going on about wetland as tertiary treatment in Turenki WWTP. Wetland is old swamp dam basin sugar industry used to treat sugar beet washing waters. Size of a dam area is about 130 000 m^2 and it is mostly growing birch, willow and different plants like mugwort and thistle. Turenki WWTP has at the moment experimental site permission to discharge treated wastewater to this wetland in order to study effects to receiving water.

Given permit includes Constructed Basin for bypass water that is used to store bypass waters until returning to treatment process or to discharge bypass water through basin when basin capacity is exceeded. Basin has 4 000 m^2 settling area and max 1,5 m water depth. Bypass water is pre-treated wastewater in Turenki WWTP. It has been observed that settling of solids and precipitation of soluble phosphorus is occurring in basin thus reducing bypass water load to receiving water.

4.3 Turenki WWTP Influent, incoming wastewater

Concentration and load measurements from Turenki WWTP influent are done from samples taken based on Government Decree on Urban Wastewater Treatment (888/2006) and Turenki WWTP environmental permit (2015). Minimum number of samples for Government decree and permit is 12 samples in a year. 12 excess samples are done for the

site permission and in addition samples are taken as needed. All samples are analysed in accredited and certified laboratory. In this chapter basic influent parameters are explained.

In Turenki WWTP effluent flow is measured as online measurement. Influent flow is assumed to be the same as effluent flow. In case of bypass the bypass water flow is also measured and added to calculation of total influent flow. Influent and effluent flows are needed to calculate both influent and effluent loads and WWTP treatment efficiencies and reductions. From flow to WWTP, also sewer network infiltration coefficient is calculated annually. The infiltration coefficient indicates the leakage of the network, i.e. how much stormwater and rainwater enter the wastewater network. High variation in influent flow i.e. variation in diurnal flow over 250% causes great threads to the process due to the loss of activated sludge in the settling phase (Samer M. 2015). Average daily flow to Turenki WWTP is 4100 m^3, but in history it has raised once as high as 19 000 m^3 at spring time flood when snow was melting rapidly. Simultaneous rain with snow melt increases the infiltration flow to sewers. Infiltration water preventing by continuous sewer network repair and renovation is important to decrease infiltration water floods in WWTP.

Thanks to dairy industry, Turenki WWTP influent temperature is several degrees higher compared to normal WWTP influent that consists only of normal municipal wastewater. In annual average Turenki WWTP effluent temperature has 15.5 °C and the lowest value was 9.6 °C in the last three years. Without the warm industry water during winter time effluent temperature could drop to 6-4 °C. Warm water over the year helps the biological process and it specially donates to denitrification process that reduces under 10 °C temperatures, which is the case normally during winter time in Finland. Due to the warm industrial waters denitrification process can be obtained fully functioning around the year in Turenki WWTP.

pH is 7.5 in average and it varies between 6.9 and 7.9 when reviewing the measurements from the last three years. Chemical addition in order to rise pH is not usually needed because the high alkalinity of incoming dairy wastewater.

Because of the high organic wastewater load from the dairy industry, BOD load to the plant is elevated. Typical BOD:N:P ratio in influent is approximately 100:17:5 (KVVY 2024), but in Turenki WWTP the average ratio in 2023 was 100:12:2. The optimal ratio for biomass growth is 100:5:1 (Metcalf & Eddy Inc., 2013). Dairy effluent elevated BOD makes dairy effluent a good carbon source for nitrogen removal processes, especially denitrification.

Denitrifying bacteria require organic carbon (BOD) for nitrogen removal. Thanks to this high BOD dairy effluent additional carbon source is not required in Turenki WWTP.

4.3.1 Overview of typical influent parameters in Turenki WWTP

Influent characteristics in Turenki WWTP are strongly influenced by the dairy industry. Dairy industry wastewater characteristics varies a lot depending on the ongoing production. Dairy wastewater increases BOD and COD concentrations in wastewater coming to Turenki WWTP. BOD and COD load in dairy wastewater is 4 to 10 times higher than in average municipal wastewater. Approximately 90% of load in dairy wastewater origins from washes cleaning in place (CIP) operations. Internationally In-house treatment with activated sludge or DAF is usually used in dairy industry as pre-treatment for dairy effluent before discharging to municipal sewer. (Żyłka et al. 2020) However, in Turenki there isn't in-house wastewater treatment in dairy industry. Influent flow to Turenki WWTP, concentrations and loads from the past 3 years are presented in Table 4. as yearly averages.

Table 4. Influent concentrations in mg/L and load in kg/d from the last 3 years at Turenki WWTP.

Measure	2022	2023	2024	**3-year mean**
Flow $_{mean}$ m^3/d	3927	4158	4090	**4058**
[mg/L]				
$BOD_{7\text{-}ATU}$	450	430	487	**456**
TP	8	7,3	7	**8**
TN	59	53	54	**55**
TSS	400	370	379	**383**
COD_{Cr}	970	950	843	**921**
FOG	51	71	73	**65**
[kg/d]	2022	2023	2024	**3-year mean**
$BOD_{7\text{-}ATU}$	1800	1800	1873	**1824**
TP	31	31	27	**30**
TN	230	220	204	**218**
TSS	1600	1600	1445	**1548**
COD_{Cr}	3800	4000	3204	**3668**
FOG	200	300	265	**255**

BOD load is good for nitrogen removal process in denitrification process BOD: N = 100:12, but high BOD and COD concentrations also means high load to activated sludge process and

to aeration air flow production. COD:BOD ratio is 2 which means that wastewater should be quite easy to treat. (Bouknana et al. 2014). Dairy wastewater has its benefits by keeping influent warm over the year and being a source of carbon, but it also includes lots of FOG that decreases treatment capacity by interfering sludge settling properties and also clogging devices specially in the pre-treatment process. FOG separates in aeration tanks to surface and it's difficult to remove from there. Less settling sludge may also more easily runoff from settlers thus resulting solid residue in treated water and leading to permit limits exceeding.

4.4 Turenki WWTP Effluent, discharged wastewater

Turenki WWTP discharges wastewater to downstream water average 4 100 m^3/d. Quality of water is observed by online monitoring and with sampling in according to the environmental permit. Also, according to the experimental site permission, extra samples are taken between every obligatory environmental samples.

4.4.1 Government Decree and Environmental permit

Turenki WWTP has limits based on Government Decree on Urban Wastewater Treatment (888/2006) and based on Environmental Permit (2015). Limits in permit are assessed to fit Turenki WWTP and therefor are tighter than limits based on Government Decree that are more in general level.

In Government Decree there are three sample specific limits based on concentrations and efficiencies that one or other must be passed and for TP limits for concentration and reduction that are annual averages. In Environmental Permit there is three (BOD, COD and TP) concentration and efficiency limits in four calculation period per year that both has to be passed and also one (NH_4) yearly concentration limit and one (TN) alternative yearly concentration or efficiency limit.

Table 5. Government decree on Urban Wastewater Treatment and Turenki WWTP Environmental Permit (2015) limits for effluent concentrations and treatment efficiencies.

	Environmental permit, 2015 Indefinite				Government decree on Urban Wastewater Treatment (888/2006), sample specific (s.s.), annual average (a.a)			
	Concentration [mg/L]		Treatment efficiency %		Concentration [mg/L]		Treatment efficiency %	
$BOD_{7\text{-}ATU}$	15	and	95	periodically	30	or	70	s.s.
COD_{Cr}	90	and	85	periodically	125	or	75	s.s.
TP	0.4	and	95	periodically	2	or	80	a.a.
TN	15	or	70	yearly				
NH_4	4			yearly				
TSS					35	or	90	s.s.

4.4.2 Treatment results compared to agreement and permit conditions

In the last four years that have been taken to account in this review, Turenki WWTP has met the Government Decree on Urban Wastewater Treatment limits, except in a couple of cases that are explained below. Environmental permission limits have been met otherwise, but in 2 maintenance related cases and due to total phosphorus limit exceeding's and $BOD_{7\text{-}ATU}$ exceeding's when solids residue in effluent has been elevated so that treatment efficiency and effluent concentration limits has not been fully filled.

From the Table 6. can be seen that limit exceeding's has been mostly due to the TP residue. Both TP concentration in effluent and insufficient removal efficiency have usually been exceeded. According to KVVY laboratory reports and WWTP operation data the reason for these exceeding's is solids runoff in infiltration water floods due to poor settling properties.

Table 6. Based on Environmental permit COD_{Cr}, $BOD_{7\text{-}ATU}$, TP concentrations in discharged effluent and reductions periodically (I-IV) calculated during the years 2021-2024 at Turenki WWTP. Detected values exceeding permission limits are highlighted with red colour.

	Concentration [mg/L]			Reduction rate %			
	COD_{Cr}	$BOD_{7\text{-}ATU}$	TP	COD_{Cr}	$BOD_{7\text{-}ATU}$	TP	
Perm.Limit	≤90	≤15	≤0,4	≥85	≥95	≥95	PERIOID
2021	61	13	0,77	91,0	96,0	90,0	I
	51,0	11,0	0,47	93,0	97,0	95,0	II
	65,0	11,0	0,98	95,0	98,0	94,0	III
	110,0	25,0	1,50	90,0	95,0	88,0	IV
2022	48,0	9,1	0,52	95,0	98,0	94,0	I
	100,0	34,0	1,00	83,0	90,0	81,0	II
	33,0	4,5	0,16	97,0	99,2	98,0	III
	33,0	3,3	0,18	97,0	99,3	98,0	IV
2023	51,0	13,0	0,31	94,0	97,0	96,0	I
	35,0	4,7	0,14	97,0	99,0	98,0	II
	34,0	6,1	0,27	96,0	98,6	96,0	III
	26,0	4,3	0,14	96,0	98,8	98,0	IV
2024	71,0	26,0	0,54	91,0	94,0	91,0	I
	51,0	18,0	0,35	93,0	95,0	94,0	II
	35,0	5,1	0,45	96,0	99,0	94,0	III
	26,0	4,3	0,14	96,0	98,8	98,0	IV

Other problems in WWTP have been in the spring 2022 period II, when during aeration tanks maintenance tanks were emptied and cleaned one by one, nitrification and denitrification was reduced to the due loss of activated sludge and anoxic conditions turning to oxic during the work. Situation was normalized after the work, but the bacteria responsible for nitrification/denitrification growth to normal took almost three months. Also, 2021 problems in period IV were related to maintenance, when samples were taken right after aeration line clean-up and in maintenance startup solids residue escaped to effluent causing high concentrations in samples.

Below Table 7. shows the similar limit exceeding's in Government Decree limits during maintenance works in spring 2022 as described above and in the year 2021 exceeding that was due to the sample collected on 21.7.2021 where was for some reason extremely high influent concentration in COD, BOD, TN, TP, SS and FOG that resulted to SS concentration in effluent exceeding.

Table 7. Government decree on Urban Wastewater based limits for COD_{Cr}, $BOD_{7\text{-}ATU}$, TSS and TP and maximum concentrations and minimum reduction % in Turenki WWTP effluent in years 2021-2024. In red colour is highlighted the Government decree exceeding values. Above limits are for single sample (s.s.) and below for annual average (a.a.)

s.s.	≤125	≤30	≤35		≥75	≥70	≥90	
a.a.				≤2,0				≥80
	COD_{Cr}, mg/L	$BOD_{7\text{-}ATU}$, mg/L	TSS mg/L	TP, mg/L	COD_{Cr}, %	$BOD_{7\text{-}ATU}$, %	TSS, %	TP, %
2024	47	10	26,00	0,76	89	93	91	96
2023	37	6	15,00	0,38	95	99	97	98
2022	170	50	140,00	2,10	75	88	48	93
2021	96	18	76,00	1,60	98	99	99	99

4.5 Overview of problems in the current pre-flotation situation

All thought majority of the environmental permit limits are reached in Turenki WWTP, there have also been some difficulties to reach all environmental permit limits in some years. Reasons for permission limits exceedings have been due to solid residues in the discharged effluent that has been carrying also phosphorus pound to solids and in few cases also BOD limits have been exceeded for same reason. There have been exceedances of permitted values both in concentrations and in efficiencies.

Limit exceeding's has been in process conditions when during slightly elevated influent flow solids has not been settled properly in the separation process and some solids have run off in effluent flow and thus decreasing treatment results. Other major reason is that during bigger floods operators have had to rely on bypassing in order to stop sludge running off from clarifiers, even though hydraulic capacity limits have not been met. Examples of slightly elevated influent flow coming to WWTP are in 27.1.2021 and 21.7.2021 when influent flow was slightly elevated 4 803 m^3/d and 4 930 m^3/d, but not even close to designed maximum flow 12 200 m^3/d and still solids concentration in effluent was high resulting permit limits exceeding due to phosphorus bounded to solids. In the year 2024 period 3 exceeding's in TP concentration and treatment efficiency were caused by the sampling period during 13-14.8.2025 when storm water effected to process to that solids run off clarifiers during sample collection and ended up in effluent sample. Some cases like in 16.2.2022 sample solids concentration was elevated thus resulting exceeding permission

limit in TP level due to phosphorus bound to solid matter, even though water flow was during the 24 hours sample collection only 3 627 m3/d. In KVVY year reports 2021-2024 (KVVY Tutkimus Oy 2022-2025) have been reported that the treatment process has had difficulties because of the greasy sludge accumulation in the surface of aeration tanks and settlers. Permission limits have been exceeded in years 2021, 2022 and 2024 due to elevated solids concentration in effluent because phosphorus bound to solids increases the TP concentration in effluent. Also, in 2023 there were elevated concentrations for the same reasons, but permit limits were met thought. (KVVY Tutkimus Oy 2022-2025)

4.5.1 Bypass waters overview

Number of days when operator has had to rely on bypassing could be significantly reduced if all hydraulic capacity could be fully in use. Below in Figure 4. is presented the amount of actual bypassing days in the years 2021-2024 and compared to amount of days when designed hydraulic capacity 8 500 m^3/d or maximum hydraulic capacity 12 200 m^3/d was exceeded in WWTP influent flow. Days are calculated from WWTP operational data.

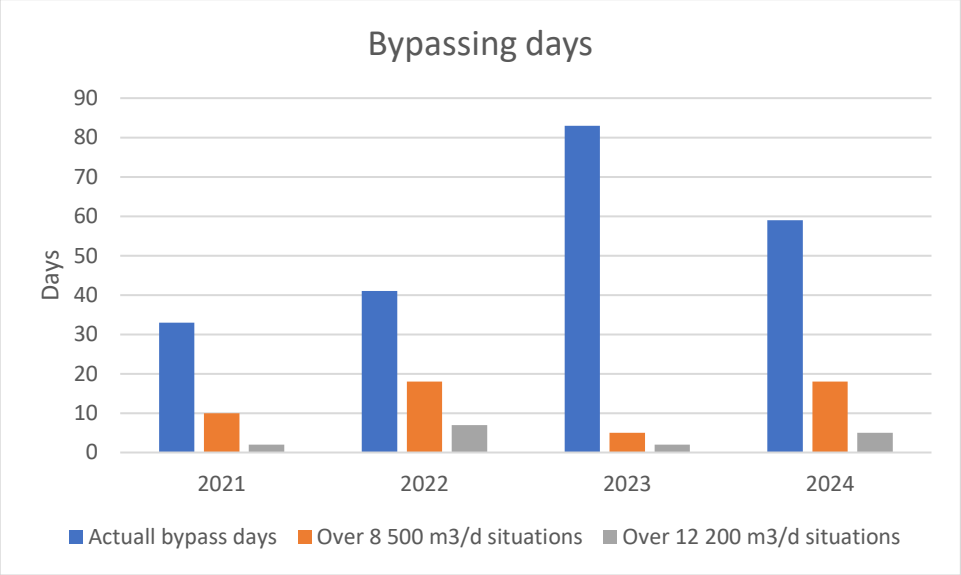

Figure 4. Number of bypassing days in Turenki WWTP during the years 2021-2024

In the year 2021 between January 1st and July 1st there were 33 days when operator had to resort to bypass water to protect the activated sludge in process. This was for the elevated influent flow due to infiltration flood, but only in 10 days flow were greater than settling design value 8 500 m^3/d and only 2 days flow was greater than maximum flow 12 200 m^3/d.

In the year 2022 between January 1st and May 13th there were 41 days when operator had to resort to bypass water to protect the activated sludge in process. This was for the elevated influent flow due to infiltration flood. At 18 days of this flow was greater than settling design value 8 500 m^3/d and only in 7 days greater than maximum settling flow value 12 200 $m^{3/}$d. In the year 2022 the constructed basin for bypass water was already in use and therefore some of the bypass flow was returned to the treatment process.

In the year 2023 constructed basin was fully at use so bypassed water has been discharged there and attempted to be returned to treatment process. During January 1st 2023 and November 14th 2023 there were 83 days when water was bypassed, mostly small amounts to basin. Only 5 days of these influent flow exceeded the settling design value 8 500m^3/d and only 2 days exceeded the maximum flow 12 200 m^3/d.

In the year 2024 there were 59 days when bypass water was discharged to river or to constructed basin. Like in the year 2023 some of the water discharged to basin was pumped back to treatment process. From these 59 days 18 days exceeded the design settling volume 8 500 m^3 and 5 days flow was greater than the 12 200 m^3/d maximum flow.

From Table 8. below we can see the total bypassed pre-treated wastewater amounts and how much was yearly bypassed in floods over design settling flow 8 500 m^3/d and over maximum settling flow 12 200 m^3/d. Here we can see that 53% of bypass could be avoided if the designed flow for settler could be in use fully and 88% if could be achieved total maximum capacity 12 200 m^3/d without need for bypass.

Table 8. The amount of water bypassed [m^3/a] during the years 2021-2024: total amount, only the water amount exceeding the 8 500 m^3/d flow and water amount exceeding 12 200 m^3/d situations.

	2021	2022	2023	2024	total
total bypass [m^3/a]	53 302	119 742	64 934	88 559	326 537
over 8 500 m^3/d [m^3/a]	23 879	69 720	7 978	50 347	151 924
bypass reduction %	55 %	42 %	88 %	43 %	53 %
over 12 200 m^3/d [m^3/a]	8 256	22 575	762	6 657	38 250
bypass reduction %	85 %	81 %	99 %	92 %	88 %

Appendix 1. presents the effects to treatment efficiency and discharged water concentration if bypass water flows could be reduced accordingly. From there we can see that in the year

2024, permission concentration limits and treatment efficiencies were exceeded in period 1. and 2. due to bypass water reducing treatment efficiency leading to $BOD_{7\text{-}ATU}$ and TP concentration elevations over permit limits and reduced treatment efficiencies in period 1. and $BOD_{7\text{-}ATU}$ concentration limit exceeding and TP efficiency reduction in period 2. All permission limits in period 2. and period 1. TP concentration limits could have been fully filled if designed hydraulic capacity 8 500 m^3/d had been in use and also in period 1. $BOD_{7\text{-}ATU}$ concentration and TP treatment efficiency limit would have met the permission limit if maximum hydraulic capacity 12 200m^3/d had been fully in use. Similar results were observed in the bypass water flow analysis for other years as well.

To control and decrease the storm water and snow melting floods causing leakage waters in sewer investments to sewer network renovation and potential infiltration sites research is done every year. According to network infiltration coefficient Janakkala Vesi sewer network is not very leaky (KVVY Tutkimus Oy 2024). Despite of that fact, flood waters have caused sludge over flow situations in WWTP and to protect the valuable sludge not to run out of the WWTP with discharge effluent operators have had to resort to bypasses. Bypass situations have been necessary even though flow hasn't met the WWTP designed hydraulic capacity flow 8 500 m^3/d. The cause of the easily escaping sludge has been considered to be a higher FOG content compared to normal municipal wastewater, which decreases the sludge's settling ability in clarifiers that rely on a gravity-based sedimentation separation process. (Chao et al. 1981) FOG in activated sludge along with the Denitrification-Nitrification process provides M. parvicella bacteria good environment to grow the lipids in FOG being the carbon source for M.parvicella and the advantage that it can survive in anoxic conditions. Apart the fact that M.parvicella bacteria also degrades LCFA's caused by the FOG it also contributes to the poor settling properties and sludge/foam accumulation in aeration surface.

4.6 Designing DAF as a new pre-treatment process

Dairy industry in Turenki has not been able to build sufficient pre-treatment in their sites due to lack of space and therefore, it was agreed to investigate the implementation of a pre-treatment for the FOG removal process in Turenki WWTP. Authority official supervising the environmental permit also ordered Turenki WWTP to build the pre-treatment process to avoid the limit exceeding's. For that reason, and because the dairy industry wastewater has been discharged through the public sewer, it will be mixed into the municipal wastewater before pre-treatment of influent at WWTP

Dissolved air flotation (DAF) was selected as pre-treatment process because of its maturity and well-known performance in separation of light substances. DAF separation capability of processed FOG separation was tested successfully in pilot scale flotation unit first. There were expectations that emulsified oils will not be separated from wastewater without biological treatment and therefore flotation pilot was set in many process phases to found the most suitable.

Flotation was tested in pilot scale to be sufficient to remove FOG from the Janakkala dairy industry sewage. Pilot test was done in a small flotation unit which surface area was 3.7 m². Tested flow rates were 2, 5 and 10 m³/h leading to surface loads of 0.54 - 2.7 m/h. Pilot test was done in many process phases and the most suitable was found to be the incoming wastewater before any treatment, but highest concentration of dairy sewage. This found phase is sewer well in Easter sewer pipe in WWTP site, but before the WWTP process, that carries all the wastewater from dairies and also Turenki municipality wastewater to WWTP. In pilot test at this point ferric sulphate as precipitation chemical was not added, but it was tested earlier that SS removal could rise to 99% when the precipitation chemical is used. Results from the piloting are presented in Table 9 below.

Table 9. Results from pilot scale experiment presented as reduction % for BOD, TP, TN, TSS and FOG in different surface loads and polymer concentrations.

Surface load [m/h]	Polymer g/m³	$BOD_{7\text{-}ATU}$	TP	TN	TSS	FOG
0,54	6	57 %	56 %	57 %	70 %	63 %
1,35	2	40 %	31 %	31 %	64 %	50 %
2,7	1,2	29 %	20 %	6 %	49 %	39 %

From pilot test results we can see, that flotation successfully separates FOG from raw wastewater. Having that knowledge and the fact that flotation was planned to separate existing dairy industry's FOG from wastewater, the process was determined to build so that influent to flotation is drawn from Easter sewer pipe where the industry effluent is discharged to WWTP. The selected Easter sewer pipe flow is approximately 2 200 $m^{3/}$d from which 1 600 m^3/d is normal municipal wastewater and 800 m^3/d is from the dairy industry. Eastern sewer pipe wastewater contains also 60% of COD_{Cr}, 70% of $BOD_{7\text{-}ATU}$ and 90% of FOG load to Turenki WWTP. The selected solution reduces the process size and investment and operation costs because all influent streams to WWTP are not forced to treat in flotation which would have significantly increased the total flow volume and equipment size. Measured sewage flow and loads from east sewer pipe are presented in Table 10.

Table 10. Wastewater flow and loads in eastern sewer pipe.

Parameter	Unit	Eastern sewer pipe
Mean Flow Q_{mean}	m^3/d	2 226
$BOD_{7\text{-}ATU}$	kg/d	1 378
COD_{Cr}	kg/d	2 737
TP	kg/d	25
TK	kg/d	130
TSS	kg/d	1 305
FOG	kg/d	229

Based on the pilot experiment the flotation process minimum removal efficiencies are assessed. Assessment included the idea that BOD cannot be reduced too much so that the biological treatment won't be compromised. Designed removal efficiencies are presented in Table 11.

Table 11. Designed minimum reduction % for $BOD_{7\text{-}ATU}$, TSS and FOG.

	Minimum reduction [%]
$BOD_{7\text{-}ATU}$	50
TSS	50
FOG	60

Based on information above about the wastewater flow and load in Eastern sewer pipe, flotation process was designed for the following parameters.

- $q_{average}$ 170 m^3/h (2 500 m^3/d)
- q_{max} 340 m^3/h
- $BOD_{7\text{-}ATU}$ 1 500 kg/d
- TSS 1 400 kg/d
- FOG 250 kg/d

DAF process is aimed remove FOG, so that it wouldn't cause problems in WWTP and also to equalize BOD loads. But also, must be in concern the appropriate separation so that there is not separated too much good nutrients and carbon so that the very good biological process in Turenki WWTP is not compromised. In this selected option to place flotation to Eastern sewer pipe and using in Table 11 given removal efficiencies BOD:N ratio is evaluated to be 100:20. This would probably affect negatively to nitrogen reductions in the DN process, considering that average municipal wastewater BOD:N ratio is 100:17 and in Turenki WWTP it has been in more DN process favourable 100:12. Optimal BOD:N ratio for efficient biological treatment would be 100:5. Too much nitrogen to BOD ratio causes problems in nutrient removal. Some effects are also expected to microbial composition in activated sludge microbiology due to the changes in influent complex to biological process. Also, if too much other solids are separated than FOG there may be problem with high amounts of greasy sludge that has to be somehow disposed. P&I diagram below presents the flotation situation in Turenki WWTP.

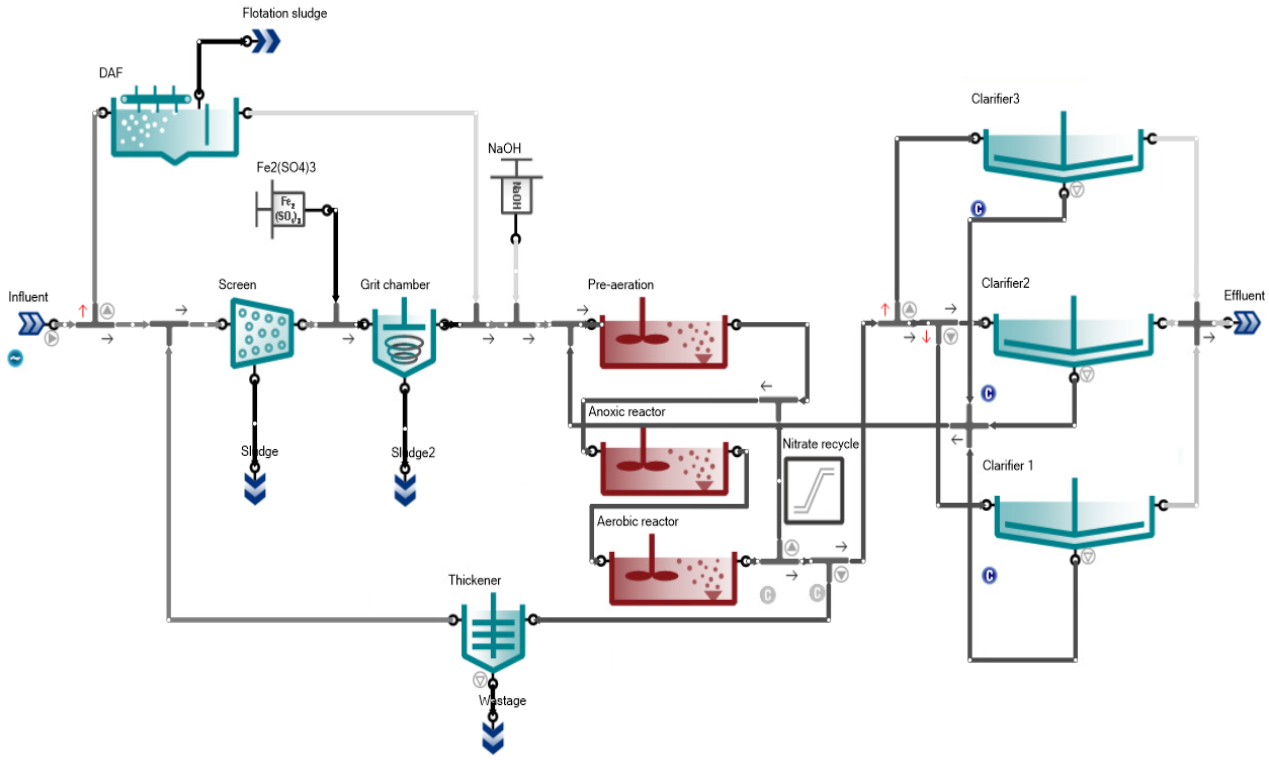

Figure 5. PFD diagram of Turenki WWTP with flotation unit installed as pre-treatment to dairy wastewaters.

4.7 Selected DAF unit, Krofta Multifloat

Influent to DAF is pre-treated in combi unit including screening, sand and grit removal and grease trap. Actual DAF process installed to Turenki WWTP is manufactured by Krofta company. Unit model is Multifloat dissolved air flotation (Krofta 2023) and it is containing 2 units. Process flow is170 m^3/h per unit. Multifloat design includes flotation enhancement cells (FECs), U-Elements seen in Figure 4. that allows evenly disturbed flow across the unit. FECs also reduce hydraulic head over the particles allowing more efficient rising rate to flotated material. Retention time is minimum 3-4 minutes. Clarified water is drawn back down between the FECs to a collection area below the bottom of the FECs. The clarified water flows up over a divider plate at the top of the tank and continues into a clearwater well phase shown in figure 6. from where it is then discharged by gravity out of the unit. 15-50 % of the flow is used as recycle flow back to the air dissolving tube (ADT) where it is saturated by air and then mixed back to flotation influent. Used recycle water pressure is 5.4

bar. Recycle maximum capacity is 60 m^3/h and air consumption in process is 1-2 m^3/h at 6,2 bar pressure. Floated materials are collected at the top of the FECs and directed towards the sludge collection rake assembly. The rake pushes the floated material over a simple beach design and deposits the material into a small sludge collection trough that is discharged by gravity. Heavier particles settle to the bottom of the unit and are removed from there.

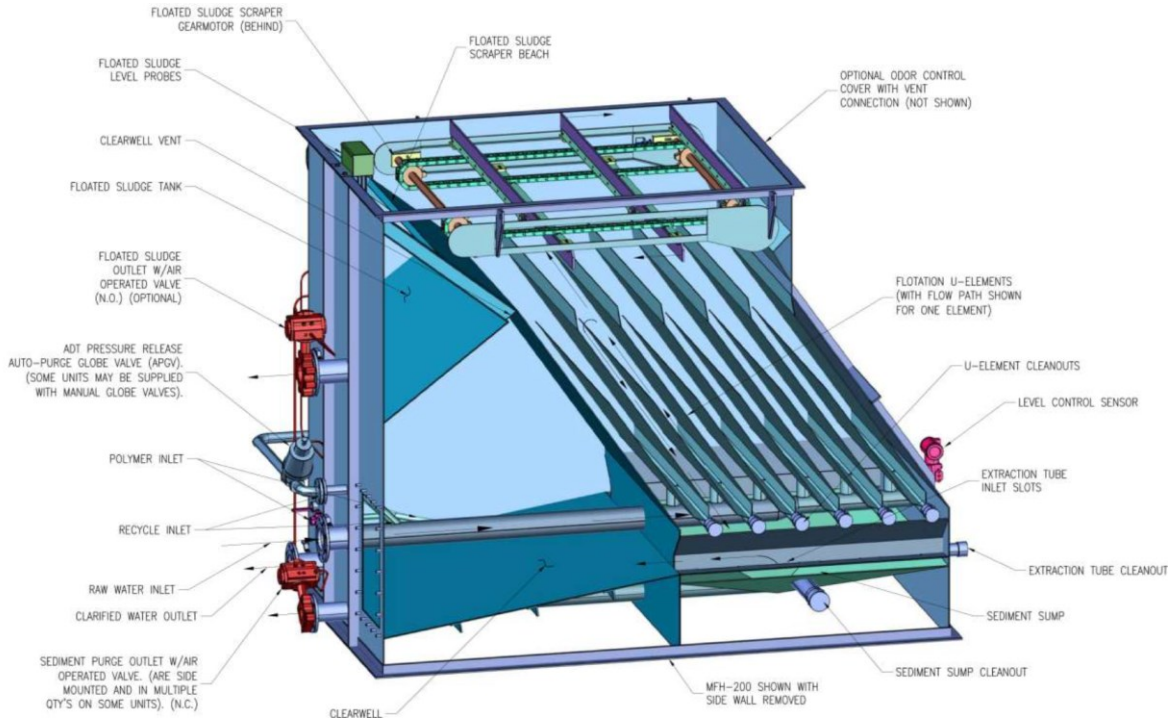

Figure 6. Internal view of Krofta Multifloat (Krofta, 2023)

Coagulation and flocculation with gentle mixing contact tanks are installed before the DAF unit. Coagulation chemical may be poly aluminium chloride of ferric sulphate. Cationic polymer is used for flocculation chemical as it suits for both typically negative charged municipal wastewater and dairy wastewater. Sodium hydroxide (NaOH) and sulfuric acid H_2SO_4 are used for pH adjustment.

5 Practical studies

Objective of the practical study was to learn how the installed Flotation unit operates in Turenki WWTP. Aim was to take sufficient number of samples during long enough period from flotation influent and effluent to determine how good separation efficiency can be achieved with the flotation. The purpose was then to study what kind of impact the flotation has to Turenki WWTP biological treatment when biological stage influent chances due flotation removing FOG, BOD and TSS. To find out the changes in the biological stage influent, also the WWTP influent that is not pre-treated in flotation must be analysed. Below is defined terms for different influents and effluent in Turenki WWTP.

WWTP influent is raw wastewater coming to WWTP that is not treated in flotation

Flotation influent is raw wastewater incoming to flotation unit

Flotation effluent is wastewater exiting flotation process

Biological influent is flotation effluent + WWTP influent

Total WWTP influent is flotation influent + WWTP influent

WWTP effluent is biologically treated water discharged to wetland

Flotation unit has been running in Turenki WWTP since January 2025 and first samples have been taken from flotation effluent in January 23th 2025.

5.1 Methods and equipment

Samples from flotation influent, WWTP influent, flotation effluent and WWTP effluent were taken as 24-hour composite samples with five automatic Elmacron VA/V3 samplers that were set to throw water sample every 10 minutes from water stream and discharges it to 30 L plastic container. Below in Figure 7. is flotation influent automatic sampler.

Figure 7. Flotation influent sampler Elmacron VA/V3.

Samples from flotation effluent were collected at the same time as the samples based on environmental permit were taken. FOG analysis were done from both, flotation influent sample and WWTP influent sample so that FOG reductions could be calculated.

After 24 hours sample collection samples were delivered to KVVY Tutkimus Oy laboratorio in Visamäki Hämeenlinna. Samples were analysed in KVVY Tutkimus Oy certified and accredited laboratory according to standards presented in chapter 2.4.

Activated sludge in biological treatment was microscoped in order to study how the flotation effected on activated sludge. Used microscope was Turenki WWTP microscope Euromex iScope attached to CMEX-10 Pro camera. Software used was Imagefocus Alpha. Objectives 10x, 20x, 40, 60x and 100x-oil immersion were used. Darkfield microscopy and phase contrast microscopy were included observation methods.

5.1.1 Chemical used in Turenki WWTP flotation process

Polyaluminum chloride (PAC) was used as coagulation chemical at the beginning and in May 5th Ferric sulphate ($Fe_2(SO_4)_3$) was changed to coagulation chemical. PAC was used in the beginning because flotation process supplier guarantees reductions requirements given

when PAC is used in process. However, the ferric sulphate should also be suitable coagulant and as seen in list below according to literature the flotation influent that average pH is 7.4 in Turenki WWPT should be good for ferric coagulant.

Optimal pH-values given in the literature for ferric coagulants in water treatment:

- Ferric sulphate pH 5-9 (Sulistyo et al. 2012)
- Ferric chloride pH 7.5-8 (Gurup et al. 2019)
- Ferric chloride pH 7-8 (Song et al. 2012)
- Ferric chloride pH 7-9 (Liang et al. 2009)
- Ferric sulphate pH 6-7 for BOD and 7-9 for TSS (Agulair et al. 2005)

It was also suggested that both charge neutralization and co-precipitation are the predominant coagulation mechanism when pH is above neutral using ferric chloride and co-precipitation when pH is close to 6. (Liang et al. 2009) In flotation process has however been prepared to adjust influent pH by sulfuric acid or caustic dosing. Used coagulation concentrations are expressed in chapter 6.3 Table14.

Flocculation chemical used in flotation process was long chain cationic polymer product name Superflock. To study if there is more suitable polymer on market, a jar test was conducted. In jar test flotation influent water was mixed with three different Zetag polymers 8125, 8165 and 8147. In jar test was discovered that the polymer in use wasn't the most suitable. Flotation influent in the jar where was added a the Superflock polymer in use was clearly more turbid and flocs that form did not float. Jar test results are shown in Figure 8 below. In the Figure 8 left is the Superflock polymer in use and number 8125, 8165 and 8147 are tested Zetag polymers. From the Figure 8. can be clearly seen that the polymer in use doesn't flocculate very well, the water in the left jar is very turbid and there aren't any flocs in surface and few in bottom of the jar. The best result is show in jar 8147 where water is clearer meaning the turbidity has decreased when solid particles are flocculated to bigger flocs and most of them in this case rise to surface and some settled to bottom of jar. Based on the jar test it was suggested to use polymer 8147 in full scale test as flocculation polymer in flotation process. However, the better performing polymer in jar test was not available during the DAF process tests so the DAF test were done with Superflock polymer.

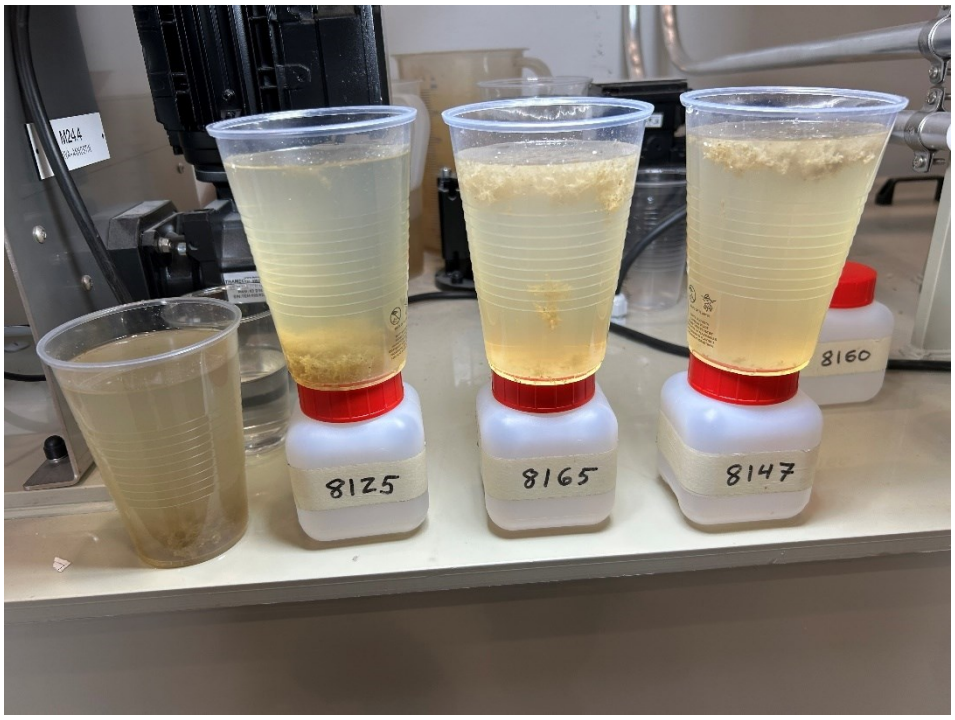

Figure 8. Polymer Jar tests for flotation influent. Left is the used polymer and number 8125, 8165 and 8147 are tested polymers.

Polymer dosage was at first 1-1.8 g/m^3, but in April 2025 it was increased to 3 g/m^3 in order to increase the reductions. Flocculant i.e. polymer dosages are presented in result Table 14. below.

Sulfuric acid was used to decrease influent pH during June to enhance coagulation, because even though good FOG removal results were obtained already, BOD reduction struggled to meet the guarantee reduction requirement. Flotation supplier conducted the sulfuric acid test with help of the WWTP operators. Lowering the pH wasn't ideal, because the pH must be adjusted up again with base after flotation so that it wound negatively effect on biological process. For that reason, sulfuric acid test was done only for short 3.5 hour period and only for one of two flotation lines. No laboratory test was done during the sulphuric acid test. Effect were seen from online TSS measurements. Effluents TTS was lower in the line where sulfuric acid was used. In Figure 9 is presented flotation effluent TSS (mg/L) from line 1 and 2. Line 2 pH was adjusted closer to pH 5 during the test. From figure can be seen that effluents TSS concentrations separate as Line 1 concentration climes to near 500 mg/L and Line 2 stays at 300 mg/L. That result suggests that lower pH increases separation efficiency.

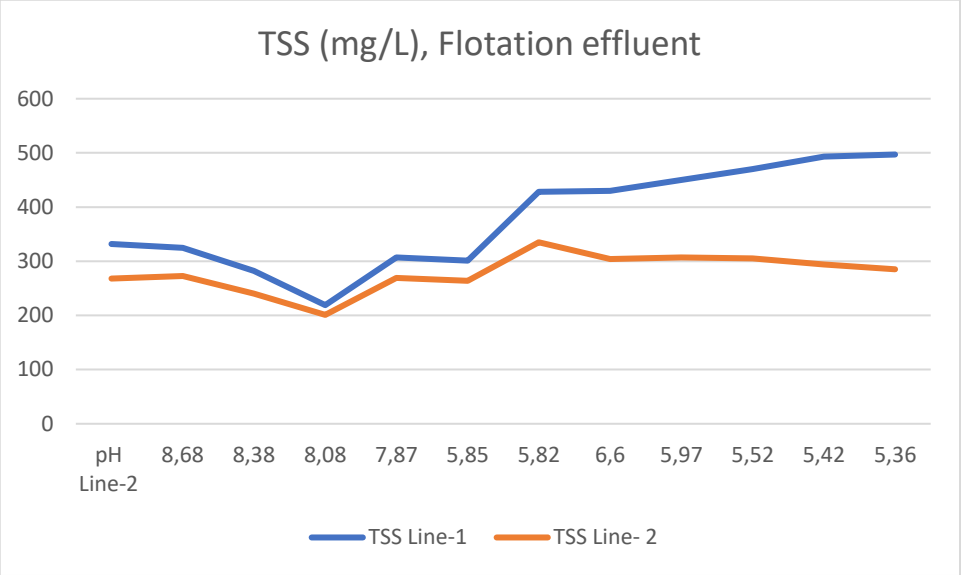

Figure 9. TSS concentrations of flotation effluents from line 1 and 2; pH values from line 2.

6 Results and discussion

In order to study the flotation separation efficiency and effects to WWTP process, samples from flotation influent, flotation effluent, WWTP influent and WWTP effluent were collected and analysed from January 23th 2025 to June 11th 2025. Total 14 results of BOD_{7ATU}, COD_{cr}, TSS, TN, TP and FOG concentrations were obtained and results based on these analyses is presented in this chapter.

6.1 Flotation influent

Flotation was installed to pre-treat dairy wastewaters in Turenki WWTP to which influent is drawn from eastern sever pipe that contains sewage mixed with municipal wastewater and dairy wastewater. Dairy wastewater quality varies a lot by the hour and the quality influences greatly to flotation performance. The variation makes it harder to study the impacts of chemical dosing to separation efficiency. pH and TSS values were monitored by online monitoring and from fourteen 24-hour composite samples. From composite samples BOD_{7ATU}, COD_{cr}, TSS, TN, TP and FOG concentrations were analysed in a certified and accredited laboratory. Results of flotation influent composite samples are presented in Table 12. Samples were taken during January and June 2025.

Table 12. Influent flow to Flotation unit. 24-hour composite samples 1-14 results of BOD_{7ATU}, COD_{cr}, TSS, TN, TP and FOG concentrations, pH and flows of incoming wastewater to flotation during January and June 2025.

Sample nro:	Q_{in} m_3/d	COD_{Crin} mg/L	BOD_{7ATUin} mg/L	TP_{in} mg/L	TN_{in} mg/L	TSS mg/L	FOG_{in} mg/L	pH_{in}
1	1690	1200	640	7.6	51	380	56	7
2	1690	1200	820	6.7	51	440	74	7.2
3	1690	1200	600	6.9	33	390	-	-
4	1690	1100	550	7.9	55	390	58	7.5
5	845	1200	600	7.1	51	510	-	-
6	1690	1200	600	9.3	49	480	140	7.2
7	1381	1200	780	9.8	61	460	50	-
8	2070	1100	500	7.8	54	260	45	7.6
9	2048	870	500	6	39	360	47	7.1
10	2039	1100	420	6.1	42	310	54	8.1
11	1299	1200	630	7.7	48	380	61	7.1
12	2053	1100	630	7.5	47	360	60	7.4
13	2021	1200	650	8.5	58	400	60	7.5
14	1959	1300	620	9	54	410	66	7.7
Mean	1726	1155	610	8	50	395	64	7.4

6.2 Flotation effluent

Flotation-treated wastewater i.e. flotation effluent was studied by online monitoring pH and TSS and fourteen 24-hour composite samples. From composite samples BOD_{7ATU}, COD_{cr}, TSS, TN, TP and FOG concentrations were analysed in a certified and accredited laboratory. Results of flotation effluent composite samples are presented in Table 13. Samples were taken during January and June 2025. Flotation unit has two flotation tanks i.e. two lines. Effluent samples were collected from each line and studied separately. The differences between the two lines were minor and the results are given as mean values between the two lines.

Table 13. Effluent flow from Flotation unit. 24-hour composite samples 1-14 results of BOD_{7ATU}, COD_{cr}, TSS, TN, TP and FOG concentrations, pH and flows of flotation-treated wastewater during January and June.2025.

Sample Nro	Q_{out} m_3/d	COD_{Crout} mg/L	$BOD_{7ATUout}$ mg/L	TP_{out} mg/L	TN_{out} mg/L	TSS mg/L	FOG_{out} mg/L	pH_{out}
1	1690	870	525	6.2	48	205	24	7.0
2	1690	825	500	5.6	45	265	45	7.3
3	1690	810	445	4.2	36	235	35	7.3
4	1690	720	405	5.0	44	235	36	7.3
5	845	750	420	4.7	42	280	39	7.3
6	1690	710	390	6.3	45	245	29	7.3
7	1381	815	490	6.6	53	220	16	
8	2070	705	395	5.5	49	235	14	7.4
9	2048	520	345	4.3	39	215	18	7.4
10	2039	680	285	4.6	39	185	27	7.7
11	1299	755	435	5.7	45	230	25	7.2
12	2053	680	370	4.9	42	195	23	7.1
13	2021	740	405	5.9	53	245	19	7.3
14	1959	800	385	6.1	48	225	33	7.2
Mean	1726	741	414	5.4	45	230	27	7.3

6.3 Flotation reductions

Reduction rates for BOD_{7ATU}, COD_{cr}, TSS, TN, TP and FOG can be calculated from the results shown in chapter 6.1 Table 12 and 6.2 Table 13. FOG determination was not done from flotation influent samples samples 3 and 5 and for this reason FOG reductions of samples 3 and 5 were not calculated. Used coagulation chemical type and coagulation and flocculation chemical dosage are presented in Table 14 with the reduction percentages of BOD_{7ATU}, COD_{cr}, TSS, TN, TP and FOG.

Table 14. BOD_{7ATU}, COD_{cr}, TSS, TN, TP and FOG reduction in used coagulation chemical types and doses and polymer doses.

Sample	Coagulant		Polymer	COD_{Cr}	BOD_{7ATU}	TP	TN	TSS	FOG
Nro	g/m^3		g/m^3	red %	red %	red %	red %	red %	red %
1	120	PAC	1	28	18	19	7	46	57
2	120	PAC	1	31	39	17	12	40	39
3	120	PAC	1.5	33	26	39	-8	40	
4	120	PAC	1.5	35	26	37	20	40	38
5	120	PAC	1.8	38	30	34	18	45	
6	120	PAC	3	41	35	32	9	49	79
7	120	PAC	3	32	37	33	14	52	69
8	120	PAC	3	36	21	29	9	10	70
9	120	PAC	3	40	31	28	1	40	63
10	120	PAC	3	38	32	25	8	40	51
11	120	$Fe_2(SO_4)_3$	3	37	31	26	7	39	59
12	180	$Fe_2(SO_4)_3$	3	38	41	35	12	46	63
13	180	$Fe_2(SO_4)_3$	3	38	38	31	9	39	68
14	180	$Fe_2(SO_4)_3$	3	38	38	33	11	45	50
Mean				36	32	30	9	41	59

It can be seen that dosage 180g/m^3 of ferric sulphate and 3.0 g/m^3 of polymer shows the best results in removing $BOD_{7\text{-}ATU}$ at 39% reduction in average, when PAC dosage 120 g/m^3 with same polymer dosage 3.0 g/m^3 gave 31% average reduction. $BOD_{7\text{-}ATU}$ reductions are presented in Figure 10. For FOG PAC 120 g/m^3 and 3.0 g/m^3 polymer dosage gave in average 66% reduction and 180 g/m^3 gave only 60% average reduction. FOG reduction percentages are presented in Figure 11. In case of TSS in sample number 8 influent TSS was only 260 mg/L and effluent 235 mg/L in so the reduction percentage was only 10%. COD, BOD, TP, TN and FOG values were in normal range in the same sample, but the influent TSS concentration in sample 8 differs a lot from the mean sample concentration 405 mg/L with

standard deviation 52 mg/L. There might have been some problem in the influent TSS determination in laboratory or the influent TSS was analysed from the effluent sample by mistake. For that reason, the result of the sample 8 was left out of the closer examination. In Figure 12. TSS reduction percentages calculation does not include sample 8 results, thus best TSS reduction 45% was achieved with PAC 120 g/m^3 and polymer 3.0 g/m^3.

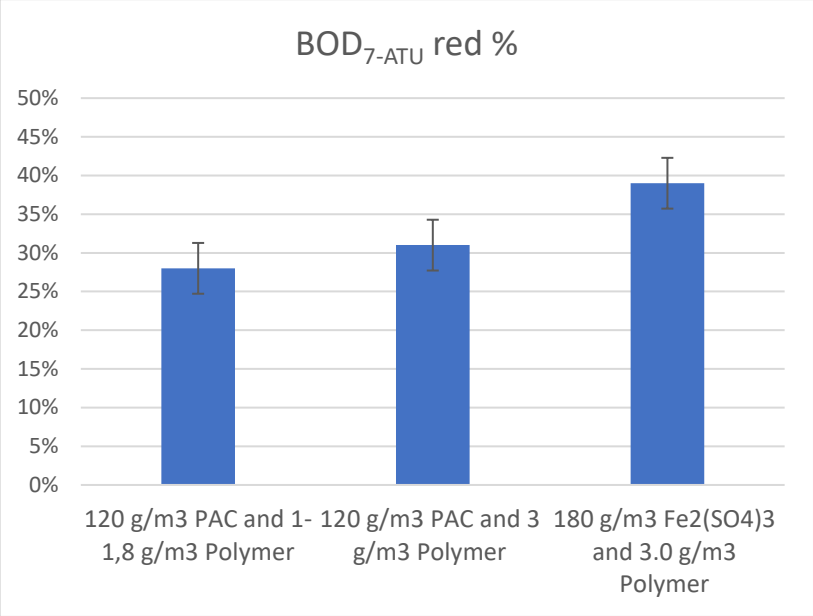

Figure 10. The mean reductions of $BOD_{7\text{-}ATU}$ in polymer dosage 1-1.8 g/m^3 and 120 g/m^3 PAC, polymer dosage 3.0 g/m^3 and 120 g/m^3 PAC, polymer dosage 3.0 g/m^3 and 180 g/m^3 of ferric sulphate.

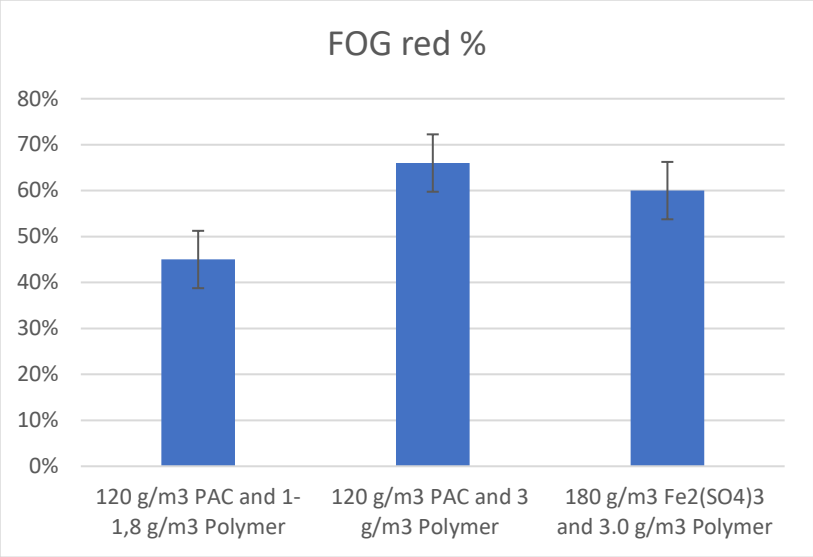

Figure 11. The mean reductions of FOG in polymer dosage 1-1.8 g/m^3 and 120 g/m^3 PAC, polymer dosage 3.0 g/m^3 and 120 g/m^3 PAC, polymer dosage 3.0 g/m^3 and 180 g/m^3 of ferric sulphate.

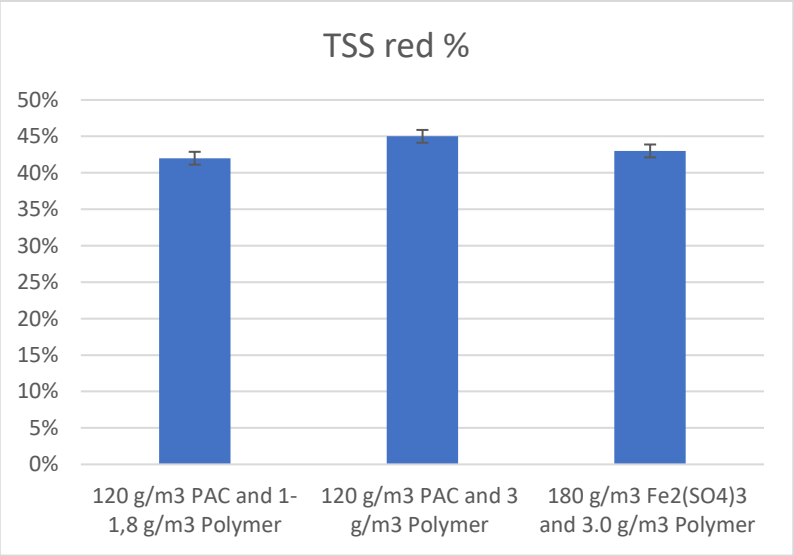

Figure 12. The mean reductions of TSS in polymer dosage 1-1.8 g/m^3 and 120 g/m^3 PAC, polymer dosage 3.0 g/m^3 and 120 g/m^3 PAC, polymer dosage 3.0 g/m^3 and 180 g/m^3 of ferric sulphate.

According to the results ferric sulphate 180 g/m^3 dosage and polymer 3.0 g/m^3 have given the best results for $BOD_{7\text{-}ATU}$ reduction and PAC 120 g/m^3 and polymer 3.0 g/m^3 gave best result for FOG separation. TSS reduction was little better with PAC than Ferric sulphate, but the difference was very small.

6.4 Total influent to biological treatment

The flotation separates mainly COD_{Cr}, $BOD_{7\text{-}ATU}$, TSS and FOG. In Table 15. there is presented flow-weighted concentration calculated from flotation-treated, i.e. flotation effluent water and WWTP influent water entering the treatment plant that isn't treated in flotation process. Concentrations are analysed from 24-hour composite samples by certified and accredited laboratory.

Table 15. Biological influent. BOD_{7ATU}, COD_{cr}, TSS, TN, TP and FOG concentrations, pH and flow m^3/d, when dairy wastewater containing part of influent (flotation influent) is threated by flotation before biological stage.

Sample Nro	Q_{in} m^3/d	COD_{Crin} mg/l	BOD_{7ATUin} mg/l	TP_{in} mg/l	TN_{in} mg/l	TSS mg/l	FOG_{in} mg/l	pH_{in}
2	4120	987	406	11	57	616	39	7,3
3	4939	659	284	7	23	337	34	7,3
5	4520	677	298	8	51	369	35	7,3
7	3982	897	385	13	63	547	28	7,3
9	4011	525	269	5	36	276	26	7,3
12	3676	910	379	11	61	537	21	7,3
14	3127	949	361	11	59	485	31	7,3
Mean	4054	800	340	9	50	452	31	7,3

From Table 15. can also be calculated BOD_{7ATU}, COD_{cr}, TSS, TN, TP and FOG loads kg/d in biological influent and compare them to previous loads presented in chapter 4.3.1. Table 2. before flotation was in use.

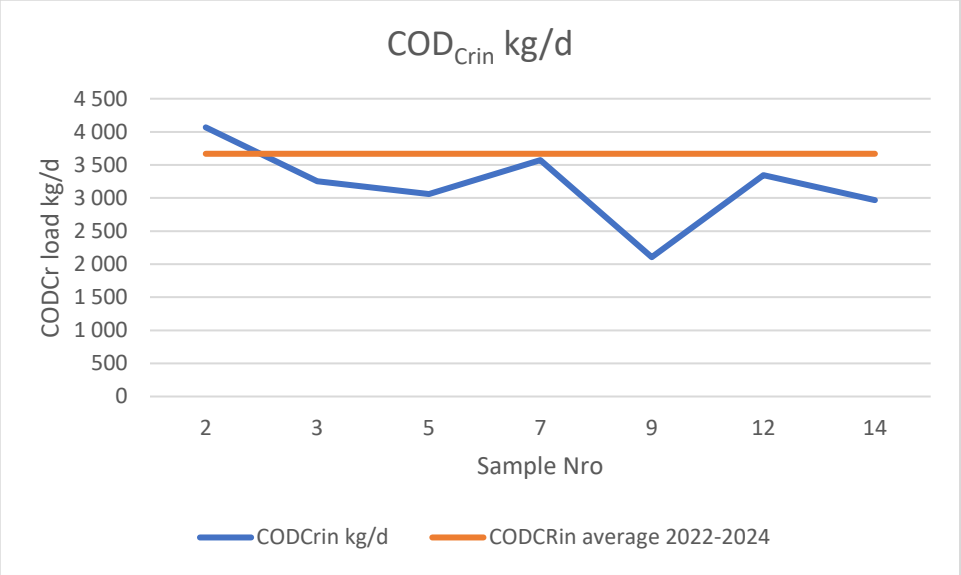

Figure 13. COD_{Cr} load kg/d to biological stage during January-June 2025 and average load of 3 668 kg/d in years 2022-2024.

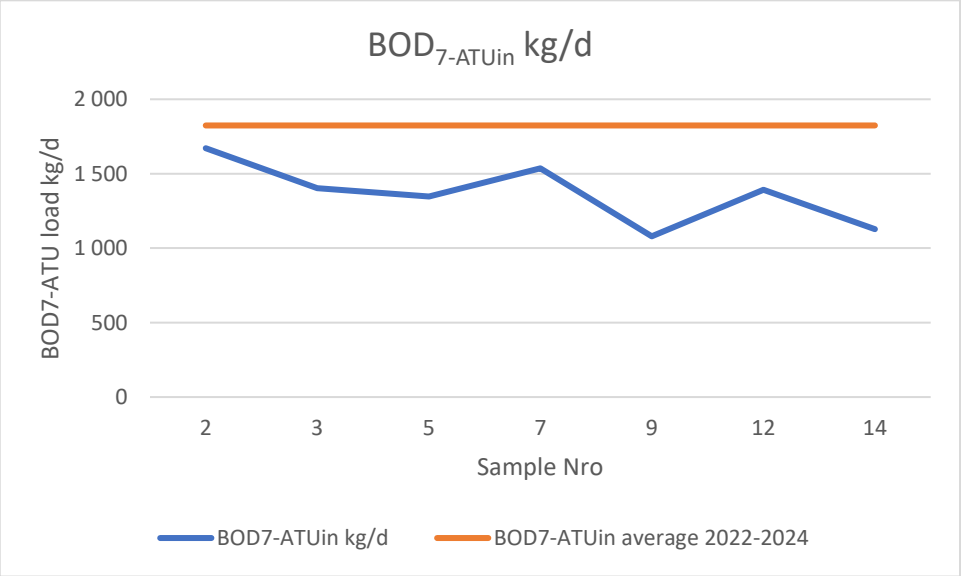

Figure 14. BOD7-ATU load kg/d to biological stage during January-June 2025 and average load of 1 824 kg/d in years 2022-2024.

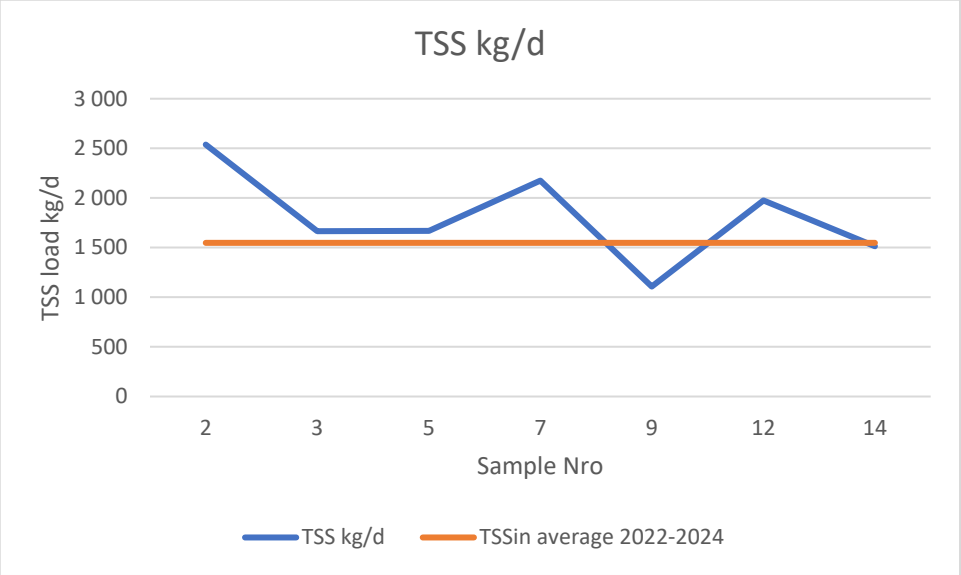

Figure 15. TSS load kg/d to biological stage during January-June 2025 and average load of 1 548 kg/d in years 2022-2024.

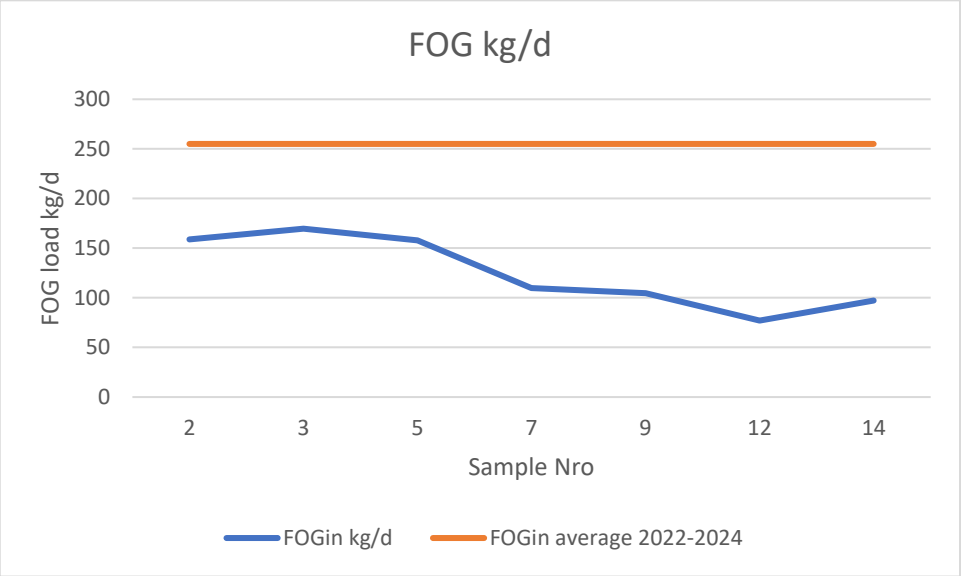

Figure 16. FOG load kg/d to biological stage during January-June 2025 and average load of 1 548 kg/d in years 2022-2024.

From Figure 16. it can be seen that polymer dosage addition to 3.0 g/m^3 which was used in samples 6-14 has been improved especially FOG separation. Polymer dosage was 1.5-.1.8 g/m^3 in samples 1-5 and 3.0 g/m^3 in samples 7-14. FOG load to biological stage was reduced 62% compared to average FOG load in years 2022-2024. Respective load reductions of $BOD_{7\text{-}ATU}$ and COD_{Cr} were 30% and 18%. Interestingly TSS load has been raised after the implementation of flotation process, Figures 13-15. Closer investigation of years 2022-2024

analyse reports and year 2025 January-June analyse reports reveals that in years 2022-2024 average TSS concentration in Turenki WWTP influent has been 383 mg/L and in year 2025 from January to June flotation influent TSS concentration has been average 395 mg/L. Flotation effluent TSS has been average 230 mg/L in January-June 2025 and WWTP influent part not pre-treated in flotation TSS has been average 656 mg/L at the same time period January-June 2025. Also, TN concentration in the WWTP influent part not pre-treated in flotation is elevated in every sample where TSS is elevated. In Figure 17. is presented the correlation between WWTP influent not pre-treated in flotation TN_{WWTP} and TSS_{WWTP} concentrations and flotation influent TSS_{FLOT} concentrations. This suggest that reject water from dewatering is contaminating the samples taken from WWTP influent part not pre-treated in flotation.

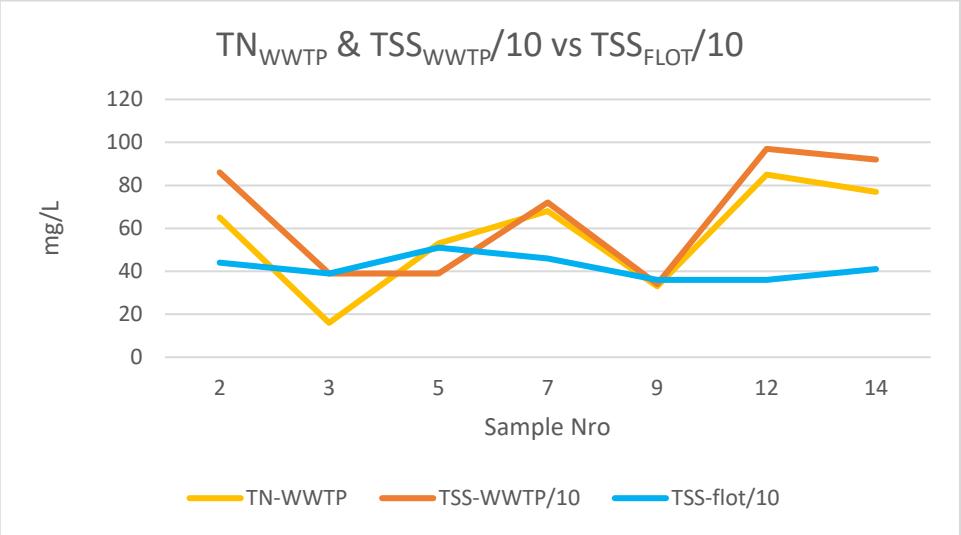

Figure 17. Correlation between WWTP influent not pre-treated in flotation TN_{WWTP} and TSS_{WWTP} concentrations and flotation influent TSS_{FLOT} concentrations. TSS concentrations are divided by 10 to improve comparability between the graphs.

6.5 Flotation sludge production

Flotation process produces scum that is floated sludge which is scraped from the water surface to flotation sludge tank. Tank is at this point emptied by sewage truck. Sludge has been formed average 7.3 tonnes per day. In Table 16 is presented the flotation sludge characteristics. Sludge is outsourced to Gasum for biogas production and it is considered to have good biogas potential because of the high FOG and good carbon/nitrogen (C:N) ratio.

Flotation sludge average C:N ratio in Turenki is 22. Gasum has informed that the optimal C/N ratio for biogas production is 20-30.

Table 16. TS, LOI%, TN, TC, TOC, ash content and FOG concentrations from flotation sludge analysis.

Parameter		Unit	Sample 1	Sample 2
Total solids	TS	g/kg	140	70
Loss on ignition	LOI	%-TS	88	87
Total nitrogen	TN	g/kg TS	21	27
Total carbon	TC	g/kg TS	560	480
Total organic carbon	TOC	g/kg TS	560	480
Ash content		g/kg TS	17	9,1
Fats, oils and grease	FOG	mg/kg TS	29000	5600

Flotation sludge was spilled to asphalt and dried there in sun. Dried sludge was like cardboard suggesting that sludge contained lots of fibre as can be seen from the Figure 18. below.

Figure 18. Spilled and sun-dried flotation sludge on asphalt yard.

7 Flotation process over all effects on WWTP

Flotation process installed to Turenki WWTP has reduced wastewater load to WWTP as results given in chapter 6 show. Flotation process has decreased significantly FOG but also BOD and COD load to old WWTP pre-treatment unit and to biological process has been decreased.

7.1 Activated sludge microscoping

Activated sludge from aeration tanks was microscoped three times during test period 2025 in April, May and June. Microscope study showed that sludge had healthy microorganisms like free-swimming and stalked ciliates. Below are images in Figures 19-28 from microscoping presenting activated sludge microorganisms from biological treatment aeration tanks.

In Figures 19-24. are shown images taken in April 2025 with microscope from activated sludge. Activated sludge samples were taken from aeration 2 tank. Images in Figures 19-23 show that in April activated sludge contained microorganisms like free-swimming ciliates, flagellate protozoa and stalked ciliates that is sing of healthy sludge. The images are showing a problem that is a loose flock structure. Loose flocs have poor settling properties and for that reason more dense and firm flock structure is more desirable. (Koivuranta 2016)

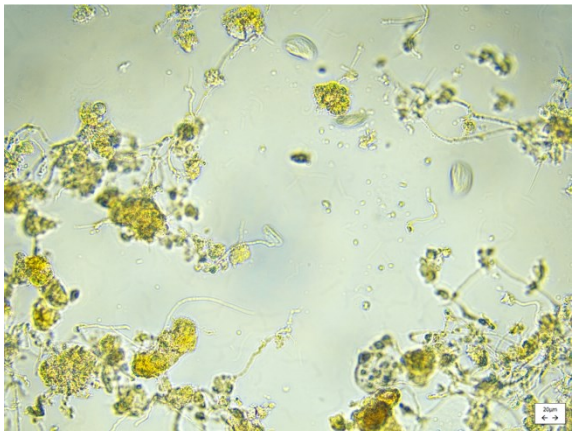

Figure 19. Free-swinging ciliates and some smaller flagellate protozoa. Loose floc. Magnification X200 (28.4.2025)

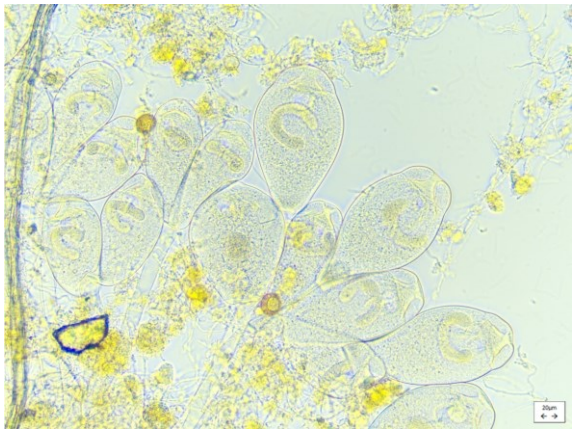

Figure 20. Stalked ciliates indicate stable conditions and healthy sludge. Magnification X200 (28.4.2025)

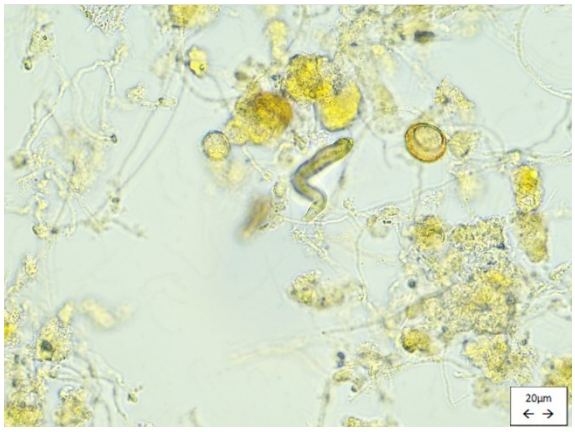

Figure 23. Worm on the left and round cup shape algae on the right. Magnification x400 (28.4.2025)

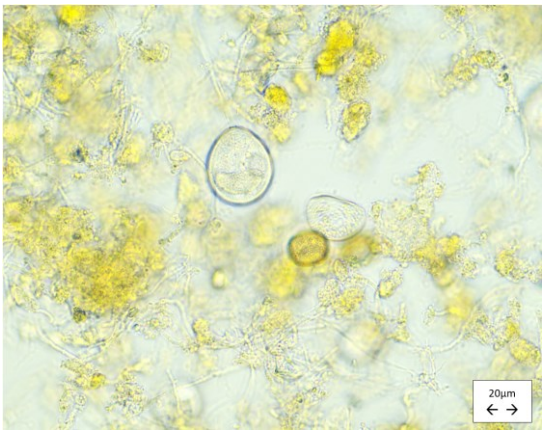

Figure 21. Free swimming ciliates and filament bind floc structures. Magnification x400 (28.4.2025)

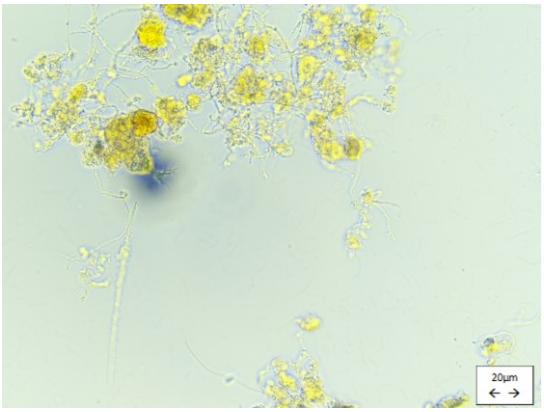

Figure 22. Loose flocs with inter-floc filament bridging. Magnification x400 (28.4.2025)

In Figure 24 can been seen *Spirochaete bacteria* that can be a sing of septic conditions and it is often seen in anaerobic municipal sludge (Lee et al. 2013).

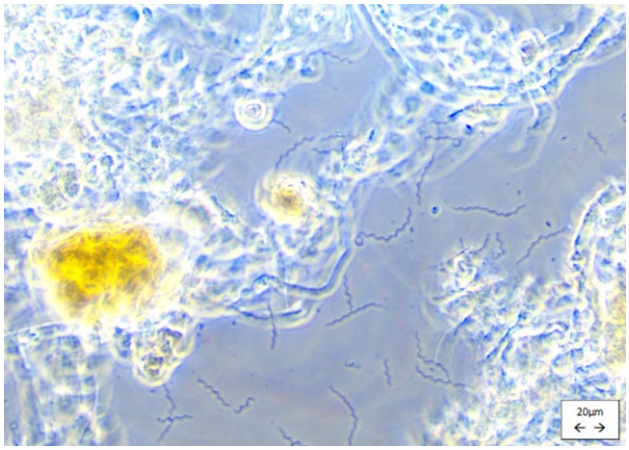

Figure 24. Spirochaete bacteria in aeration 1. Dark field microscopy Magnification x400 (28.4.2025)

When activated sludge from aeration 1 was microscoped in May 15th 2025. Microscope study showed healthy microorganisms in activated sludge, like in Figure 25 where is stalked Vorticella ciliate image taken in May 15th 2025.

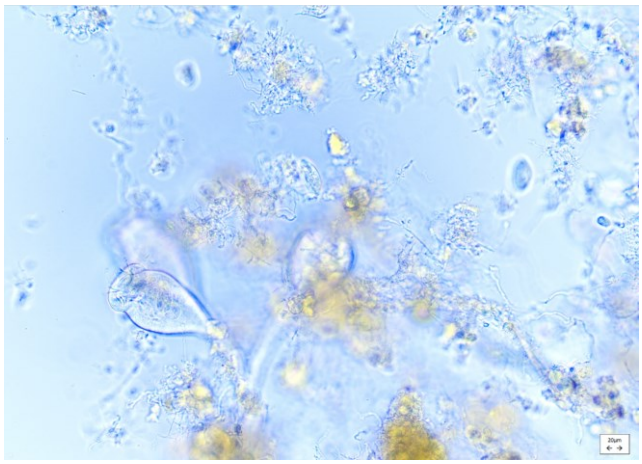

Figure 25. Stalked ciliate (*Vorticella*) indicate stable conditions and healthy sludge. Magnification x200 (15.5.2025)

Figures 25-28 show images of microscoping study in June 26th 2025. In these images are seen less *spirochaete* bacteria than in earlier microscoping studies during spring. This is probably result from the manual sludge planked removal from aeration tanks surface in June. In the removal process the anaerobic stage was also aerated for few hours which has not been favourable for *spirochaete* bacteria and also there is no greasy sludge planked anymore that may offer anaerobic conditions for *spirochaete* bacteria growth.

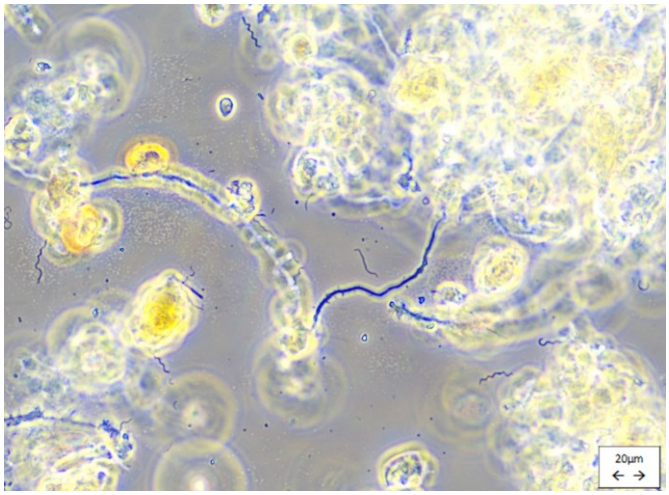

Figure 26. *Spirochaete* bacteria are shown less now than in 24.4.2025. Magnificationx400 (26.6.2025)

In figure 27. is clearly seen more dense and firm floc. Improved conditions for good floc forming bacteria growth has been able to develop since flotation has reduced the FOG load to biological treatment and old greasy sludge from aeration surfaces has been removed. Lipids rich FOG is favourable to filamentous bacteria growth and may be toxic to good bacteria inhibiting good bacteria growth as presented previously in chapter 2.4.8.

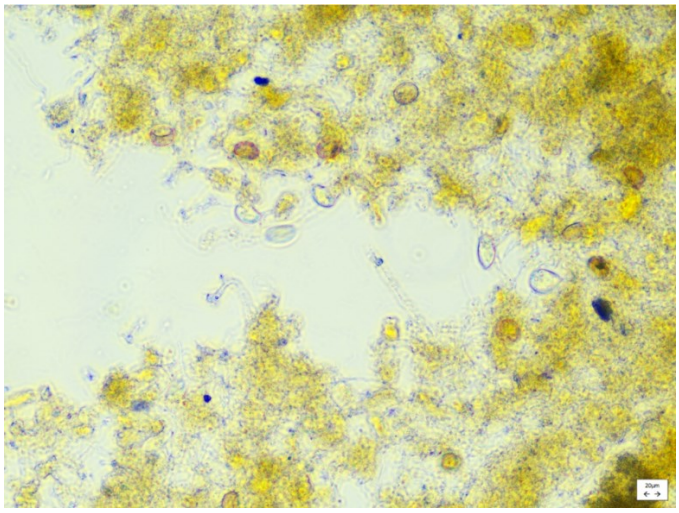

Figure 27. Many free-swimming ciliates and more dense flocs. Magnification x200 (26.6.2025)

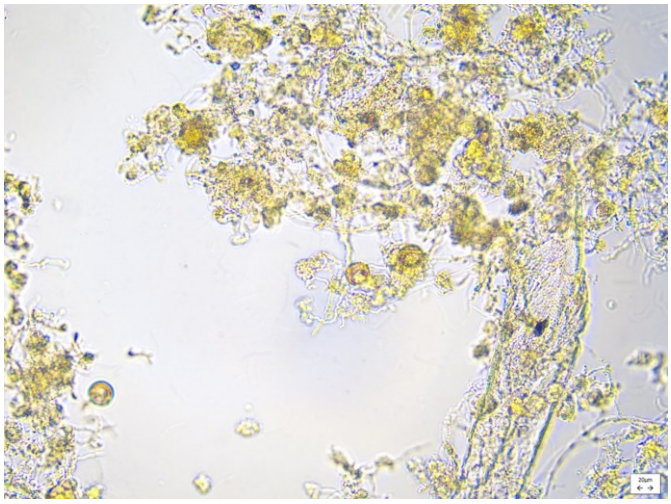

Figure 28. Filamentous bacteria in floc structure as it should and not in free water. Also, Round cup shape algae. Magnification x200 (26.6.2025)

In this microscope study, more loose floc was shown in earlier samples taken in April 28th 2025 than in last samples taken in 26.6.2025. Also, the presence of *Spirochaete* bacteria was decreased from April to June based on microscope study. That may be the result of physical removing the old greasy sludge from aeration surfaces. Overall it was noticeable that sludge structure was firmer in June than in April and healthy microorganisms was found from sludge. Filamentous bacteria were present in flock structure as it should be, not in free water between flock. This gives hope that the sludge will change from loose and poorly settling to denser and firmer.

7.2 Flotation effects on WWTP pre-treatment unit

Before flotation the WWTP pre-treatment unit equipment got clogged for the fat and grease constantly. Especially problems were in screening washer unit that got often clogged and disturbed the process. From Figure 29a fat and grease clogged screening washer pipe can be seen. From Figure 29b can be seen removed fat and grease from screens conveyor screw before flotation was in use.

Figure 29. In picture a. Screening washer clogged by fat and grease and in picture b. fat and grease removed from pre-treatment equipment before flotation process was implemented.

After flotation process was implemented in January there hasn't been clogging problems in old pre-treatment process. Water surfaces in grit removal and screening washer have looked clear. In flotation process pre-treatment Combi-unit has also presented clogging problems, but the use of warm washing water has decreased the problem.

7.3 Flotation effects on biological treatment

Flotation process has decreased FOG load to biological treatment in average 62% and $BOD_{7\text{-}ATU}$ 30%. Influence of reduced FOG has not been seen on biological treatment as much as on pre-treatment. Problem might be exciting greasy sludge in aeration tanks surfaces that needs to be physically removed. After surface sludge is removed it is assumed not to accumulate as fast as before because the decreased FOG load. BOD:N ratio was assumed to be changed in a way it would interfere the biological process. If BOD is separated too much in flotation, BOD:N ratio may increase to level that is not optimal for microbes mass growth in biological treatment. BOD:N ratio should be over 5 and optimum BOD:N ratio would be 20. COD:BOD ratio was also calculated and observed in case of possible chances. COD:BOD ratio should be under 3.3 in readily biodegradable wastewater. In Figure 30. is presented the BOD:N and COD:BOD ratio before flotation implementation and after.

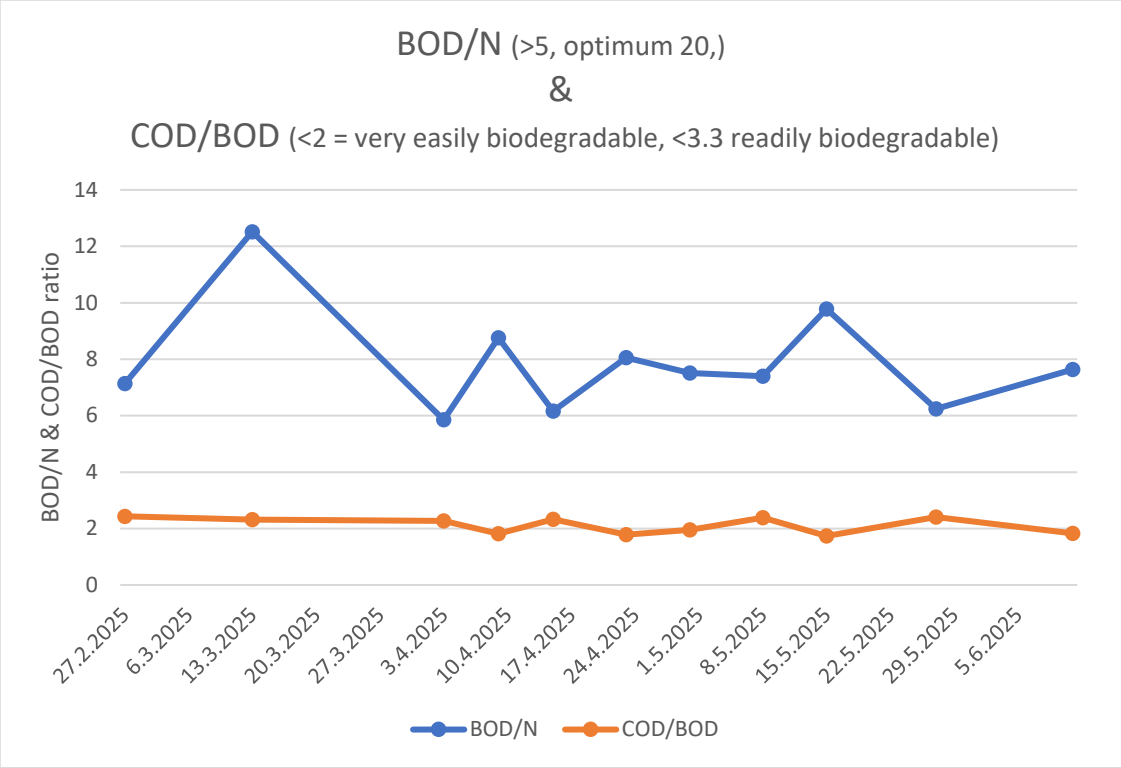

Figure 30. BOD:N and COD:BOD ration in Turenki WWTP biological treatment influent after flotation implement.

Average BOD:N ratio has been 8.3 in year 2024 before flotation implementation. After flotation process has started BOD:N ratio has decreased to average 7. Optimum BOD:N ratio would be 20. If BOD:N ratio is too low denitrification process may be compromised. BOD:N ratio is also often expressed as BOD=100 ratio, where BOD is 100 parts and N is then calculated to be X part. BOD=100 ratio has been in Turenki WWTP 100:12 before flotation and 100:14 now after flotation implementation. Optimum ratio would be 100:5. Average municipal ratio is 100:17 (KVVY 2024). COD:BOD ratio has increased little and made wastewater slightly less biodegradable, but difference between before flotation COD:BOD ratio 1.9 and after flotation 2.1 is not very remarkable.

Biological treatment has worked in normal level even though somewhat changed circumstances as FOG load has decreased even 62% and BOD 30%. In Table 17. are presented treatment reductions averages for COD_{Cr}, $BOD_{7\text{-}ATU}$, TP, TSS, TN and nitrification rate in year 2024 and 2025 between January and June when flotation has been in use for environmental permit parameters. It can be seen that reductions have been very good.

Table 17. Turenki WWTP reductions and nitrification rate in year 2024 and in January to June 2025 when flotation process has been in use.

	Reduction %	
Parameter	year 2024	spring 2025
COD_{Cr}	96	96
BOD_{7ATU}	98	99
TP	96	98
TSS	97	98
TN	93	94
Nitrification rate	99	100

However, at the end of January and in March was period when pre-treated wastewater was led to constructed basin in order to stop the sludge escaping from the process when high amount of melting snow and rainwater was flooding WWTP. In those flooding situations was not seen improvement in hydraulic capacity, but it was learned that return sludge flow limited the capacity. In June there was heavy rain period of few days when influent flow was elevated near 300 m^3/h for 33 hours and when return sludge flow was adjusted accordingly with more powerful pump, WWTP seemed to be able to handle 400 m^3/h flow peaks. In Figure 31a is picture taken from aeration before flotation unit installation in summer 2024 and on the Figure 31b is picture of aeration tank surface in June 2025. Sludge was also removed manually from aeration surface. The sludge planked was thinner and also clear water is shown in surface of aeration in June 2025 compared to summer 2024 picture.

a. b.

Figure 31. Picture a. Aeration surface in summer 2024, before flotation and on right side picture b. summer 2025 when flotation has been used.

For further development, all the old existing greasy sludge should be removed from aeration tanks surfaces. There is also need to develop the flotation sludge disposal so that the transported amount of flotation sludge would decrease. That could be accomplished by dewatering it more as on its own sludge fraction or together with the Turenki WWTP primary sludge separated from aeration tanks. In this study it was also found the lack in return sludge capacity as one of the return sludge pumps was equipped with too small impeller and for that reason couldn’t reach the adequate flow to keep the sludge planked steady in clarifier.

8 Conclusions

In this thesis flotation separation efficiency and separation effects to WWTP process was studied. Purpose was first to study the reduction efficiency and optimal coagulant and polymer dosing of the floatation unit. Then the effect of the implemented and optimized flotation unit to Turenki WWTP biological process was studied.

Dissolved air flotation (DAF) was placed as pre-treatment unit to municipal wastewater treatment plant (WWTP) to remove excess fats, oil and grease (FOG) from mixture of dairy and municipal wastewater. The preliminary expectation was that the flotation affects wastewater treatment process by reducing device and instrument clogging, reduce greasy sludge accumulation in aeration tanks surfaces. It was also expected that flotation would influence the process by reducing the negative impact of FOG on clarification performance, thereby improving the hydraulic capacity towards the design specification and reduce the need for bypassing in floods. Concerns regarding nitrogen removal compromising due loss of BOD in activated sludge were also predicted.

According to this study, reduction rates for mixture of dairy and municipal wastewater achieved with the installed flotation unit were from January 2025 to June 2025 for FOG, biological oxygen demand (BOD) and total suspended solids (TSS) 66%, 31% and 45% respectively, when dosages were for polyaluminum chloride (PAC) 120 g/m^3 and for polymer 3.0 g/m^3. Ferric sulphate 180 g/m^3 and polymer 3.0 g/m^3 dosage gave 60% reduction for FOG, 39% reduction for BOD_{7ATU}, and 43% reduction for TSS. It was estimated as a conclusion of jar test conducted with different polymers that different polymer may give better results. Also, according to the flotation unit supplier coagulation would be more efficient if influent pH would be heavily reduced. However, the lowered pH of the wastewater would have to be adjusted back up with a base, for that practical reason the pH was not lowered any further.

Tests done in this study showed that the FOG is removed efficiently in flotation, which was the original main purpose of the flotation unit investment. Test results are shown in Table 14. and Figures 9-11. Also, it seems that flotation has not have affected to nitrogen removal as it was considered to be possible affect due BOD reduction in flotation. In the test period, BOD:N ratio has lowered from 100:12 to 100:14 which is slightly less optimal for bacteria

growth in biological phase. Greasy sludge has not been diminished on its own from aeration surface during this study. Sludge has been removed from aeration surfaces physically after the end of the test period and it is assumed that greasy sludge won't accumulate in aeration surface ass easily now that FOG load is reduced in the flotation unit. Test period ended in June 2025, but in August 2025 it was seen that aeration surfaces were significantly improved as the greasy sludge planked had been diminished. WWTP hydraulic capacity couldn't be fully tested in summer because there were not real flood situations. In early spring during snow melting and rain hydraulic capacity seemed normal i.e. lower than designed, but at that time flotation had been used only short period of time and the effect on treatment process weren't fully accomplished. In summer at the end of the test period and after physical old sludge removal from aeration during smaller summer storm flood hydraulic capacity seemed somewhat better, but the change cannot be confirmed at this point. Also, later in autumn little pit less than 24-hour period of 350 m^3/h inflow to WWTP flow didn't yet jeopardize the process which was a good sign.

Flotation process produces lots of flotation sludge. Disposal of that sludge is challenging and expensive so it is vital to decrease the sludge production. It might be possible to try flotation with less coagulant dose, if then sufficient amount of FOG is still removed, but sludge need to dispose is reduced. Also, sludge dewatering before transport to final disposal must be studied and developed.

Over all according to this study, it can be concluded that dissolved air flotation removes efficiently FOG from mixed dairy wastewater in municipal WWTP. BOD and TSS removal from mixed dairy wastewater were less efficient. According to this study nitrogen removal did not get compromised in biological treatment even though BOD load to biological treatment was decreased due flotation process. Flotation also resolved the grease accumulating and clogging problems in pre-treatment devices as the FOG from dairies is now separated in flotation process.

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Appendix 1. Calculated effects to total discharged water including WWTP effluent and possible bypass water that is only pre-treated. Calculation are done in actual situation in year 2024 and in situation when WWTP could tread 8 500m^3/d and 12 000 m^3/d and bypass water amount would be reduced accordingly.

					$BOD_{7\text{-}ATU}$		COD_{Cr}		TP		TN	NH_4	SS
	Period				**<15 [mg/L]**	**>95%**	**<90[mg/L]**	**>85%**	**<0,4 [mg/L]**	**>95%**	**<15 [mg/L]**	**<4 [mg/L]**	**<35 [mg/L]**
2024	I	Total m^3/d	4809	kg/d	31		160		1,20		16	0,5	64
		All bypass	100 %	kg/d	93	94 %	180	91 %	1,50	91 %	11	0,1	87
				mg/L	26		71		0,56		6	0,1	31
		>8 500 m^3/d	58 %	kg/d	54	96 %	104	93 %	0,87	93 %	6	0,1	50
				mg/L	18		55		0,43		5	0,1	24
		>12000 m^3/d	9 %	kg/d	8	98 %	16	95 %	0,14	96 %	1	0,0	8
				mg/L	8		37		0,28		4	0,1	15
	II	Total m^3/d	4992		25		130		0,75		18	5,0	39
		All bypass	100 %	kg/d	67	95 %	130	93 %	0,98	94 %	8		53
				mg/L	18		52		0,35		5	1,0	18
		>8 500 m^3/d	52 %	kg/d	35	97 %	68	94 %	0,51	95 %	4		28
				mg/L	12		40		0,25		4	1,0	13
		>12000 m^3/d	5 %	kg/d	3	98 %	7	96 %	0,05	97 %	0	0,0	3
				mg/L	6		27		0,16		4	1,0	8
	III	Total m^3/d	3272	kg/d	17	99 %	120	96 %	1,50	94 %	10	0,3	42
				mg/L	5		37		0,46		0	0,1	13
		>8 500 m^3/d											
		>12000 m^3/d											
	IV	Total m^3/d	4150	kg/d	18		120		0,73		10	0,2	28
		All bypass	100 %	kg/d	15	98 %	31	96 %	0,23	96 %	2		13
				mg/L	8		36		0,23		3	0,0	10
		>8 500 m^3/d	49 %	kg/d	7	98 %	15	96 %	0,11	97 %	1	0,0	6
				mg/L	6		33	99 %	0,20		3	0,0	8
		>12000 m^3/d	8 %	kg/d	1	99 %	2	96 %	0,02	97 %	0	0,0	1
				mg/L	5		30		0,18		2	0,0	7