LUT University

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Chemical Engineering

Chemical and Process Engineering

Master’s Thesis

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FOLDING BOXBOARD MILL WASTEWATER TREATMENT PLANT PERFORMANCE AND OPERATION

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TIIVISTELMÄ

Lappeenrannan-Lahden teknillinen yliopisto LUT
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Kartonkitehtaan jätevesilaitoksen toiminta

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Tämän diplomityön tarkoituksena oli arvioida taivekartonkitehtaan jätevesilaitoksen toimintaa ja ajotapaa, ja luoda ratkaisuja laitoksen ongelmakohtiin. Suurimpana ongelmakohtana esiin nostettiin rikkivedyn muodostuminen prosessissa, mikä on merkittävä turvallisuusriski laitoksen operoinnin kannalta. Kirjallisuusosassa perehdyttiin taivekartongin valmistusprosessiin ja kartonkitehtaan jäteveden tyypillisiin ominaisuuksiin, ja esiteltiin kartonkitehtaan jätevedenpuhdistuksessa käytettävät mahdolliset käsittelymenetelmät. Tämän lisäksi kirjallisuusosassa esiteltiin jätevesilaitoksella syntyvän lietteen käsittelymenetelmiä. Tapaustutkimuksessa käsitellään Inkeroisten kartonkitehtaan jätevesilaitoksen toimintaa kerätyn datan ja teorian perusteella. Laitoksen ongelmakohdat kartoitettiin prosessidatan sekä käyttöhenkilökunnan muistiinpanojen avulla.

Jätevesilaitoksen massataseiden tutkimista varten luotiin simulaatio VTT:n BALAS-simulaatio-ohjelmalla. Selkeytys- ja puskurialtaan pintakuormitusten ja viipymäaikojen huomattiin olleen altaiden kunnollisen toiminnan kannalta epäsuotuisalla tasolla. Keskimääräisen tulovirtauksen mukaan laskettuna selkeytysaltaan pintakuormitusarvo oli 0.29 m/h ja viipymäaika 16.7 h. Puskurialtaan tapauksessa vastaavat arvot olivat 0.33 m/h ja 12.6 h. Tavoiteltu pintakuormitus selkeytysaltaille on 0.8 – 1.2 m/h viipymäajan tavoitearvojen ollessa 3 – 6 h. Rikkivedyn muodostuminen laitoksella on todennäköisesti seurausta hapettomista olosuhteista, jotka syntyvät altaiden pohjaan liian pitkien viipymäaikojen seurauksena.

Tavoiteltujen pintakuormitusarvojen perusteella selkeytys- ja puskurialtaille määritettiin ideaalinen tulovirtaustaso, joka oli 213.8 – 320.7 L/s selkeytysaltaalle ja 190.1 – 285.1 L/s puskurialtaalle. Nykyinen keskimääräinen tulovirtaus molemmille altaille on noin 78 L/s. Työssä selvitettiin, kuinka jätevesivirtauksen kierrätys olisi järkevää toteuttaa. Virtauksen

lisäämiseen ehdotettiin kahta mahdollista toimintatapaa. Puskurialtaan alitteelle voitaisiin rakentaa uusi putkilinja suoraan selkeytysaltaalle, tai olemassa olevat puskurialtaan lietepumput ja -putket korvattaisiin vastaavilla pumpuilla ja putkilla, jotka soveltuvat uusille, suuremmille virtausmäärille.

ABSTRACT

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Folding Boxboard Mill Wastewater Treatment Plant Performance and Operation

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91 pages, 20 figures, 24 tables

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Keywords: folding boxboard, wastewater, wastewater treatment, sludge handling

This thesis was done to evaluate the performance of a folding boxboard mill wastewater treatment plant. In the literature part the folding boxboard production process was introduced, and the different board mill wastewater characteristics were discussed. Also, possible board mill wastewater treatment methods were presented. Lastly, the board mill sludge handling prospects were presented and compared. In the case study, the Ingerois mill wastewater treatment plant was introduced. The plant performance and operation were examined based on the theory and gathered data. The plant's operational hazards and problems were mapped out with the help of process data and operational notes. The formation of hydrogen sulphide (H_2S) was recognized as one of the major issues in the treatment plant as it impacts on the operational safety.

A simulation was done with VTT BALAS to study the mass balances in the primary treatment and sludge handling. It was discovered that the surface loading rate (SLR) and detention period (DP), were significantly off in the primary clarifier and the buffer tank. Calculated with the average inflow rate, the primary clarifier had the SLR of 0.29 m/h and DP of 16.7 h. The buffer tank's SLR and DP were 0.33 m/h and 12.6 h, respectively. The desired SLR rates for a primary clarifier are within 0.8 and 1.2 m/h and detention periods should be 3 – 6 h. The H_2S formation is most likely the result of the long detention periods, as they augment the anaerobic conditions in a clarifier.

The ideal inflow rates were calculated based on the desired SLR and DP values, and they were 213.8 – 320.7 L/s for the primary clarifier and 190.1 – 285.1 L/s for the buffer tank. As the average inflow for both tanks is currently approximately 78 L/s, the mission was to determine how the inflow increase should be implemented. Two possible inflow increase implementations were presented. Either a new pipeline should be constructed to lead the return flow from the buffer tank to the primary clarifier, or the existing buffer tank sludge pumps and pipelines should be replaced with ones that can handle the significantly increased flow rates.

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Thank you all.

Heidi Saastamoinen

Kotka, 30.8.2019

LIST OF ABBREVIATIONS

AOX	Adsorbable organic halides
BAT	Best available technique
BOD	Biological oxygen demand
BT	Buffer tank
COD	Chemical oxygen demand
DMC	Dry matter content
DP	Detention period
DTPA	Diethylenetriaminepentaacetic acid
ET	Equalization tank
FBB	Folding boxboard
GAC	Granulated activated carbon
IWTP	Integrate wastewater treatment plant
MF	Microfiltration
ORP	Oxidation reduction potential
PAC	Powdered activated carbon
PC	Primary clarifier
SLR	Surface loading rate
SP	Screw press
TC	Test centre
TN	Total nitrogen
TP	Total phosphorus
TS	Total solids
TSS	Total suspended solids
UF	Ultrafiltration
VF	Vacuum filter

Contents

1. Introduction

Forest industry is one of the biggest industry sectors in Finland. The usage of renewable materials and processing them in a sustainable way makes the industry a viable part of the future bioeconomy. The processes of forest industry are usually highly water demanding. Pulp, paper and board manufacturing require large amounts of chemically cleaned water for their processes. Thus, the wastewater generation in the process is significant. There needs to be a high concentration to the wastewater treatment in forest industry in order to fit the environmental standards and limits considering the discharge levels and the wastewater quality.

This thesis was done for Stora Enso Ingerois Mill, which is a Finnish folding boxboard mill located in the Southern Finland. The mill is part of an integrate that consists of a wood handling, chipping and grinding section, a power plant, a paper mill and a board mill. The paper mill has a wastewater treatment plant, and in normal conditions the board mill's wastewaters are also treated in there. There is a primary wastewater treatment plant located in the Case Mill's site including a sludge dewatering section. If the integrate wastewater treatment plant is incapable to receive the board mill's wastewaters, the treatment is carried out in the board mill's own treatment plant. In that case, the treated wastewaters are led to the nearby river through a sand bed. The object of this thesis was to study the Case mill's wastewater treatment plant's performance, to find the possible malfunctions or operational problems in the process and to propose solutions for these problems. Ensuring the proper functioning of the wastewater treatment process despite any wastewater flow fluctuation is the most important matter that this thesis is serving.

A simulation was done with VTT BALAS to study the mass balances of the treatment plant. As a result, an operating model was created to help the plant operation in the situations where the wastewaters must be treated on-site. The simulation serves also as a useful tool to study the mass balances of the treatment plant later on.

It was found out that the primary clarifier as well as the buffer tank of the treatment plant are not working efficiently enough due to too long detention times. The clarifier and buffer tanks haven't got enough inlet flow to have the desired detention times and surface loading rates. The long detention times favour the anaerobic conditions in the tanks, which boosts the formation of hydrogen sulphide, H_2S. Preventing the formation of the toxic hydrogen sulphide is extremely important for the operational safety.

It was proposed that the flows can be increased by boosting the return flow from the buffer tank to the primary clarifier. This was modelled in the simulation considering the ideal flow rates, the current maximum return sludge rates and the peak flows. Finally, proposals were made considering the possible improvements in the Case Mill wastewater treatment plant. Based on the clarifier flow calculations and the simulation, two possible implementations were presented for the return flow boost from the buffer tank to the primary clarifier.

2. Folding boxboard production

Boards can be divided into packaging boards and container boards. Folding boxboard (FBB) is a packaging board type that is mostly used for food packages, but also medicine, alcohol and cosmetics packages are possible end uses. The most important attributes for FBB are bending stiffness and surface smoothness. FBB as a material needs to make durable cases and achieve good printing on the surface. As FBB is in many cases used for food packages, no additional taste or odour can be transferred to the food from the packaging material. Packaging boards typically have multiple layers, which are achieved with separate wires and headboxes or with a headbox that ejects multiple layers simultaneously. (Häggblom-Ahnger & Komulainen, 2001; Knowpap, 10.0)

2.1 Process description

The main parts of the paperboard machine are the headbox, wire section, press section, drying section and coating section. The headbox, wire section and the press section form the wet end of the machine, and the part from the drying section forward is called the dry end. (Knowpap, 10.0)

Diluted fibre mixture is evenly fed from the headbox to the wire. The wire has a web structure that allows water to pass through it as the fibres leave on the surface. Over 95 % of the water is removed at the wire section leaving the sheet at 15 – 20 % dryness. After wire section the formed sheet is lead to press section where the sheet is pressed between cylinders in order to reduce the water content and to tighten the fibre bonds. At press section the sheet dryness reaches 40 – 60 %. At the drying section hot cylinders are used to reach the final sheet dryness level by evaporating the water. The final moisture content of the board is 3 – 10 % depending on the product. After drying the surface of the FBB is coated 2 – 3 times and the back side is either once pigment coated, or it is surface sized with a starch glue. (Häggblom-Ahnger & Komulainen, 2001)

The process waters are recycled in the process in short and long circulations. Over 95 % of the water coming to the headbox is removed at the wire section. With this water, a significant part of the fibres is passed through the wire section. The fibrous water is reused for pulp dilution before the headbox. This is called the short circulation. In long circulation, the excess water from short circulation is used for pulp dilution in the pulp managing and reject lines. (Häggblom-Ahnger & Komulainen, 2001)

The grammage of FBB is within the range of 170 – 450 g/m^2. Usually the surface and the back layers' grammages are kept fixed and the total grammage of the product is altered with the middle layers' grammages. The most important quality attribute for FBB is the stiffness, which is best achieved by placing most bulk into the middle layer. This affects the thickness, which is economical for the stiffness as is seen from Equation (1) below (Häggblom-Ahnger & Komulainen, 2001):

$$J = \frac{E \cdot h^3}{12} \quad , \qquad (1)$$

where J Stiffness

E Matter depended elastic modulus, and

h Product thickness.

2.2 Raw materials

The layer structure of folding boxboard is presented in Figure 1 below. FBB consists of three layers with the addition of a coating layer on the surface. By choosing stiff materials for the surface and back layers the bending stiffness is maximised. Also, the pulp of the surface layer is chosen to achieve the desired smoothness and brightness for the final product. (Häggblom-Ahnger & Komulainen, 2001)

The surface layer is usually made of finely grinded bleached pulp to ensure the smoothness and good printing qualities. The pulp used is hardwood pulp, in most cases birch pulp. Aspen pulp is in some cases used also for the surface layer, but its strength is not as good as for birch pulp. The surface layer is coated two or three times with a pigment paste, which makes it a good printing surface. The pigment coating is most often kaolin clay, which is composed of aluminium silicate. Calcium carbonate ($CaCO_3$) can be used as coating material either in pulverized or precipitated form. (Häggblom-Ahnger & Komulainen, 2001; Grönstrand et al., 2000)

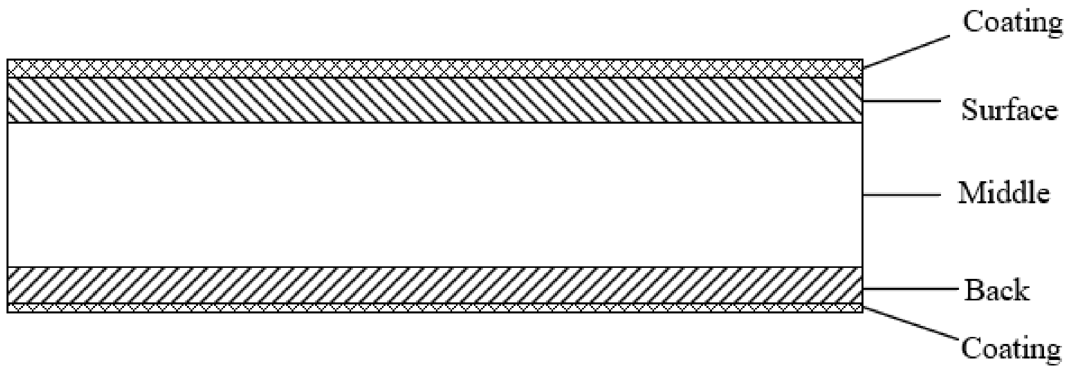


Figure 1 Folding boxboard layer structure (edited from Grönstrand et al., 2000).

The middle layer of FBB are typically produced from mechanical spruce pulp. Birch and pine are not as good raw materials for mechanical pulp. Aspen, however, is in some cases used for its good brightness qualities. The mechanical pulp can be thermomechanical pulp (TMP) or chemi-thermomechanical pulp (CTMP). Chemical pine pulp is also used as reinforcement material for its strength. (Häggblom-Ahnger & Komulainen, 2001) Mechanical pulp is a bulky material, which helps the board reach the desired thickness, and the stiffness qualities are in that way achieved (Grönstrand et al., 2000).

The back layer is made with semi-bleached chemical pulp. Depending on the use there can be a pigment coating on the back side, or it is at least surface sized with e.g. starch glue. In the case of foodboards, the back material can also be fully bleached chemical pulp. (Grönstrand et al. 2000)

2.3 Additives

Additives are used in paper and board production for two purposes: to improve the product quality and to better the paper or board machine runnability. Additives that affect the product attributes are called functional additives. However, the wet end process control gets more difficult as more functional additives are used. (Häggblom-Ahnger & Komulainen, 2001)

Functional additives are e.g. retention chemicals, colours and optic brighteners, mold and fungi growth preventing chemicals, preservatives, dry and wet strength enhancers, grease repelling substances and lubricants. Fillers are used for surface layers of FBB to fill the spaces between fibres. The board machine runnability is ensured with the aid of retention and dispersion chemicals, pH adjusting chemicals, biosides, defoaming substances and washing agents. (Häggblom-Ahnger & Komulainen, 2001)

Diethylenetriaminepentaacetic acid or pentetic acid, DTPA, is a chelating agent used in the pulp production for ensuring the proper bleaching. It acts as a complex former and helps to separate metals from the wood mass. In board manufacturing, DTPA is used to prevent the decomposition of wood's fatty acids into hexanal. Hexanal causes unwanted taste and odour to the final product. (Bajpai, 2014)

2.4 Wastewater generation

Water plays a crucial role in the paper and board production. Water is used for carrying the fibres through the process, as steam to carry energy, for machinery cooling and cleaning. Thus, there is a significant amount of wastewater generated in the process that needs to be treated before discharging it to the nature water bodies or reusing it on-site. (Pöykiö et al., 2018) Folding boxboard production generates approximately 10 – 25 m^3 wastewater effluent per produced metric tonne of boxboard. (Dahl, 2008)

The used water circulation system effects the wastewater generation. Internal purification methods are used to close the circulations. Closed water cycles are the next step in reducing raw water usage and minimizing the generation of wastewater. However, closed water cycles can cause problems related to inorganic substances building up in the system. This causes corrosion and scaling and eventually deteriorating in product quality, such as unwanted taste and smell. (Choi et al., 2003)

3. Board mill wastewater characterization

Board mill wastewaters usually contain wood and substances generated from wood, such as starch, alcohols, lignin etc. The process also utilizes additive chemicals, which can also be found in the wastewaters in some form. As there can be complex substances in the wastewaters, it is not reasonable to measure all the substances but rather the total effects of these substances. Therefore, sum parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD), adsorbable organic halides (AOX) and total suspended solids (TSS) are used to indicate the wastewater quality. (Dahl, 2008)

3.1 Chemical oxygen demand

Chemical oxygen demand (COD) defines the amount of oxygen (mg/L) that is consumed by the chemical reactions in organic matter degradation. COD can also be defined as a measure of the chemical waste's pollutional strength on the water's dissolved oxygen. (Bahadori & Smith, 2016)

As seen from Table I, COD values vary greatly depending on the source of the wastewater effluent. The values transpire the effectiveness of a simple primary treatment to the COD levels. The biggest impact on papermaking wastewater's COD load is made by lignin-related substances from lignin degradation. (Andersson et al. 2008)

Table I Chemical oxygen demand (COD) values for wastewater effluents from different sources in paper and board industry.

COD (mg/L)	**Source**	**Reference**
200 – 260	Disk filtered and flotation treated board mill wastewater	Laitinen et al., 1998
840	Bleached and unbleached sulphate pulp specially targeted for paper and linerboard manufacture	Roppola et al., 2009
2054 – 2075	DAF treated paper and board mill wastewater	Afzal et al., 2008
2065 – 2161	Anaerobically treated paper mill process water	Vogelaar et al., 2002
10 300	Board mill end-of-pipe, raw material recycled fibre	Jamil et al., 2011
33 000	Packaging board mill whitewater	Latorre et al., 2007

The most used COD testing method includes oxidizing the COD with acid and then utilizing indicator compounds to perform a colorimetric analysis. Typical indicator compound used is hexavalent dichromate. The colorimetric analysis is sometimes impossible to carry out because of some interfering compounds in the sample. In these cases, titration must be used for COD level determination. (Merck KGaA, 2016) COD is often presented as kg/day, tonnes/month or tonnes/year in mill-specific environmental permits (Suhr et al., 2016).

3.2 Biological oxygen demand

Biological oxygen demand (BOD), is a measure of how much oxygen (mg/L) is consumed by the organic substances. The BOD value informs the amount of degradable organic matter in the effluent. There are two types of BOD measures; BOD_5 and BOD_7. Both are measures of the bacteria-consumed oxygen as they break down the organic compounds from the wastewater over a 5- or 7-day period. In Finland, the BOD_7 is more typically used. (Dahl, 2008) The varying of BOD values in different paper and board processes' wastewaters are shown in Table II below.

Table II Biological oxygen demand (BOD) values for wastewaters from different sources in paper and board industry.

BOD (mg/L)	Source	Reference
488 – 507 [a)]	DAF treated paper and board mill wastewater	Afzal et al., 2008
585 [b)]	Bleached and unbleached sulphate pulp specially targeted for paper and linerboard manufacture	Roppola et al., 2009
595 - 635 [a)]	Anaerobically treated paper mill process water	Vogelaar et al., 2002
615 – 670 [a)]	Cooking-washing section of an agri-based kraft paper mill, raw material wheat straw	Mahesh et al., 2006.
2200 [a)]	Board mill end-of-pipe wastewater, raw material recycled fibre	Jamil et al., 2011

[a)] BOD_5 measurement, [b)] BOD_7 measurement

The traditional, standardised method for testing the BOD value during a 5- or 7-day period is not considered as he most convenient method because of its time-consuming nature. For faster and real-time monitoring, instead of the actual BOD_5 value, a predicted value is determined. (Jouanneau, 2014)

The ratio of BOD to COD is used to determine the biodegradable fraction of the studied effluent. Also, the ratio of COD to BOD indicates the size of a wastewater treatment plant needed for proper treatment of the studied effluent. (Jouanneau et al. 2014)

The most effective and used treatment method for BOD removal is activated sludge treatment. Depending on the source of the wastewater, the BOD removal percentage is 92 – 98 after activated sludge treatment. (Dahl, 2008)

3.3 Adsorbable organic halides

Adsorbable organic halides (AOX) in forest industry wastewaters generate from the pulp bleaching process. AOX compounds form when chlorine compounds and wood fibres' residual lignin react with one another. Chlorine is used for bleaching. AOX have shown a tendency of bioaccumulation and carcinogenic nature. Thus, it is of high importance to remove these compounds from wastewaters before discharging into nature water bodies. (Jamil et al., 2011; Savant et al., 2006)

AOX compounds are categorized into high molecular weight (HMW) and low molecular weight (LMW) compounds, which are compounds over 1000 and under 1000 molecular weight, respectively. Because of the small size, the LMW compounds are more harmful, able to permeate cell membranes and have tendency to bioaccumulate. HMW compounds contrarily are usually biologically inactive and have little or no relation to toxicity. (Savant et al. 2006) AOX compounds can be analysed from wastewater samples with specific AOX analysers that utilize column adsorption method (Deshmukh et al., 2009).

3.4 Total suspended solids

Total suspended solids (TSS) determines all suspended solids in a liquid (Bahadori & Smith, 2016). Suspended solids are organic particulate matter, and in contribution to the BOD levels of the wastewater. Thus, removing TSS lowers the BOD and the energy consumption of the following treatment processes. (Davis, 2010)

Total suspended solids are measured to observe the quality of the wastewater and to control the wastewater treatment processes. TSS is conventionally measured by filtering a sample with a known volume and weighing the dried filter and captured solid matter. The unit of TSS is mg/L. Online measuring of TSS is also possible and useful for e.g. adjusting the process conditions or chemical dosing for the solids removal. (Thermo Fisher Scientific, 2016) Table III below shows different values for TSS from different sources regarding the paper and board industry processes.

Table III Total suspended solids (TSS) values for wastewaters from different sources in paper and board industry.

TSS (mg/L)	**Source**	**Reference**
4 – 15	Disk filtered and flotation treated board mill wastewater	Laitinen et al., 1998
145 – 158	DAF treated paper and board mill wastewater	Afzal et al., 2008
2100	Cooking-washing section of an agri-based kraft paper mill, raw material wheat straw	Mahesh et al., 2006
5950	Board mill end-of-pipe wastewater, raw material recycled fibre	Jamil et al., 2011

As seen from Table III, the TSS in board mill wastewater can be rather high for end-of-pipe samples. This is due to the high fibre content of the wastewaters. A simple primary treatment, such as flotation in the Laitinen et al. (1998) study successfully removes a major part of the TSS.

3.5 Total nitrogen

Total nitrogen (TN) includes nitrate (NO_3), nitrite (NO_2), ammonia (NH_3) and organic nitrogen summed together. Total Kjehldahl nitrogen (TKN) is the sum of ammonia and organic nitrogen, and must not be mixed with TN. (Bahadori & Smith, 2016)

Nitrogen (N) is often added to the wastewater to enhance the functioning of activated sludge process, because it acts as a nutrient for the microorganisms' growth. The nitrogen is usually added in the form of urea. Wastewater's nitrogen can originate from the raw material wood. Therefore, nitrogen in wastewater originates from both wood and added urea. Forest industry wastewater nitrogen load is mostly dissolved organic nitrogen or nitrogen bound to solid matter. Nitrogen-containing wastewater causes excessive algae growth, eutrophication, if it is discharged to nature water bodies (Bahadori & Smith, 2016).

There are several methods to determine the TN of a wastewater sample. Colorimetric analyses are commonly used for TN determining. The inorganic nitrogen, nitrate and nitrite, can be determined chromatographically. The TKN method converts the organic nitrogen into ammonia and analyse the ammonia to get the TKN. On-line monitoring is the most preferred way of determining the TN levels when operating a biological treatment. Table IV shows the TN values for wastewaters from different sources in paper and board industry. The usage of nitrogen-containing chelating agents such as ethylenediaminetetraacetic acid (EDTA) and diethylenetriaminepentaacetic acid (DTPA) in chemical pulping lift the TN levels in wastewaters. (Suhr et al., 2016)

Table IV Total nitrogen (TN) values for wastewaters from different sources in paper and board industry.

TN (mg/L)	**Source**	**Reference**
0.07	Coated paper mill wastewater, raw material chemical pulp (biologically treated in activated sludge process)	Suhr et al., 2016
1.9 – 2.4	DAF treated paper and board mill wastewater	Afzal et al., 2008
10.1	Coated paper mill end-of pipe, raw material chemical pulp (untreated)	Suhr et al., 2016
11	Paper mill end-of-pipe wastewater	Bajpai, 2017

3.6 Total phosphorus

Total phosphorus (TP) is the sum of all forms of phosphorus in the wastewater. Total phosphorus includes orthophosphates, polyphosphates and organic phosphates. Phosphorus is typically found in wastewaters in the form of monohydrogen phosphate (HPO_4^{2-}). Phosphorus (P) typically ends up in wastewaters from the raw material wood. If the wastewater treatment plant has an activated sludge process, some phosphorus may be added as phosphoric acid to enhance the process functioning. Phosphorus causes serious eutrophication if ended up in water bodies in larger quantities. (Davis, 2010; Bahadori & Smith, 2016; Suhr et al., 2015)

The only form of phosphorus that can be directly measured are orthophosphates, which are measured with a colorimetric analysis. To be able to measure total phosphorus, the other forms must be converted into orthophosphates. This can be done with digestion. On-line monitoring is the most preferred way of determining the TP levels when operating a biological treatment. (Suhr et al., 2015)

Table V shows phosphorus content in wastewaters from different sources in paper and board industry. Paper and board mill wastewaters are often in need of nutrient addition before proceeding to secondary activated sludge treatment.

Table V Phosphorus values for wastewaters from different sources in paper and board industry.

P (mg/L)	**Source**	**Reference**
0.6	Paper mill end-of-pipe	Bajpai, 2017
0.77	Paper mill wastewater effluent (treated)	Suhr et al., 2016
1.0	Coated paper mill, raw material chemical pulp (untreated)	Suhr et al., 2016
1.07 – 1.33	DAF treated paper and board mill effluent	Afzal et al., 2008

3.7 pH

pH is one of the most important parameters to monitor in wastewater treatment processes. Determination of pH is easy with pH meters that utilize special electrodes. Proper calibration is important for a functioning and reliable pH measurement. Continuous pH monitoring is extremely important for example in biological wastewater treatment, since the microorganisms are sensitive for acidic or alkaline conditions. Hence, neutralization is usually implemented before biological treatment. (Weiner & Matthews, 2003)

Table VI shows pH values from different sources in paper and board industry wastewaters. Usually the optimal pH value for forest industry wastewater treatment is near neutral (7) depending on the possible biological treatment. pH 6.5 or lower can cause corrosion (Dahl, 2008). As seen from the Table VI, the wastewaters that have been through primary treatment tend to have lower pH compared to the end-of-pipe sample. Of course, the presented values are of different sources and processes, which is why they are not directly comparable.

Table VI pH values for wastewaters from different sources in paper and board industry.

pH	Source	Reference
6.4	Disk filtered and flotation treated board mill effluent	Laitinen et al., 1998
6.6	DAF treated paper and board mill effluent	Afzal et al., 2008
6.8 – 7.2	Anaerobically treated paper mill process water	Vogelaar et al., 2002
6.9	Aerobically treated paper mill effluent	Devi et al., 2011
8.5	Board mill end-of-pipe, raw material recycled fibre	Jamil et al., 2011

3.8 Conductivity

Conductivity is used as an easy way to determine total ions in the wastewater. It correlates with the total salt concentration as salts are comprised of ions. The relation of electrical conductivity and total suspended solids of wastewater is studied. Conductivity is determined with specific conductivity analysing meters. The unit of conductivity is mS/cm. (Ali et al., 2012; Nataraj et al., 2007)

Presented in Table VII, there are conductivity values for wastewaters from different sources in paper and board industry. As seen from the Bülow et al. (2003) conductivity values before and after closing the water cycle, there tends to be build-up with salts when closing a water cycle.

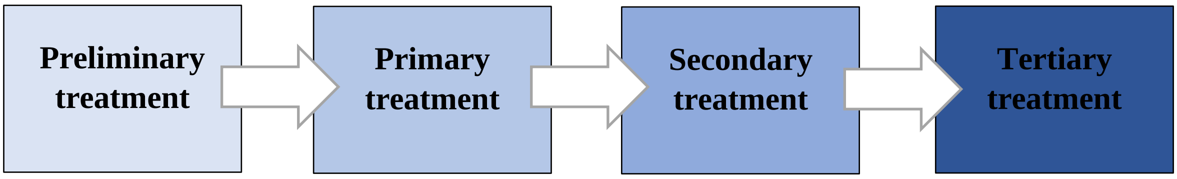
Table VII Conductivity values for wastewaters from different sources in paper and board industry.

Conductivity (mS/cm)	**Source**	**Reference**
2.2	DAF treated paper and board mill effluent	Afzal et al., 2008
2.7	Paper mill white water, before closing water cycle	Bülow et al., 2003
5.1	Paper mill white water, closed water cycle	Bülow et al., 2003
10.78	Filtrated paper mill effluent	Nataraj et al., 2007

4. Wastewater treatment methods

Functional and cost-effective waste management, especially wastewater treatment, has a major impact on the mill efficiency evaluation (Hernández-Sancho & Sala-Garrido, 2009). Wastewater treatment methods are usually sorted in two ways: by the order of the treatment steps and by the physical, biological or chemical phenomenon occurring in the treatment. The most used wastewater treatment in forest industry is mechanical clarification. (Hynninen, 2008)

The target of primary treatment is to remove the solids from the wastewater. Secondary and tertiary treatments are used for reducing the organics content and remove the colour and toxic organics from the wastewater. The categorization and scheme of wastewater treatment is presented in Figure 2 below. (Ochoa de Alda, 2008.)



Preliminary treatment	Primary treatment	Secondary treatment	Tertiary treatment
- Mechanical treatment - Grit removal - Screening	- Mechanical treatment - Clarification, flotation - Solids removal	- Biological treatment - Activated sludge treatment - COD, BOD, N, P removal	- Chemical, electrochemical treatment - Colour, toxicity removal

Figure 2 Wastewater treatment classification (Hynninen, 2008; Ochoa de Alda, 2008)

4.1 Preliminary treatment

Preliminary treatment of wastewater carries out three actions. It removes the solid matter that is untreatable, such as grit. Having a preliminary wastewater treatment protects the following treatment steps when the untreatable solid matter is removed beforehand. Preliminary wastewater treatment also boosts the following treatment steps' performance. The typical unit operations in preliminary treatment consist of screens, grinders and flow equalization. (Davis, 2010)

Flow equalization is usually performed with an equalization tank. An equalization tank is a key part in board mill wastewater treatment plant, because the effluent flow and composition can have high fluctuation. Steady flow rates stabilize the treatment processes and thus make the process more reliable. (Žarković et al., 2010)

Grit removal is performed to protect the mechanical equipment, to prevent build-up in channels and pipe lines and to prevent the frequent cleaning of accumulated grit. Also, it is beneficial to have the grit separated from the wastewater's organic matter that is treated in the following treatment steps. (Davis, 2010)

4.2 Primary treatment

In board mill wastewater treatment removing the solids from the effluent is one of the main objectives. As stated before, the suspended solids removal contributes to the BOD levels and the energy consumption of the following treatment steps. (Davis, 2010) Clarification, flotation and filtration are principal method types in solids removal, selection depending on the solid matter characteristics. (Hynninen, 2008)

4.2.1 Clarification

Primary clarifiers are vastly used due to their low operational costs and high rates of solids removal. With suspended solids removal, significant amount of BOD is reduced. (Davis, 2010) On the other hand, according to Odegaard (1998), the disadvantage with clarifiers are the large space requirements compared to the treatment efficiency.

Clarification is based on gravity: the solid particle having higher density compared to water. Effluent is fed to a clarifier, where the solid matter settles to the bottom of the clarifier tank within hours of retention time. The settled solid matter, sludge, is removed from the bottom of the clarifier by pumping, usually with the aid of scrapers. (Žarković et al., 2010) The clarified wastewater is removed as overflow from the clarifier tank (Odegaard, 1998).

Clarification has three stages: pretreatment, clarification and sludge handling. Pretreatment can include neutralization, flow equalisation, cooling and grit removal. 60 - 95 % of solid matter is possible to be removed with clarification. (Hynninen, 2008) With a normal overflow rate of 2 m/h, approximately 50 % of suspended solids and 30 % of organic matter can be removed with primary clarification (Odegaard, 1998). Better results are obtained with the aid of chemicals or mechanical flocculation. The final stage, sludge handling, usually consists of thickening, dewatering and disposal. (Hynninen, 2008)

There are four sorts of settling: individual particles' settling, floc settling, hindered settling and thickening. Individual particles and flocs have different settling attributes. The discrete settling of individual particles is not affected by other particles; only the individual particle's physical characteristics and the fluid viscosity matter. Floc settling is more difficult to predict since the flocs' shape and size are constantly changing; usually the settling of flocs is empirically tested to determine the settling rate. Hindered settling can be most often seen at the end of the settling cycle when the flocs merge while sinking and create large agglomerates. Settling ends with thickening of the flocs. (Hynninen, 2008)

According to Stokes' law of the velocity of a particle falling through a viscous medium (equation 2), particle size and shape has the biggest impact on the settling (Hynninen, 2008):

$$V_s = \left(\frac{\frac{1}{18}}{\left(\frac{\rho_P - \rho_L}{\mu} \right)} \right) * gd^2 \tag{2}$$

Where	V_s	velocity of the particle
	ρ_P	density of the particle
	ρ_L	density of the liquid
	μ	viscosity of the fluid
	g	acceleration due to gravity
	d	diameter of the particle

Equation 2 shows, that density and viscosity decrease would augment the settling rate. This can be achieved with temperature increase, for example. Flow in most clarifiers is laminar type, and Stokes' law is valid for these clarifiers. (Hynninen, 2008)

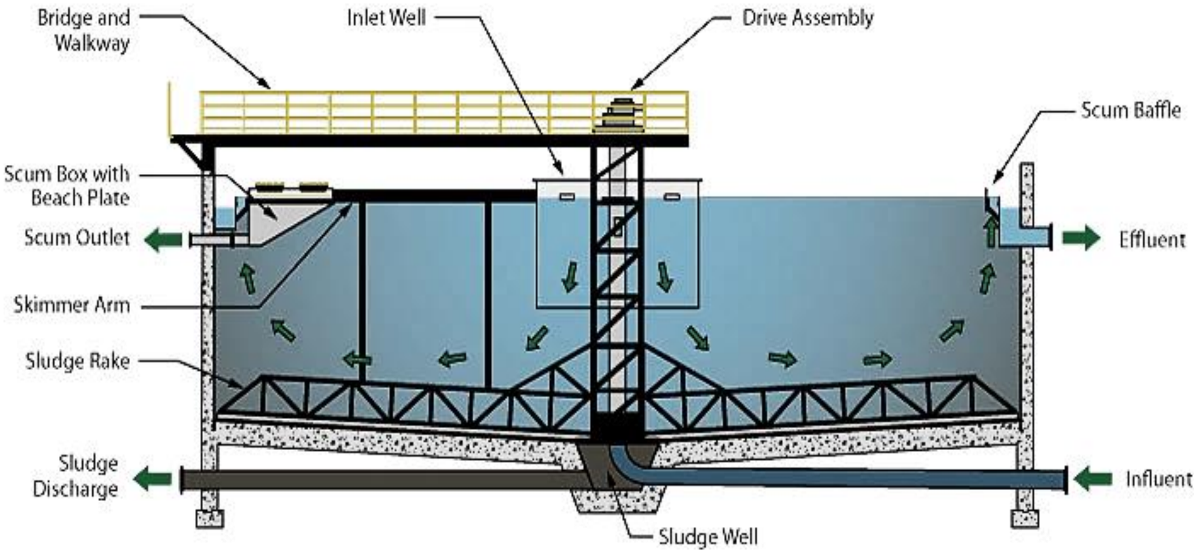


Figure 3 Primary circular clarifier flow diagram (Monroe Environmental, 2018)

There are a few important design parameters for primary clarifiers. The surface loading rate (SLR) implicates the proper inlet flow rate (m^3) according to the clarifier surface size (m^2). According to Hynninen (2008), the SLR of a primary clarifier is typically 0.8 – 1.2 m/h. Clarifiers are normally designed based on the SLR. It is important to have good flow rates in the clarifier, so that the retention times don't get too high. The SLR is calculated with the flowrate (m^3/h) and the surface area of the clarifier (m^2). The equation is presented below in Equation 3.

$$SLR = \frac{\dot{V}}{A} \tag{3}$$

Where $\dot{V}$ flow rate, m^3/h,

A surface area of the clarifier, m^2.

The detention time or detention period (DP) is very important for the clarifier functionality. Usually the theoretical detention times for primary clarifiers are around 1.5 – 2.5 hours. In real cases, the detention times can be even shorter. Too long detention times can result in resolubilization of the organic matter, which impacts the BOD removal rate. Septic conditions and unwanted odours can be results of poor BOD removal. (Davis, 2010) The detention time is calculated as the ratio of the flow rate to the clarifier volume, which is presented in Equation 4 below.

$$DP = \frac{V}{\dot{V}} \tag{4}$$

Where V Volume of the clarifier, m^3

$\dot{V}$ flow rate, m^3/h

The design of the primary clarifier should be done to minimize the biological activity promoting conditions while maximizing the clarifier efficiency. Usually the clarifier hydraulic load is addressed in the design with a specific peak flow value. Peak flow can be managed with flow equalization or by sizing the clarifier specifically for the peak flow. (Davis, 2010)

4.2.2 Flotation

Flotation is used to separate light particles and oils from wastewater. This method utilises air bubbles to carry the light particles to the surface from where they are easy to remove with skimming. Polymers and other chemicals are often used to aid the process. Flotation can be executed also after biological treatment for suspended solids removal. (Wang et al., 2010)

Flotation is carried out in a clarifier in which the solids are carried to the surface with the aid of air bubbles. There are four steps in the flotation process: bubble generation, particle and air bubble contact, particle attachment and the rise of the bubbles. The flotation systems are divided based on the method how the bubbles are generated: dissolved air (DAF), induced air (IAF), froth, electrolytic and vacuum. The most used in industrial level are dissolved air flotation (DAF) and induced air flotation (IAF). (Hynninen, 2008)

Dissolved air flotation utilises high pressure to dissolve air in the wastewater. After depressurization the gas bubbles are formed and rise to the surface with the suspended solids attached. (Wang et al., 2010) A scheme of a DAF unit is presented below in Figure 3.

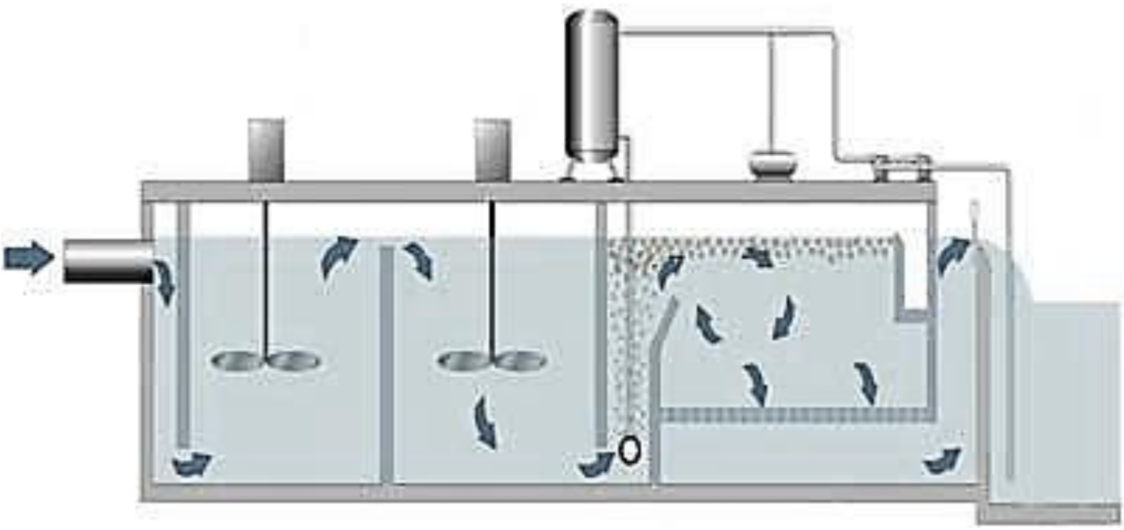


Figure 2 Dissolved air flotation (DAF) unit scheme. (Wong, 2013)

The air is pumped to the clarifier or it is released from dispersion water: the pressure of fresh water is lifted to 4 – 6 bar by a pump and air is ejected into it where it dissolves under the high pressure. The dispersion water is fed to the clarifier through nozzles. Small air bubbles are released to the fluid when the pressure decreases. The bubbles attach on suspended or colloidal particles and create agglomerations. As the formed agglomerations contain air in the form of bubbles, they are lighter than water and rise to the surface. The sludge is collected from the surface by a skimming procedure. The heaviest particles still settle on the bottom of the tank, thus there needs to be a separate system for removing the bottom sludge. (Hynninen, 2008; Wang et al., 2010)

Flotation sludge is notably different from settling sludge as it contains air. Thus, the air must be removed before the sludge is further treated or mixed with other sludge. The solids content of flotation sludge is between 1 – 3 % or with DAF even at 2 – 5 %. (Hynninen, 2008; Wong, 2013)

Although flotation is an effective option for removing light particles, it has some disadvantages. The air bubble formation requires a lot of energy, which makes the operating costs high. Also, the additional step of removing air from the surface sludge increases the costs even more. Flotation is also sensitive for weather conditions, such as raining and freezing. Flotation unit needs some type of protection from these elements so that the floated solids don’t settle. (Wong, 2013)

4.2.3 Filtration

In filtration, the wastewater is led through a porous media or a membrane to remove solid particles from the wastewater. The particles can either stay on the surface or inside the pores of the medium. The fluid that passes through the filter is called the filtrate. The filtration process efficiency can be boosted with the aid of chemicals, filter aids. There are two types of filter media used: surface- and depth-types. The difference between these two types is that in surface-type filters the particles retain on the surface of the filter media and in depth-type filters the particles penetrate into the pores of the filter media. (Cheremisinoff, 2002) Membrane filtration is presented in chapter 4.4.3 considering tertiary treatment.

Filtration can be a viable option in the case of smaller wastewater quantities. Otherwise, pitch and suspended solids usually cause problems such as filter blockage. Filtration has high costs due to the high maintenance level. (Hynninen, 2008) Odegaard et al. (2003) state that filtration could be better option for primary treatment than settling. This is due to the smaller space requirements of the filtration processes compared to the large settling tanks.

The most used filtration process type is granular filtration. There are five filtration mechanisms in granular filtration: mechanical screening, sedimentation, flocculation, interception and impaction. The particles bigger than the openings of the filter are separated by mechanical screening and form a cake on the top of the filter. The biggest problem of granular filtration is headloss, which shows the loss of total energy per volume of water as the water moves through the filter bed. Headloss increasing filter blockages are common in granular filters. (Davis, 2010)

Coarse media filters often avoid the headloss increasing problem, because of their highly porous structure. Odegaard et al. (2003) used plastic carriers as their coarse media, that are typically used in moving bed bioreactors. A combination of two different type of plastic filter media showed the best primary treatment results. The suspended solids removal efficiency was 75 % without polymer addition and 85 % with low polymer dosage. Approximately 70 % of the COD was also removed in the case of polymer added in the filtering process.

4.2.4 Coagulation and flocculation

The idea of chemical coagulation and flocculation is to merge smaller solid particles together and form flocs, which are easier to remove than individual particles. The chemicals used in coagulation are usually inorganic metal salts such as ferric sulphates and chlorides or aluminum. (Ahmad et al. 2007) The main target of chemical coagulation process is to neutralize the electrical charges and so avoid repulsion. Organic matter usually has a negative charge, which is why metal cations are often added. (Hynninen, 2008) The net charge of a colloidal particle is measured as the zeta potential (Shammas, 2005). (Simonić & Vnućec (2012) state that chemical coagulation paired with sedimentation afterwards is an effective combination for treating wastewater with high suspended solids, particularly those comprised of colloidal matter.

Polymeric flocculants such as synthetic polyelectrolytes are used to improve floc quality and thus better the settling compared to just using coagulation (Simonić & Vnućec, 2008; Ahmad et al., 2007). According to a study by Aguilar et al. (2001), using coagulant aids alongside with a coagulant can decrease the volume of produced sludge by up to 41.6 %. More closely, adding anionic polyacrylamide to polyaluminum chloride or ferric sulphate the settling rate can be increased.

An example of a flocculation unit is presented in Figure 4 below. The flocculation tank has several different compartments and intense mixing.

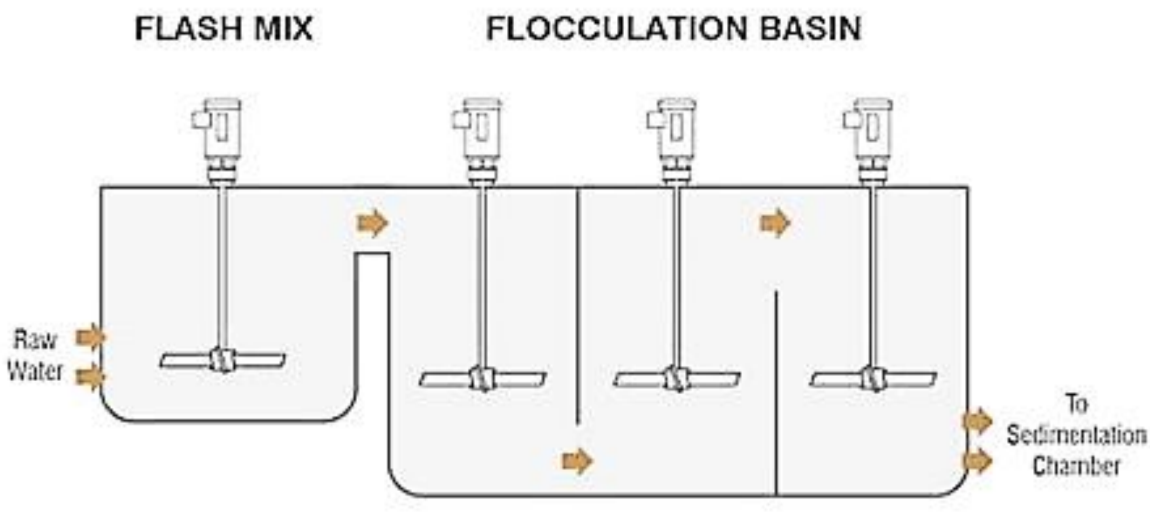


Figure 3 Flocculation unit scheme (James, 2016)

The sludge produced in chemical coagulation usually cannot be recycled back to the process since it still contains chemical coagulants. (Hynninen, 2008).

4.3 Secondary treatment

Secondary treatment is used to remove the remaining suspended solids and to oxidize the BOD that wasn't removed in primary treatment, as well as to remove nutrients from the wastewater. Secondary treatment is most often carried out as a biological treatment. (Davis, 2010)

Biological treatment methods are used for treating wastewater that contains low-molecular-mass organic matter. The process utilizes microbes that break down and feed on the dissolved and colloidal substances. The microbes live and reproduce, and the waste is converted into biomass, carbon dioxide and water. Biological treatment needs a pre-treatment, because the microbes are often sensitive for pH, temperature as well as oxygen and nutrient contents. (Hynninen, 2008)

Biological treatments are either aerobic or anaerobic. Aerobic treatments require the presence of oxygen to function, whereas anaerobic processes function in the absence of oxygen. This is due to the used microorganisms' different natures. (Davis, 2010)

One of the biggest advantages of biological treatment is the possibility to use different microbes simultaneously. This makes the treatment steady yet flexible: the different microbes succeed in different environments and feed on different nutrients. Thus, biological wastewater treatment is widely used in forest industry. (Hynninen, 2008)

4.3.1 Activated sludge treatment

Activated sludge treatment is an aerobic process, which means the microbes' metabolism require the presence of oxygen to produce new cells and water alongside with carbon dioxide as side products. Activated sludge is the name of the active mass of microbes that is formed when individual microorganisms flocculate. (Hynninen, 2008)

The microorganisms in activated sludge can be divided into three categories: carbon oxidizers, filamentous carbon oxidizers and nitrifying bacteria. The carbon oxidizers produce flocs as the bacteria excrete polymers that lower the electrical charges of the cells. This makes the biggest impact on the floc formation. Filamentous carbon oxidizers are not wanted in the system due to their settling hindering properties. In addition to these three groups of microorganisms, there are also other microorganisms present in the system, i.e. rotifiers, worms and yeast. Rotifiers are especially important for the system's proper functioning as they use the activated sludge's bacteria. This is beneficial for the sludge settling, and it removes turbidity. (Davis, 2010; Hynninen, 2008)

The activated sludge treatment is carried out in an aeration tank, to which properly mixed effluent and recycled activated sludge is led. After the aeration tank the sludge is separated from the effluent in a clarifier with sedimentation. Most of the activated sludge is recycled back to the aeration tank, and the excess is removed. (Hynninen, 2008)

Temperature, oxygen content, nutrient content and toxic substances are important factors to handle in the activated sludge treatment. The biochemical reaction rate depends on temperature. Although the treatment can operate on wide range of temperatures, rapid changes can be problematic. Lowest operating temperatures are 2 – 5 °C (municipal wastewater treatment), and highest 35 – 37 °C. Effluents warmer than 40 °C must be cooled before treatment. (Hynninen, 2008)

Another important factor is the nutrient concentration, which is usually expressed as the ratio of BOD to nutrients (BOD:N:P). A minimum concentration of nutrients is required in biological treatment. Thus, nutrients are usually added. A common error in the activated sludge treatment for wood-processing industry effluents is incorrect nutrient dosage. The industry effluents usually lack in nitrogen and phosphorus concentrations to meet the requirements of the activated sludge treatment. Other problems that occur in activated sludge process are sludge bulking, foaming and sludge rising. (Davis, 2010; Hynninen, 2008)

Activated sludge process effectively removes 92 – 94 % of the BOD and 70 – 90 % of COD from board mill effluents. (Hynninen, 2008) A study by Junna & Rintala (1990) on activated sludge treatment efficiency on pulp, paper and board mill effluents showed an average BOD removal efficiency of 80 – 90 %. For the board mill data, the average COD_{Cr} removal rate was 70 %.

4.3.2 Attached growth processes

Some type of growth media is used in attached growth processes, where the microorganisms form a film. The growth media can be a disk, bed, stones or a plastic material, and the wastewater is applied on it. Air is applied to circulate between the media elements. To prevent too high BOD and suspended solids content, excess microorganism growth gets removed from the matter. (Davis, 2010)

Trickling filter is a type of an attached growth process, where a trickling bed is filled with a media, typically modules of plastic sheets and rings to ensure high growth surface area. (Davis, 2010) An attached growth process can successfully remove 70 – 80 % of COD from wastewater (Kahmark & Unwin, 1999). Muhamad et al. (2015) studied the treatment efficiency of an attached growth sequencing batch reactor with paper mill effluent. The results showed that the treatment removed approximately 93 % of the COD and 82 % of the suspended solids of the effluent.

4.3.3 Membrane bioreactors

Membrane bioreactors (MBR) utilize suspended biomass in a biological reactor and a solid matter separation with the aid of micro- or ultrafiltration membranes. MBRs are either integrated or separate systems. Integrate systems have the membrane unit inside the bioreactor, whereas in separate systems the membrane unit is external. MBRs can be used as an add-on to an activated sludge process or biological nutrient removal process. (Davis, 2010)

Membrane bioreactors combine activated sludge treatment and membrane filtration technology for biomass separation. The effluent quality is significantly better after treatment with MBR compared to conventional activated sludge treatment: MBRs remove colloidal and suspended solids as well as bacteria. MBRs are able to treat the same quantities of wastewater as the conventional activated sludge processes but with a significantly smaller footprint as there is no need for secondary clarifier in the process. (Cornel & Krause, 2008)

Erkan & Engin (2017) studied the MBR treatment efficiency for a paper mill effluent with a submerged membrane bioreactor. The achieved COD removal efficiency was 98 %, and the nutrients removal rates were 93 – 96 %. Despite the good treatment results, a problem with calcium accumulation was found as it caused membrane fouling. Paper mill effluent treatment efficiency with MBR was also studied by Stahl et al. (2004). The MBR treatment resulted in 86 % COD and 98 % BOD removal rates.

4.3.4 Anaerobic processes

Anaerobic processes function in the absence of oxygen. The microbes break down organic matter to produce methane, carbon dioxide and water. Other gases such as nitrogen, hydrogen and hydrogen sulphide are also produced as side products. Anaerobic processes are either mesophilic or thermophilic, which means they operate in temperature ranges 29 –

38 °C or 49 – 57 °C, respectively. Mesophilic processes are more common even though the reaction rates are higher in the thermophilic processes. Thermophilic processes are more sensitive to disruption, which makes them more difficult to operate. (Hynninen, 2008)

Anaerobic treatment has three phases: hydrolysis, acid formation and methane formation. Controlling the pH is critical for the treatment to function properly. The methane formation in the final phase is especially sensitive for pH changes with a required range of 6.6 – 7.6. Also, if the pH is incorrect, there tends to be carbon dioxide build-up in the system. Anaerobic processes are usually carried out in sludge reactors or biofilm reactors. In sludge reactors the microbes are mixed with the effluent. Biofilm reactors have a medium to which the microbes attach on. (Hynninen, 2008)

Anaerobic processes typically reach the COD removal rates of 60 – 90 %, which are generally lower than in the case of aerobic processes. On the other hand, anaerobic processes require less energy as no aeration is needed. (Judd, 2010)

4.4 Tertiary treatment

Tertiary treatment is applied if the requirements for the treated wastewater are not reached in secondary treatment. Chemical precipitation, membrane and granular filtration and carbon adsorption are considered as tertiary treatment processes, although earlier they were referred to as advanced treatment. As these treatments are more conventional these days, the term advanced treatment does not particularly fit. Treatment processes such as ion exchange, reverse osmosis and nanofiltration, are correctly noted as advanced treatment. In these kind of treatment processes, the objective is to treat the water for reuse purposes. (Davis, 2010)

4.4.1 Granular filtration

If the total suspended solids (TSS) limit for the treated effluent is less than 10 mg/L, filtration is typically used. Filtration can be combined with chemical coagulation to not only remove the TSS, but also BOD within the TSS, as well as the phosphorus. Also, with nitrogen removal combined, up to 90 % nitrogen removal can be achieved. (Davis, 2010)

Granular filtration can be executed typically with normal downflow filters, deep-bed upflow continuous-backwash filters, deep-bed downflow filters, traveling-bridge filters or pulsed-bed filters (Davis, 2010). Combining granular activated carbon adsorption and deep-bed filtration into one treatment step has shown promising results in phosphorus and organic micropollutant removal (Altmann et al., 2016).

4.4.2 Chemical precipitation

Chemical precipitation is performed as tertiary treatment to meet the environmental permit levels if the used secondary treatment has not succeeded in this. Phosphorus precipitation is often carried out as excessive phosphorus causes eutrophication in nature water bodies. Chemical precipitation of phosphorus can be performed with typically one of the three compounds: aluminium sulphate ($Al_2(SO_4)_3$), ferric chloride ($FeCl_3$) or lime ($Ca(OH)_2$). From these, lime increases the pH while aluminium sulphate and ferric chloride reduce it. (Davis, 2010)

4.4.3 Membrane filtration

Membrane filtration is used for separating a wide range of different type and size particles. Membrane filtration is divided into pressure driven and electrically driven membrane processes. Within pressure driven membranes, there are four types of processes: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO).

(Davis, 2010) Electrodialysis is an electrically driven membrane, where electrically charged molecules are separated with the driving force of electrical potential gradients. (Cheremisinoff, 2002)

Typically used membrane filtration examples are microfiltration (MF) and ultrafiltration (UF). MF and UF membranes function as physical barriers. Thus, they remove the pollutants associated with the suspended material. To prevent membrane fouling and to optimize the membrane performance, a pretreatment step is needed. The pretreatment can be e.g. chemical coagulation, screening and flow equalization. Also, the feed water is usually chlorinated in order to avoid biofouling, which is the result of biofilm formation and bioorganic material accumulation. (Davis, 2010)

Ultrafiltration is used to remove suspended, colloidal and high-molecular-mass compounds. Low-molecular-mass and solvent molecules go through the membrane. As with all membrane technologies, the two fractions produced by UF are called concentrate and permeate. Concentrate includes the material that was not able to go through the membrane and permeate holds the components that passed through the membrane. Membrane separation is achieved with a pressure of 0.1 – 1 MPa. MF and UF, as other membrane treatment forms, differ from each other by the size of the particle it retains. (Hynninen, 2008)

Ultrafiltration is used in forest industry for treating the paper or board machine whitewaters as internal treatment. UF is also used in removing resin from sulphite pulping wastewaters, recovering latex and lignosulphonates and treating the mechanical pulping mill's circulating waters. (Nuortila-Jokinen, 2009)

4.4.4 Activated carbon treatment

Activated carbon treatment is used for removing toxic organic compounds. It is also used for removing refractory organics, which are soluble organic matter that don't break down biologically. (Davis, 2010)

Activated carbon can be divided into granular activated carbon (GAC) and powdered activated carbon (PAC). Activated carbon treatment utilizes the physical adsorption phenomenon. The activated carbon particles have capillaries which increase the adsorption surface area. The PAC can be placed straight to the aeration tank or it can be added to the biological treatment effluent. (Hung et al., 2005; Davis, 2010)

GAC treatment is used both as a tertiary and as a secondary treatment. The GAC treatment is carried out in an adsorption column, where the carbon particles are in a fixed bed. The wastewater flows through the activated carbon layers. The most typical activated carbon processes are upflow-pressure fixed bed, upflow fluidized-bed and downflow-gravity fixed bed processes. (Hung et al., 2005) Downflow columns are most typically used as they function in both adsorption and filtration units simultaneously (Davis, 2010).

The activated carbon structure must be regenerated regularly to remove the previously adsorbed material. The regeneration is performed e.g. by acid or base treatment, steam treatment, chemical oxidation or solvent extraction. (Hung et al., 2005) Temmink & Grolle (2005) concluded in their study “Tertiary activated carbon treatment of paper and board wastewater” that better yields were obtained when the activated carbon was regenerated with steam treatment compared to the chemical method. Also, they found out that higher effluent temperatures, which can be result from closing water cycles, made the adsorption process more efficient.

4.5 Best available techniques

The European Union compiles a document of available techniques for emission prevention and minimization for different industries to follow. Separate BAT documents are published for different industries, e.g. for the production of pulp, paper and board. The techniques are developed on the scale that the deployment and use would be beneficial technically and economically. In addition to the used technology, the techniques in this case include the plant design, construction, maintenance, operating and the way the plant is decommissioned. (Suhr et al., 2016)

The main categories of BAT for papermaking and related processes are

I. Wastewater and emissions to water,
II. Emissions to air,
III. Waste generation and
IV. Energy consumption and efficiency.

The concentration of this chapter is on the first category, wastewater and emissions to water. The BATs considering this category are presented in Table XI.

Table XI Best available technologies (BATs) considering papermaking and related processes' wastewater and emissions to water. (Suhr et al., 2016)

BAT number	Description	Technique
47	Wastewater generation reduction	4 Tanks and chests design optimation 5 Treatment of white water, fibre and filler recovery 6 Water recirculation 7 Shower water optimization
48	Fresh water use and emissions to water reduction (specialty paper mills)	8 Paper production planning improvement 9 Water circuit management to cope with changes 10 Wastewater treatment plant designed to cope with changes 11 Broke system and chest capacity adjustment 12 Chemical additive (grease- and water proof agents) release minimisation 13 Switching to product aids with low AOX content
49	Coating colour and binder emission load reduction	14 Coating colour recovery and pigment recycling 15 Coating colour containing effluents' pretreatment

The BAT-AELs are the BAT-associated emission levels that are stated in the BAT document. The yearly averages of the emissions are presented in Table XII for non-integrated paper and board mill. These emission levels are applied only for the emissions generated in normal conditions. (Suhr et al., 2016)

Table XII BAT-associated emission levels for direct wastewater discharge. (Suhr et al., 2016)

Parameter	Yearly average (kg/t)
Chemical oxygen demand (COD)	0,15 – 1,5
Total suspended solids (TSS)	0,02 – 0,35
Total nitrogen	0,01 – 0,1
Total phosphorus	0,003 – 0,012
Adsorbable organically bound halogens (AOX)	0,05 for decor and wet strength paper

Waste generation, the third category of the BATs for papermaking and related processes, states the importance of minimizing the amount of solid waste disposal. For example, the fibre sludge, can be in some cases reutilized in the production process. This requires a high fibre content in the sludge as well as a suitable process. Product quality requirements may in some cases prevent the reuse of the fibre sludge. In many cases, the best option for the generated sludge is thermal reduction method such as incineration. (Suhr et al., 2016)

5. Sludge handling

The paper and board mill wastewater treatments generate a vast amount of solid waste, which needs to be properly handled. This solid waste mostly consists of the sludge removed after primary mechanical treatment. Thus, there are significant amounts of fibres and fillers in the sludge. This primary sludge is typically landfilled or incinerated, although in some cases it could be feasible to recycle the sludge into production on-site or to reuse the sludge elsewhere in production. The approximate amount of the produced dry sludge is 4.3 % of the final product. (Ochoa de Alda, 2008)

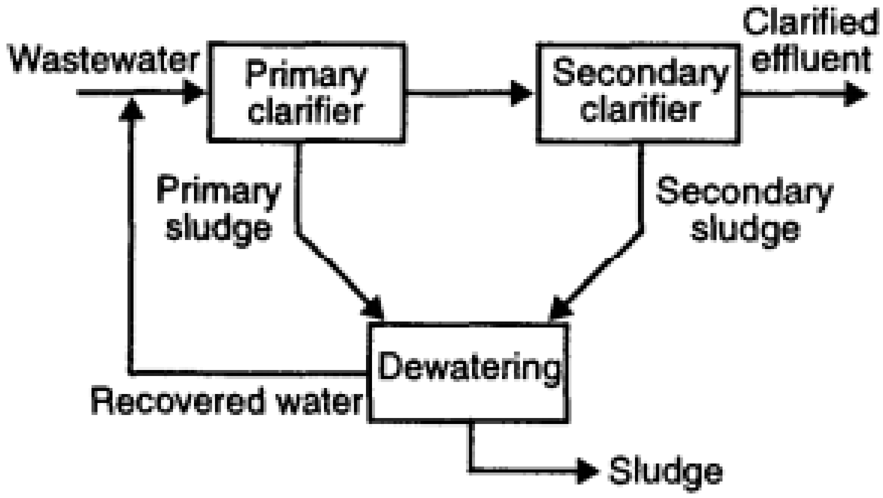


Figure 4 Wastewater treatment and sludge scheme. (Scott et al., 1995)

The sludge characteristics vary depending on the production process and the raw materials used. The produced sludge can be classified by its source: primary, secondary and tertiary sludge. Primary sludge is also called raw sludge or in the case of paper and board mills, fibre sludge. The primary sludge contains fibres, fillers, pitch, ash and small fractions of other solid components such as inert solids from the chemical recovery (Ochoa de Alda, 2008). The secondary sludge is often biosludge from biological treatment. Tertiary sludge varies greatly from case to case depending on the used treatment methods and chemicals. (Bajpai, 2015) Ash content in high-ash sludge is over 30 % of the dry weight and in low-ash sludge under 30 % of the dry weight. Ash content in board mill wastewaters originate mostly from additives, such as mineral clays used in the process. The ash content and sludge type need to be carefully examined when choosing the sludge treatment route. (Davis, 2011; Likon & Trebše, 2014)

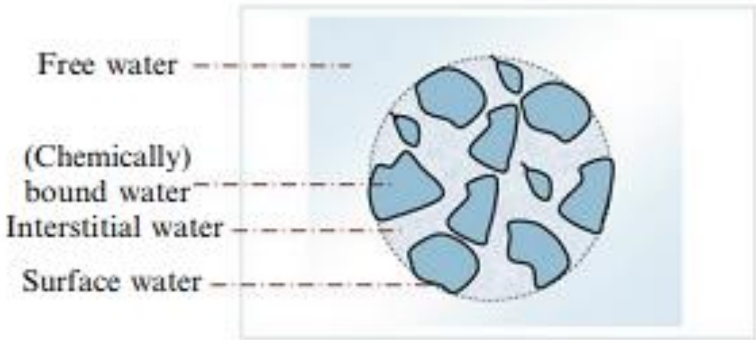


Figure 6 Wastewater sludge’s water distribution. (Mahmoud et al., 2013)

Figure 6 presents the water distribution in wastewater sludge. Mechanical dewatering methods can easily remove the free and interstitial water, but in order to have a desired rate of dewatering, a pre-treatment must be carried out. (Mahmoud et al., 2013) The water removal rates at different stages of sludge dewatering are presented in Figure 7 below.

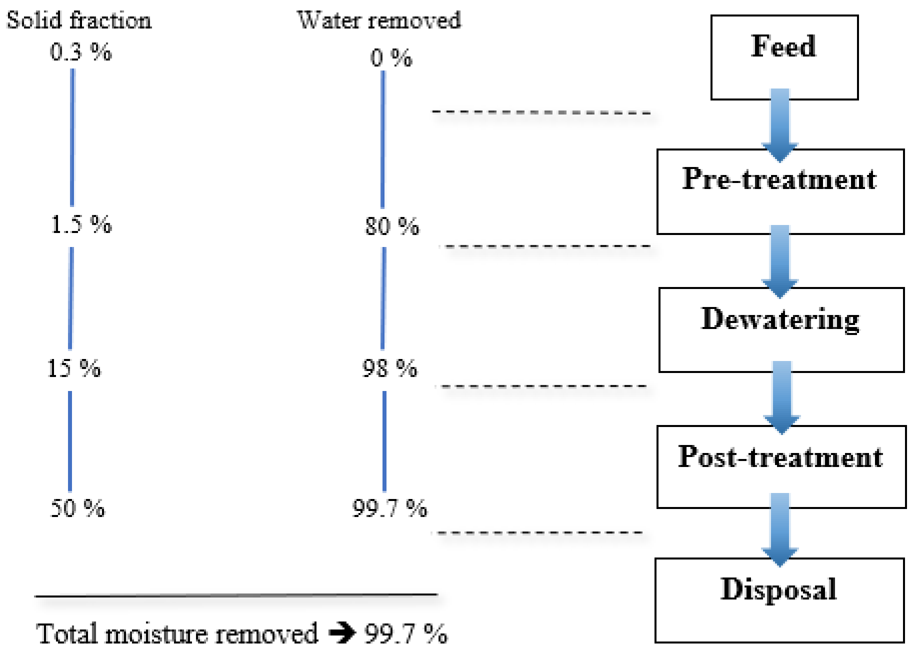


Figure 7 Water removal in sludge dewatering stages. (Edited from Lee et al., 2005)

5.1 Sludge pre-treatment

The sludge pre-treatment technologies include thickening, conditioning, dewatering and drying. Thickening and conditioning can be considered as pre-dewatering technologies as they affect the dewaterability. Dewaterability determines the volume of the sludge to be handled, which makes it a priority parameter. (Bajpai, 2015)

5.1.1 Sludge thickening

Thickening is an important step of sludge pretreatment in all cases. Rotary sludge thickeners and gravity thickeners are most used thickening methods, but gravity belt thickeners, belt presses and dissolved air flotation clarifiers are also used.

Rotary sludge thickeners are often used as pre-dewatering units before screw presses. A rotary sludge thickener utilizes a rotary screen, gravity and a tumbling motion to reduce the sludge water content.

Gravity thickening is often carried out in a clarifier, where the dry solids content increases as the sludge is settled to the bottom of the clarifier. The advantages of gravity thickening are its low operating costs and the ease of operating.

Although gravity thickening is most commonly used pre-dewatering technology, the best results are obtained with gravity tables and belt thickeners. The performances of different thickening technologies are presented in Table XIII below. (Bajpai, 2015)

Table XIII Thickening technologies' performances (Bajpai, 2015)

Thickening technology	Expected solids content (%)
Gravity thickeners	3
Rotary sludge thickeners	4 – 10
Belt thickeners	15
Flotation thickener (secondary sludge)	4
Gravity tables	12 - 22

One of the most common pre-treatments is using a polymer for flocculation and thickening purposes. Hartong et al. (2007) reported that the use of cyclodextrins improve the polymer performance. The addition of cyclodextrins increase the screw- or belt-pressing drainage rates for primary or secondary sludge dewatering, as well as improve cake solids and better filtrate clarity. In a mill trial Hartong et al. (2007) detected a 12.8 % increase in belt press drainage of biological sludge collected from paper mill wastewater treatment plant. The amount of cyclodextrins used was 0.09 kg/tonne sludge. Less polymers are needed if cyclodextrins are implemented in the dewatering process which directly lowers the costs of the treatment. Banerjee (2009) reported that during a several month trial with cyclodextrins in a paper mill, 30 % cost reductions were realized even though cyclodextrins are approximately twice the price of polymers.

5.1.2 Sludge conditioning

Sludge conditioning is performed to enhance the water repulsion of the sludge during dewatering. In forest industry, the typical conditioning treatments are thermal and reactant methods. Reactant methods are also referred as chemical conditioning. Chemical conditioning is the use of chemicals to enhance the preferred sludge qualities for later treatment. Thermal methods are e.g. wet air oxidation and heat treatment. Thermal conditioning results in better dewatering than chemical conditioning, but the costs of thermal conditioning are significantly higher. (Bajpai, 2015)

The solid cake formation can be improved with the aid of chemicals. Lu et al. (2011) reported that applying cellulase enzymes improve the cake consolidation by breaking down the fibres. Shorter fibres can be packed more tightly and thus a denser cake is formed.

Waste activated sludge (WAS) contains bound water that needs to be released with a pre-treatment before proper dewatering is achievable. The suitable pre-treatments are e.g. heat treatment and ultrasound application. (Neyens & Baeyens, 2003)

5.2 Sludge dewatering

Sludge dewatering is an important part of sludge handling. In dewatering, the volume of the sludge is reduced, and the energy value is increased. As the sludge volume is reduced, the possible transportation and landfilling costs are significantly lowered. (Lu et al., 2011)

The desired degree of sludge dewatering depends on the used disposal method. Also, the transportation method and costs in many cases affect the desired dryness level. The sludge should be pre-dewatered if the solids content is 4 – 5 % before dewatering. (Bajpai, 2015)

Primary sludge is relatively easy to dewater because it has high fibre content and low ash content. Primary sludges that contain finely ground wood fibres are more difficult to dewater. Secondary sludge is often mixed with primary sludge to enhance the dewatering process. Although, treating primary and secondary sludge separately can be beneficial. For example, when the secondary sludge can be disposed directly by landspreading, blending primary sludge in would prevent such disposal option. (Bajpai, 2015)

Sludge dewatering is usually executed with vacuum filters, belt or screw presses or flue gas dryers (Kraft & Mitchell, 1991). Natural drying methods, such as sludge drying beds have previously been the preferred method. However, the capacity of sludge drying beds is suitable for smaller plants. (Davis, 2010) Mechanical dewatering methods are often preferred for their low energy consumption. There are suggestions regarding the intensification of these conventional mechanical dewatering methods. Applying and additional force, such as shear, ultrasonic, magnetic, microwave or electricity has been studied. (Mahmoud et al., 2013) This chapter focuses on the mechanical sludge dewatering methods.

5.2.1 Belt filter press

Belt filter presses (BFPs) are widely used dewatering methods for their cost-efficiency and functionality. (Lee et al., 2005)

The belt filter presses (BFP) operate continuously by pressing the sludge between two filter belts. A schematic of a BFP dewatering unit is presented in Figure 8. Before the sludge is fed to the drainage zone of the BFP, it is conditioned with a polymer flocculant to enhance the dewatering. The conditioned sludge is then drained first with the aid of gravity, where it is led to the compression zone. At the compression zone, the sludge is pressed between two belts where the final dewatering is achieved. After the pressing, the formed cake is scraped off from the belt surface and the belts move to the washing section and start the round over. (Bajpai, 2015; Weiner & Matthews, 2003)

When the solid concentration of the feed sludge is 2 – 5 %, the reached solid content is 15 – 25 % in a continuous process. The surface loading of a BFP is 45 – 550 kg/h/meter of belt width. Energy consumption of belt filter press dewatering is 10 – 25 kWh/tonne of sludge. (SNF Floerger, 2003; Bajpai, 2015; Lee et al., 2005)

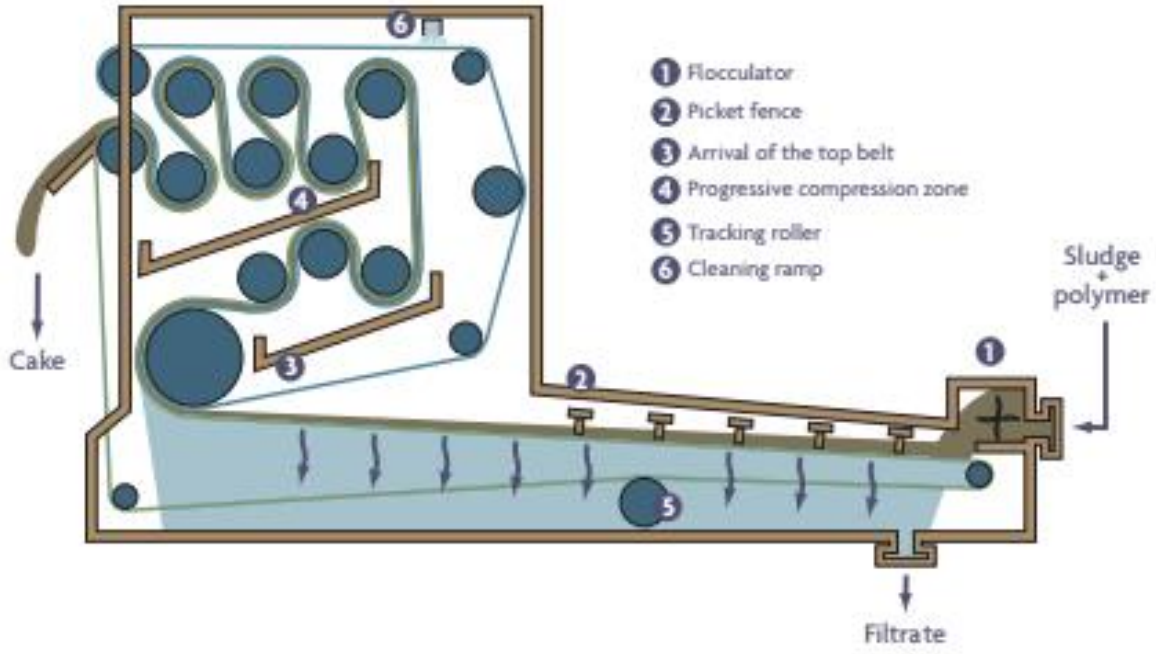


Figure 8 Schematic of belt filter press (BFP) dewatering unit (SNF Floerger, 2003)

BFP have low procurement costs and energy consumption. The disadvantages of BFP are typically associated to the possible open structure, which causes high noise levels. Also, the cylinders and belt need regular maintenance. (von Sperling, 2007)

5.2.2 Plate-and-frame filter press

Plate-and-frame filter press is a type of pressure filter, that creates pressure to squeeze the water out of the sludge. In plate-and-frame filters, the dewatering is achieved by pressing the sludge between plates and frames. (Weiner & Matthews, 2003)

The plate-and-frame filter presses are batch-operated and have three stages: sludge loading, filtration and filter cake unloading. The sludge is pumped at increased pressure into filter cloth surrounded plates. With the increased pressure, the sludge is forced to pass through the filter. A cake is formed as the solids are retained on the filter cloth. (von Sperling, 2007) The structure of a plate-and-frame filter press is presented in Figure 9.

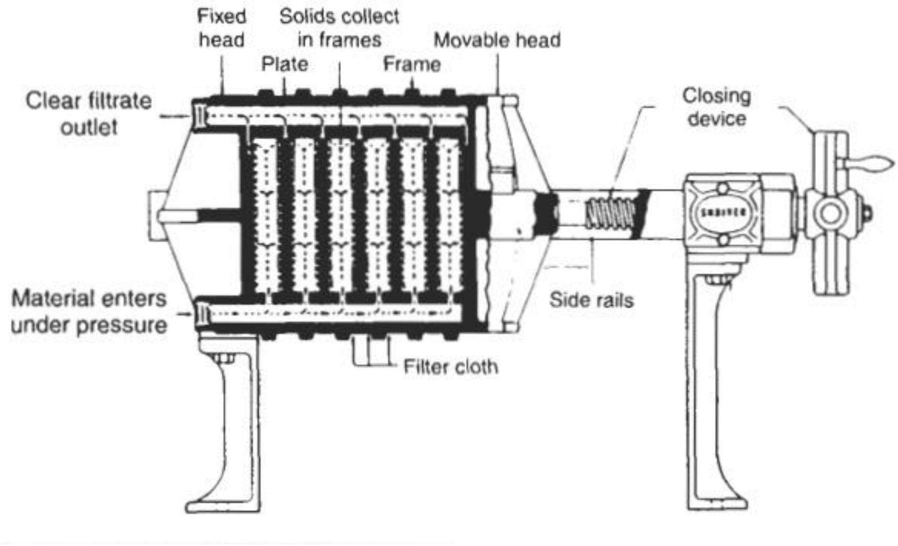


Figure 9 Structure of a plate-and-frame filter press. (Weiner & Matthews, 2003)

The main advantages of a plate-and-frame filter press is the efficiency and the low required amount of sludge conditioning. However, the filter cloths require regular substitution, which increases the maintenance costs. Despite the high level of automation in the plate-and-frame filter presses, they still require significant attention from the operator. (von Sperling, 2007)

5.2.3 Vacuum filter

In a vacuum filter, filter cake is formed on a filter medium with the aid of vacuum. Vacuum filters can be categorized to batch- and continuously operated filters. The filter cake is removed at the end of the batch run, whereas in continuous operation, the cake is continuously removed. The continuous nature of the drying unit makes processing large quantities possible. (Geankoplis, 1993)

Figure 10 shows the schematic of a rotary drum vacuum filter. The automatic valve in the centre of the rotary drum activates the different functions in the drum cycle. The filtrate water is removed from the filter axel. The filter medium, belt, is fixed to the drum. (Geankoplis, 1993; Bajpai, 2015)

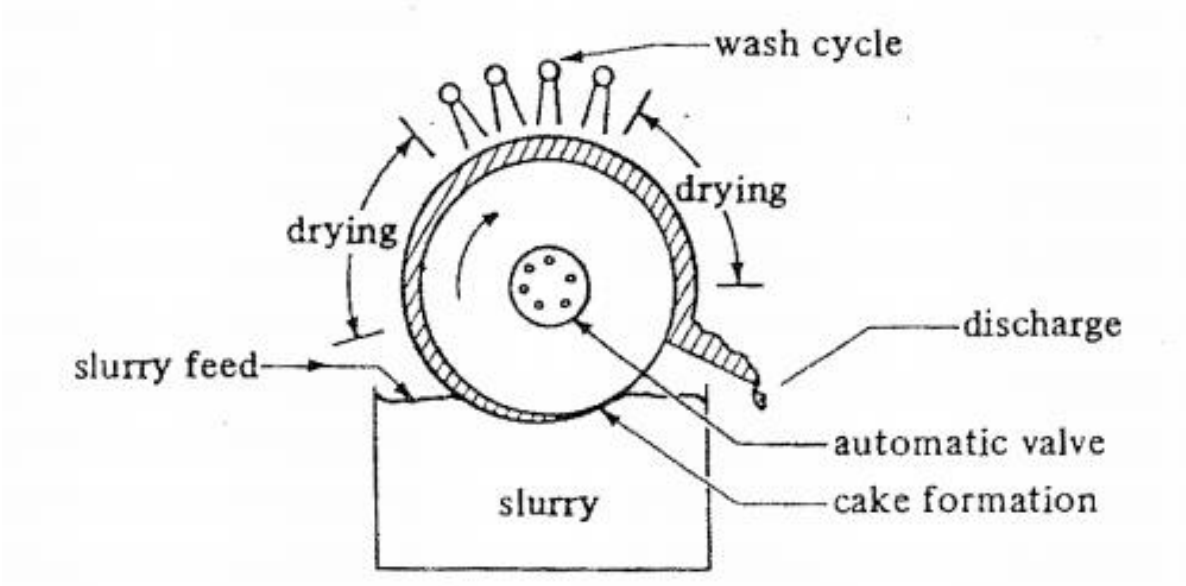


Figure 10 Schematic of a rotary drum vacuum filter. (Geankoplis, 1993)

Typically, 10 – 40 % of the drum surface is in the tank to where the sludge is fed. The cake is formed on the drum surface when vacuum migrates the water inside the drum. The dewatering area covers approximately 40 – 60 % of the drum surface. The dewatered sludge is discharged at the unloading zone, where the automatic valve switches the vacuum into atmospheric pressure and a scraper removes the filter cake from the filter medium. (von Sperling, 2007)

Rotary drum vacuum filters require very little operator attention as they operate continuously. The vacuum level limits the usage of a rotary drum vacuum filter, especially if the dewatered sludge contains small particles. (Wakeman, 2007)

5.2.4 Screw press

Screw press consists of a screw conveyor inside a wire screen casing. In screw press sludge dewatering, the sludge is pressed against a casing wall by a screw conveyor. The casing screen has typically 0.25 mm openings. The screw conveyor moves dewatered sludge forward while rotating at a rate of 1 – 4 rpm. (Hynninen, 2008; Davis, 2010) The structure of a screw press is presented in Figure 11 below. Screw presses are most suitable for primary or fibre sludges from pulp and paper industry. They are able to dewater sludges with a solids concentration of <1 %. Secondary sludges are rarely dewatered with screw presses because the slimy texture is an issue for screw press' functioning. (Bajpai, 2015)

The specific energy consumption of screw press dewatering is 10 – 30 kWh/tonne of sludge. The reached dry solids content is typically 30 – 50 % depending on the pre-dewatering and conditioning of the sludge. (Bajpai, 2015)

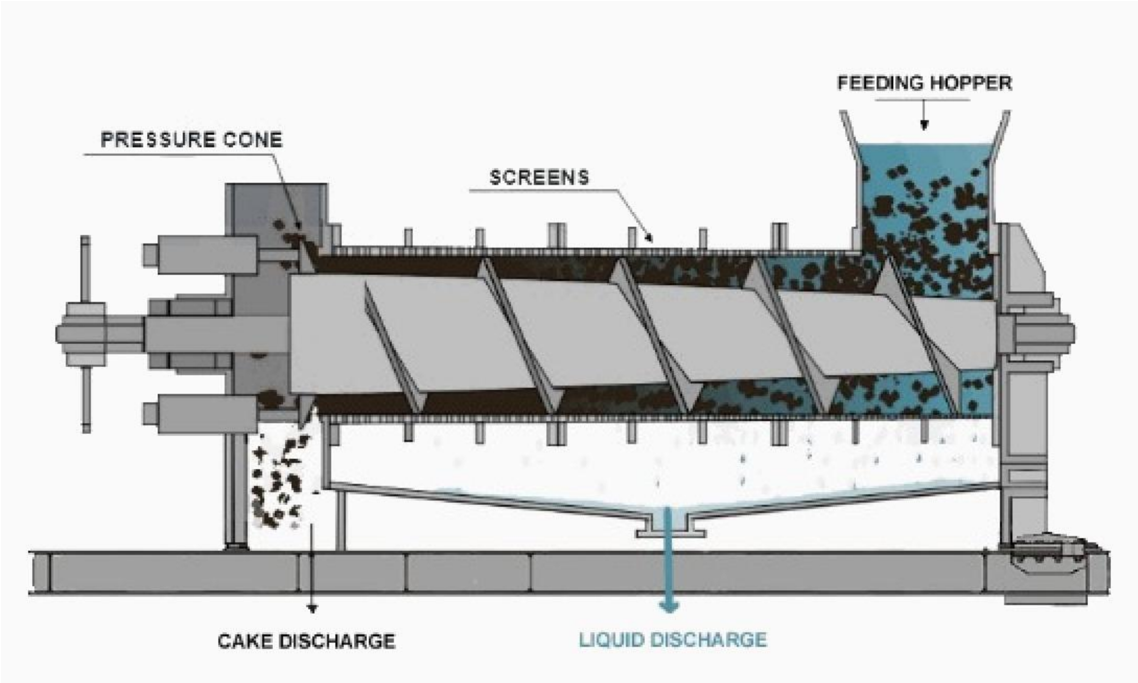


Figure 11 Structure of a screw press dewatering unit (Shredding & Dewatering, 2018)

Screw presses can be slightly inclined, so that gravity enhances the dewatering. The slope is usually about 20 ° from horizontal. (Davis, 2010)

5.2.5 Centrifuge

Centrifugal dewatering equipment consists of a spinning bowl or basket that create a centrifugal force. This centrifugal force separates the liquids from the solids in the sludge. Most commonly used centrifuge in dewatering is a solid bowl centrifuge, but there are applications of disk and basket type of centrifuges also. (Bajpai, 2015; Lee et al., 2005)

In solid bowl centrifuge, flocculants are fed to the centrifuge simultaneously with the sludge feed. The bowl rotates at 1500 – 4000 rpm and moves the solids towards the outer wall of the centrifuge bowl. The solid cake forms on the outer wall and is discharged by pushing towards the bowl's narrow end with the aid of a conveyor. (Lee et al., 2005; Hynninen, 2008) A scheme of solid bowl design is presented in Figure 12 below.

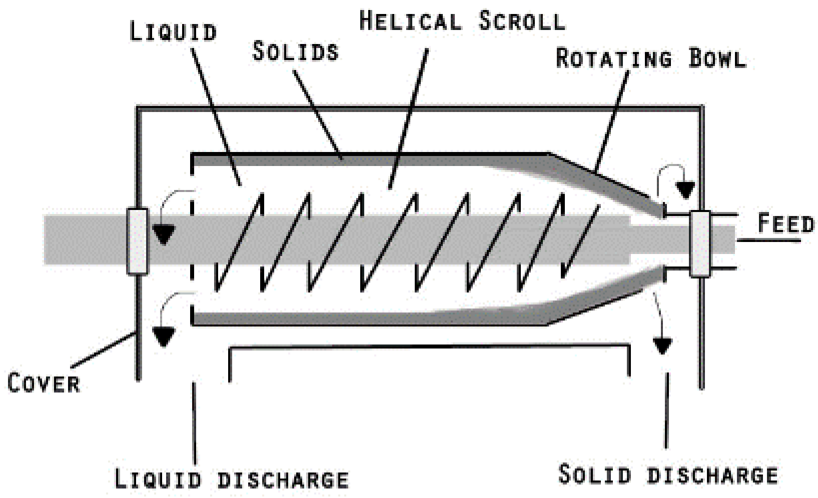


Figure 12 Solid bowl centrifuge design scheme. (Orris & Eugene, 1969)

Centrifuges can be used for both sludge thickening and sludge dewatering. They are easy to operate and require low quantities of conditioning polymers. However, centrifuges produce a lot of noise and vibration, and certain machine parts tend to wear out requiring regular maintenance. (von Sperling, 2007)

The dewatering results with centrifuges are typically between 10 and 35 % dry solids content depending on the raw sludge and sludge conditioning method. Solid bowl centrifuges show the best results in dewatering with dry solids content up to 65 %. Centrifugal dewatering specific energy consumption is 20 – 60 kWh/tonne of sludge. (Bajpai, 2015) The operational costs are rather high because of the energy consumption and the high maintenance costs. The capital costs however are typically relatively low for centrifuges due to the simple and compact structure. (Cheremisinoff, 2002)

5.2.6 Summary of the sludge dewatering methods

The previously introduced sludge dewatering methods are summarized in Table XIV in terms of the reached dry solids content (DSC), energy consumption as well as the advantages and disadvantages.

Table XIV Sludge dewatering methods' efficiency in terms of the reached dry solids content and energy consumption. (Bajpai, 2015; SNF Floerger, 2003; Hynninen, 2008; von Sperling, 2007; Metcalf & Eddy, 2003; Lee et al., 2015)

Method	**Sludge type**	**Reached DSC [%]**	**Energy consumption [kWh/tonne of sludge]**	**Advantages**	**Disadvantages**
Belt filter press (BFP)	Primary Secondary Mixed	15 – 25	10 – 25	Low energy consumption Low procurement costs Continuous operation	Noise level Maintenance costs Possible odour issues
Plate-and-frame filter	Primary Secondary Mixed	25 - 45	25 – 60	Efficiency Low quantity of conditioning polymers needed	Maintenance costs Batch operation High energy consumption
Rotary drum vacuum filter	Primary	15 - 30	-	Continuous operation	Limited usage for sludges containing smaller particles
Screw press	Primary	30 – 50	10 – 30	Low operating and maintenance costs Continuous operation Able to dewater thin sludges	High space requirements
Centrifuges	Primary Secondary Mixed	10 – 35	20 - 60	Easy operation No odour issues Continuous operation Low space requirements	Noise and vibration Wearing of components High energy consumption

5.3 Sludge disposal

The common sludge disposal method is landfilling, although it has become more and more expensive due to EU regulations and taxes. Hence, some sludges are incinerated to recover the energy within them and to reduce their volume. (Ochoa de Alda, 2008; Bonilla et al., 2015)

The incineration is often carried out on-site in existing boilers, which eliminates the transportation costs. Normally the sludge going to the incineration has a DSC of 20 – 40 %. The incinerated sludge is reduced in volume and transformed into an inorganic form, which is then landfilled at a more inexpensive and easy way. Incineration is a viable option for forestry sludges such as the fibre sludges from pulp, paper and board mills. The primary and secondary sludges are often mixed before mechanical dewatering. However, the fibrous primary sludge has a significantly better heat value if incinerated without the secondary biosludge. (Ochoa de Alda, 2008; Bonilla et al., 2015; Hynninen, 2008)

Landfilling is a disposal method that has been widely used. The EU landfill directive determines the appropriate landfill sites. The sludge must be properly dewatered in order to reach the highest possible DSC so that the overall sludge volume is minimized before landfilling. The sludge is classified as for its composition and possible components that can be leached out of it. The EU Landfill Directive has a Waste Acceptance Criteria (WAC), that classifies the sludge into one of the three categories: inert, non-hazardous and hazardous landfills. With this knowledge, the sludge can be accepted to the suitable landfilling site. (Hynninen, 2008)

Landspreading may in some cases be a viable sludge disposal option. The sludge is applied to agricultural or forest lands as fertilizer in either nondewatered or dewatered form. The method is ideal when the mill owns enough land nearby where the sludge can be spread. Otherwise transportation costs may be quite high, especially if the sludge is spread in nondewatered form. The main concern with landspreading is the sludge composition: there must not be high concentrations of harmful compounds such as heavy metals that will bioaccumulate in plants. (Scott et al., 1995) Usually this is not a problem for forestry sludges, although in the case of bleached sulphate pulp production, there can be chlorinated organic compounds present in the sludge. In this case, there should be more research about the environmental impact before using the sludge for landspreading purposes. (Hynninen, 2008)

The primary sludges can also be utilized as filler materials directly in the production process. Scott et al. (1995) state that sludge can improve the strength and stability when applied as filler material to board grades. However, applying sludge to the production process can affect the process runnability (Hynninen, 2008).

Other possible sludge disposal methods include using the sludge in the production of construction materials, such as bricks and adhesives (Hynninen, 2008). Jaria et al. (2017) studied the use of sludge as carbon-based absorbents to be utilized in water remediation.

6. Case study: folding boxboard mill wastewater treatment

The object of this case study is the wastewater treatment plant of a Finnish folding boxboard mill that is part of a complex that consists of a wood handling section, debarking section, grindery, a power plant, paper mill and a wastewater treatment plant.

The case mill uses bleached groundwood pulp and broke as middle layer raw materials, bleached hardwood pulp for the base and surface layer. The surface is coated one or two times depending on the final product. Kaolin and calcium carbonate are used in coating and as fillers. Starch is also used as a coating material. The basis weight of the produced folding boxboard varies from 190 to 335 g/m^2.

In addition to the actual case mill's wastewaters, the treatment plant also collects waters removed from the short cycle's clear filtrate tank and the wastewaters from the on-site testing centre as well as the wastewaters removed from the chemicals department of the mill. The collected wastewaters are normally treated in the integrate wastewater treatment plant. However, if there are disturbances or malfunctions in the integrate wastewater treatment plant, the wastewaters are treated in the case mill's own plant.

6.1 Wastewater characteristics

The case mill wastewater characteristics are presented in this chapter considering COD, dry matter content, pH, conductivity and ash content. The characteristics present the quality of the wastewater that enters the treatment plant. There is always small variation in these values, which is the result of production rates, production breaks and variations with the used raw materials and additives related to the different end products.

Figure 13 presents the dry matter content in the Case Mill wastewater as monthly and yearly averages. The monthly variation has been greater in the autumn months because of the yearly maintenance break in the production. The wastewaters consist more of washwaters during the production break. This impacts the wastewater characteristics, such as the dry matter content.

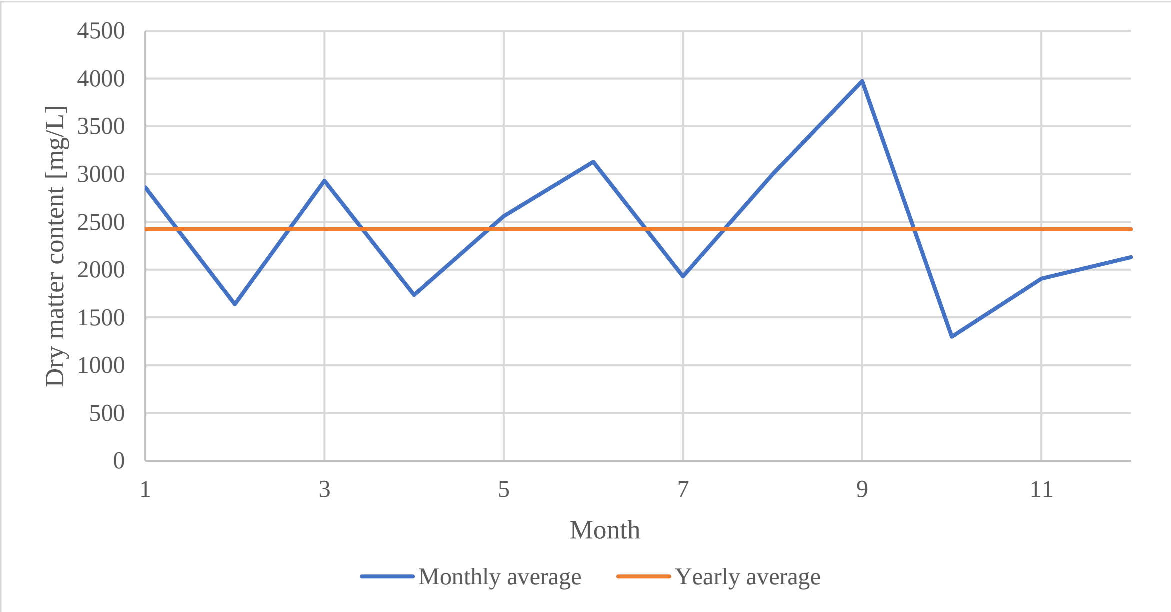


Figure 13 Dry matter content in the Case Mill wastewater in year 2018: monthly and yearly averages.

The monthly average COD levels are presented in Figure 14 below. As seen from the figure, the average COD levels have been higher in the last two years compared to three previous years. This can be due to process changes considering raw materials or additives. It can be noted that the COD levels dropped significantly at the end of the year 2017 and were for the most parts lower in the year 2018 compared to the previous year.

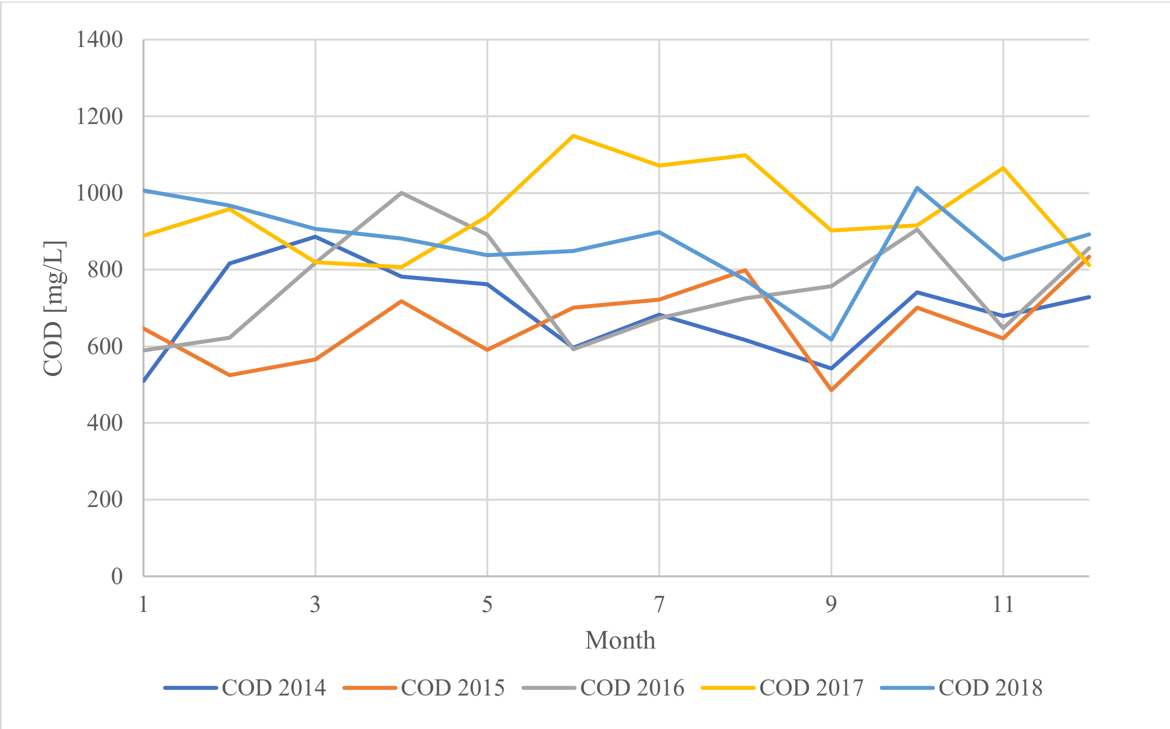


Figure 14 Monthly average chemical oxygen demand (COD) levels of the Case mill in years 2014 – 2018.

The case mill wastewater's conductivity is a parameter that is monitored daily with specific conductivity meters. Figure 15 presents the conductivity levels in the year 2018. Conductivity shows the salt concentration in the wastewaters, and salts can accumulate in the process especially with closed cycles.

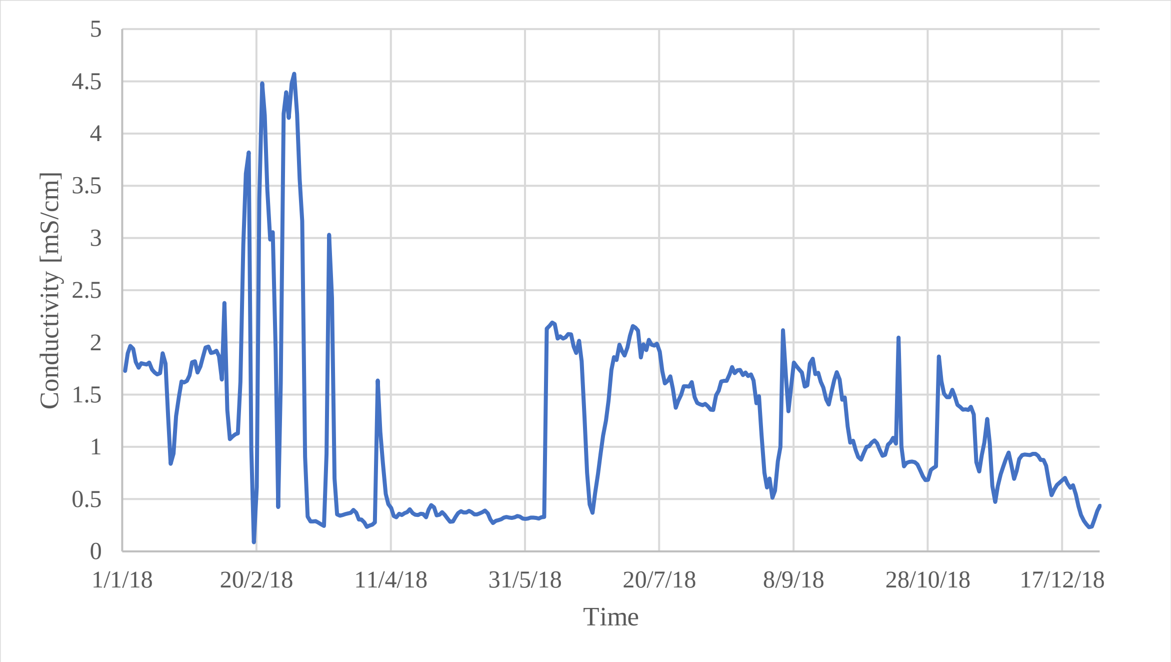


Figure 15 The case mill wastewater conductivity in the year 2018.

As seen from the Figure 15, there is major fluctuation in the conductivity levels in the year 2018. This fluctuation can be due to changes in the water usage and production rates. The period during April and May of 2018 show significantly lower conductivity levels. The conductivity is measured from the line that leads to the integrate treatment plant, and the low conductivity levels are from a time that the wastewaters were mostly treated at the Case Mill treatment plant.

Figure 16 presents the ash content in the Case Mill wastewater during the year of 2018. Ash content in the wastewater originates from the inorganic substances. For the wastewater treatment, ash content is monitored because it impacts the sludge dewatering and disposal options.

The average ash content during the year 2018 was approximately 28 %. As previously mentioned, wastewater sludge with over 30 % ash of the dry weight is considered high ash content sludge. As the ash content in the wastewater is around 30 %, it can be stated that the sludge produced in the wastewater treatment process has high ash content. The ash in wastewaters originate from the board-making additives such as clay minerals. Kaolin is a clay mineral that is used in coating and a filler in the Case Mill.

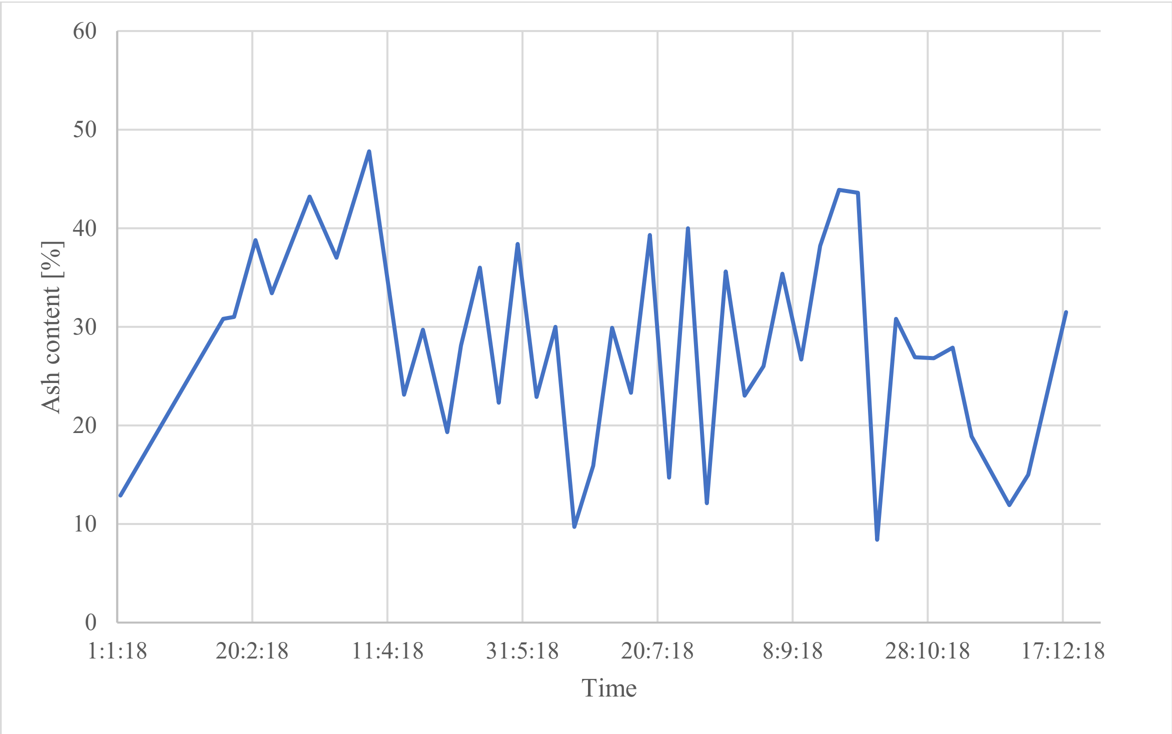


Figure 16 The case mill wastewater ash content in year 2018.

The temperature of the wastewaters is not a critical parameter. There is no secondary biological treatment at use in the Case Mill treatment plant, which would need a specific temperature for proper functioning. Although, slight increase in temperature can augment the settling rate in the primary clarifier.

6.2 Wastewater flow

The Case mill's wastewater flow to the treatment plant has fluctuation depending on the production rates. The monthly averages of the year 2018 for the wastewater flow are presented in Figure 17.

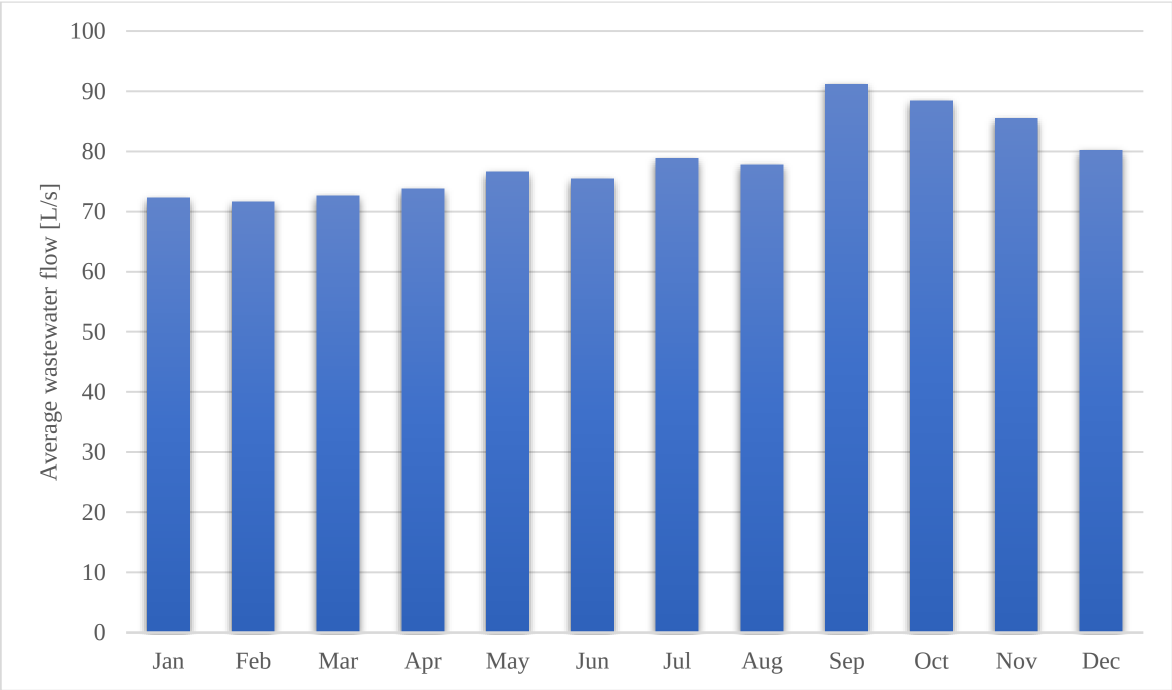


Figure 17 Monthly averages of the wastewater flow to the treatment plant in the year 2018.

The average wastewater flow was 78,6 L/s in the year 2018. There is quite a lot of fluctuation in the wastewater flows. During production breaks and washing the wastewater flows can be either zero or 2 – 3 times the normal flow. The maximum flow rate was 280 L/s in the year 2018. Although these flow peaks are only momentary, the wastewater treatment plant must be able to retain its proper operation during peak flows also. The wastewater flow during a nearly 4-day production break is presented in Figure 18.

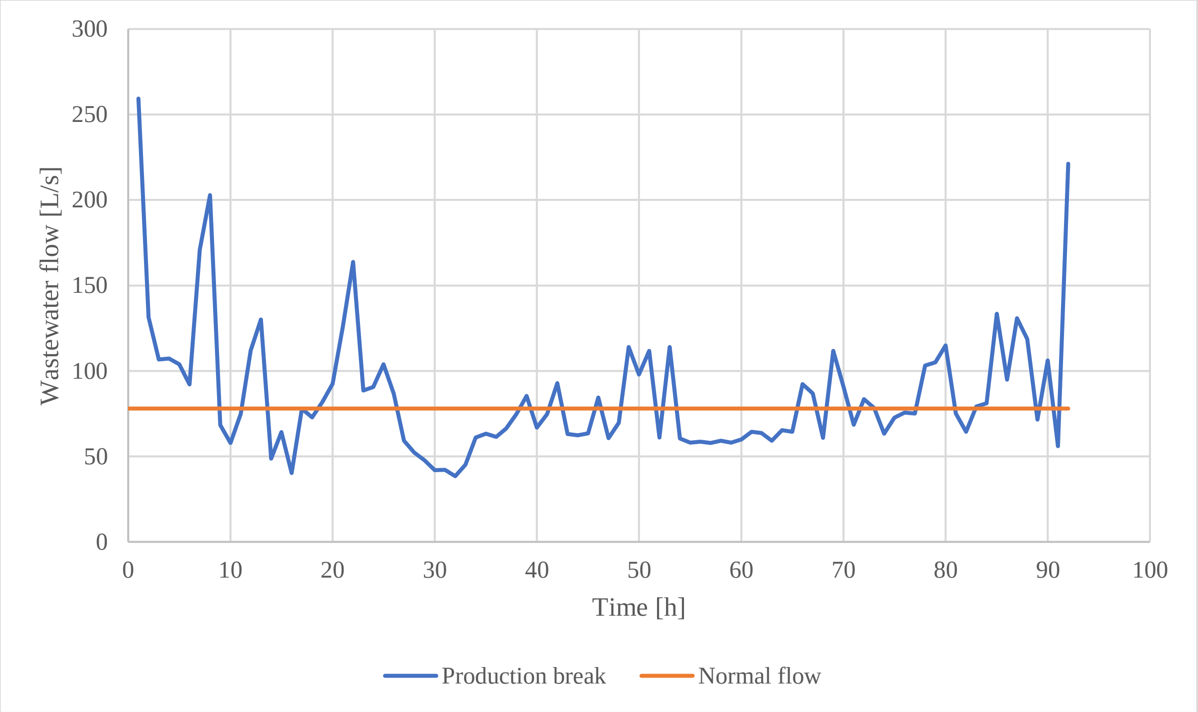


Figure 18 Wastewater flow during a production break compared to the normal wastewater flow.

6.3 Wastewater treatment

The case mill's wastewater treatment plant consists of an equalization basin, primary clarifier, buffer tank, a pressurized screen and a sludge drying unit. Thus, the primary wastewater treatment can be executed in the case mill's treatment plant, as well as the sludge handling. The case mill treatment plant equalizes the wastewater loads to the integrate treatment plant. The case mill's treatment plant structure is presented in Figure 19 below.

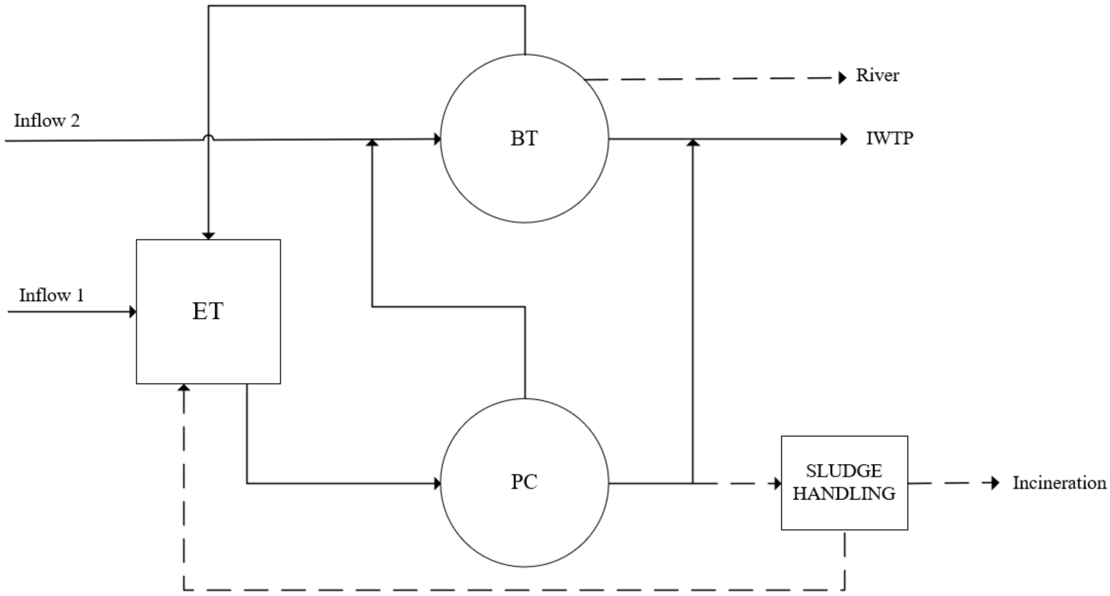


Figure 19 Case mill wastewater treatment plant structure.

As seen from Figure 19, the equalization tank (ET) helps to stabilize the flow rates to the primary clarifier (PC). Inflow 1 considers all the wastewaters from the case mill, and occasionally also the wastewaters from the test centre. Inflow 2 includes the clear filtrate removed from the short cycle. In normal conditions, the wastewaters from the equalization tank are led to the primary clarifier, where the sludge is separated. The effluent goes into the buffer tank (BT) and is led to the integrate wastewater treatment plant (IWTP). The separated sludge is also led to the integrate treatment plant. The wastewater pH is adjusted with alum when the waters are led to the integrate treatment plant.

The dash lines in the Figure 19 represent the possibility of handling the wastewater and sludge on-site. In that case, the separated sludge is dewatered and sent to the integrate power plant for incineration. The effluent is led to ground pools and filtered through a sand bed before reaching the natural water bodies.

The feed for both primary clarifier and buffer tank is through the bottom of the units. In the primary clarifier tank, the settled sludge is removed with a built-in scraper and the effluent is led to the buffer tank. There is also a possibility to remove settled sludge from the buffer tank to the sludge dewatering. However, in normal conditions the total solids content is so low that this isn’t necessary.

In addition to the settled sludge, there are also some rising sludge in the primary clarifier. This can be due to septicity. The rising sludge is removed from the surface with the aid of a baffle that directs the sludge to a sludge removing channel. The septicity is analysed with the redox potential (oxidation-reduction potential, ORP).

6.4 Sludge handling

The sludge generated in the wastewater treatment is primary sludge from the primary clarifier. The thickness of the removed sludge is approximately 4 %. The sludge is removed from the clarifier with a scraper and sorted with a pressurized screen except when the sludge is led to the drum screen filter. In normal conditions, the accept from the pressurized screen is led to the equalization basin. The reject sludge is either led to the integrate treatment plant or dewatered on-site. There is a possibility to add polymer to the reject line of the pressurized screen before the reject sludge reaches the dewatering unit to improve the sludge dewaterability. At the moment no polymer is used.

The sludge is dewatered either with a drum vacuum filter or a screw press. The screw press' capacity is only 10 dt/d, but it can reach up to 60 % dryness. The screw press is used as the main dewatering device, and the drum vacuum filter is used for its significantly larger capacity as a backup.

The capacity of the drum vacuum filter is 200 t/d, and it dewaters the sludge to 20 – 30 % dryness. As seen from the relatively low dewatering capacity, the drum vacuum filter is unable to catch the fine solids, thus some fine solids pass through the drum screen filter and go back to the primary clarifier. With time, the fine solids accumulate in the process. To solve this problem, a coagulant and flocculant can be implemented to make bigger flocs of the fine particles. A polymer has been previously used as a flocculant.

The dewatered sludge is led outside to a collecting area with a belt conveyor. During the winter there are usually major problems with the belt conveyor freezing. Thus, the control circuit is set to automatically start the conveyor if temperature drops below 2 °C. This ensures that the conveyor does not freeze shut. Also, low dewatering rate of the sludge makes the freezing problem worse. There is a need for another solution to prevent the freezing of the belt conveyor.

The dewatered sludge is burned in the integrate's power plant for thermal energy. To reach better heating value, it is possible to dry the sludge further at the power plant.

6.5 Wastewater analyses

The wastewater samples are collected with automatic sample collectors. The samples are collected and analysed once a day. The daily analyses include pH, TS and ash content. In addition to these measurements, the total wastewater flow is carefully monitored as well.

As the Case mill's wastewaters are normally led to the integrate treatment plant, the collected wastewater samples are taken and sent to the integrate paper mill's laboratory for COD analysis two times a month. Nutrients, phosphorus and nitrogen, are analysed every three months from these samples. If the tanks have any overflow, a sample is taken from it once a day and sent to the paper mill's laboratory for TS analysis and sample storing.

The oxidation reduction potential (ORP) is measured once a week from the wastewater feed stream as well as from the two buffer tank samples: the automatic sample collector's sample and a freshly taken one. The ORP shows the amount of oxidation or reduction substances in the wastewater, which indicates the disinfection potential in the water.

For the Case Mill, there are alarm limits for the overall wastewater flow and for the total solids content. These limits are 8000 m^3/d and 9000 kg/d, respectively.

6.6 Environmental permit

In Finland, the environmental permits are assigned by the Regional State Administrative Agencies. The permit covers actions that may cause harm to the environment including the emissions to water, air and soil. In this chapter, the focus is on the water emissions.

The environmental permit that applies to examined board mill considers the emission levels for the whole integrate. There are single limits for the entire integrate's emissions to water. It is impossible to create a certain limit values that consider only the board mill emissions because the environmental load depends on the sum of the whole integrate. There are set limits in the environmental permit for BOD_7, COD_{Cr}, phosphorus and nitrogen.

When considering the environmental load of the case mill only, it would be better to investigate the changes in the emission levels and the factors that impact on that.

6.7 Operational hazards and problems

In order to be able to operate the wastewater treatment plant successfully despite the conditions, possible hazards must be taken into consideration beforehand. The possible disturbance can be related for example to flow control, equipment breakage, weather, wastewater consistency and production breaks.

There has been a problem with hydrogen sulphide (H_2S) formation in the case mill wastewater treatment plant. The lack of oxygen boosts the H_2S formation reaction. This can be due to the long detention times in the clarifiers or the low capacity of the sludge handling. The sludge dewatering is carried out in a separate building, which gives the H_2S a benign formation space. Preventing the H_2S formation is important for the operability and safety, since H_2S gas is colourless and extremely toxic gas from levels 500 ppm forward. H_2S causes unwanted odours to the treatment plant. Also, hydrogen sulphide converts naturally into sulphuric acid which causes corrosion to steel and concrete.

Different substances have been implemented in trials for removing the H_2S problem. Adding ferric sulphate ($Fe_2(SO_4)_3$) to the process successfully removed the H_2S, but it hindered the sludge dewatering, as the final sludge didn’t have high enough dryness. This was a major problem during winter, when the wet sludge freezes the belt conveyor. The unwanted odours can be caused by septicity in addition to the H_2S. There has been septicity in the equalization tank and the primary clarifier.

Weather must be taken into consideration when discussing about wastewater treatment plant operability in Finland. Freezing is a problem with the conveyor belts, and the primary clarifier settling rate slows down as a result of water getting colder. There is an infrared heater and a brush integrated on the primary clarifier’s rotating bridge to prevent the tank’s edges from freezing during winter. During the summer and autumn, heavy raining may disturb the primary clarifier and buffer tank and result in overflow in the worst case.

During production breaks the wastewater quantities are typically higher than normal. Thus, the clarifier and buffer tank surface levels can be lowered beforehand to prevent overflow.

7. Materials and methods

7.1 Data handling

The data from the wastewater treatment plant was obtained from the Case Mill process analysis programme, Savcor Wedge. The software collects all on-line data from the mill with time stamps enabling in-depth analysis for needed process parameters. The data analysed in this study was all related to the wastewater flow rates. The data analysing was done with MS Excel.

7.2 BALAS simulation

The mass balances of the wastewater treatment were simulated with BALAS simulation tool. BALAS is a steady state simulation programme developed by the Technical Research Centre of Finland (VTT) and especially for pulp and paper industry process modelling. There is a vast selection of different unit operations and it is possible to simulate a paper mill from the mechanical pulping all the way to wastewater treatment.

The BALAS simulation tool includes a flow sheeting programme called Flosheet. The streams and unit operations added to the Flosheet file are initialised and classified BALAS based on the databanks within the programme. Each unit operation has selection of different calculation modules to match the real case as closely as possible. To simplify the simulation, an assumption was made that 1 kg of wastewater equals 1 litre of wastewater. The simulation tool presents wastewater flow as kg/s and the Case mill flow data is presented as L/s. This is an adequate estimation and serves the objects of this simulation well enough. The Flosheet model of the wastewater treatment process is presented in Figure 20.

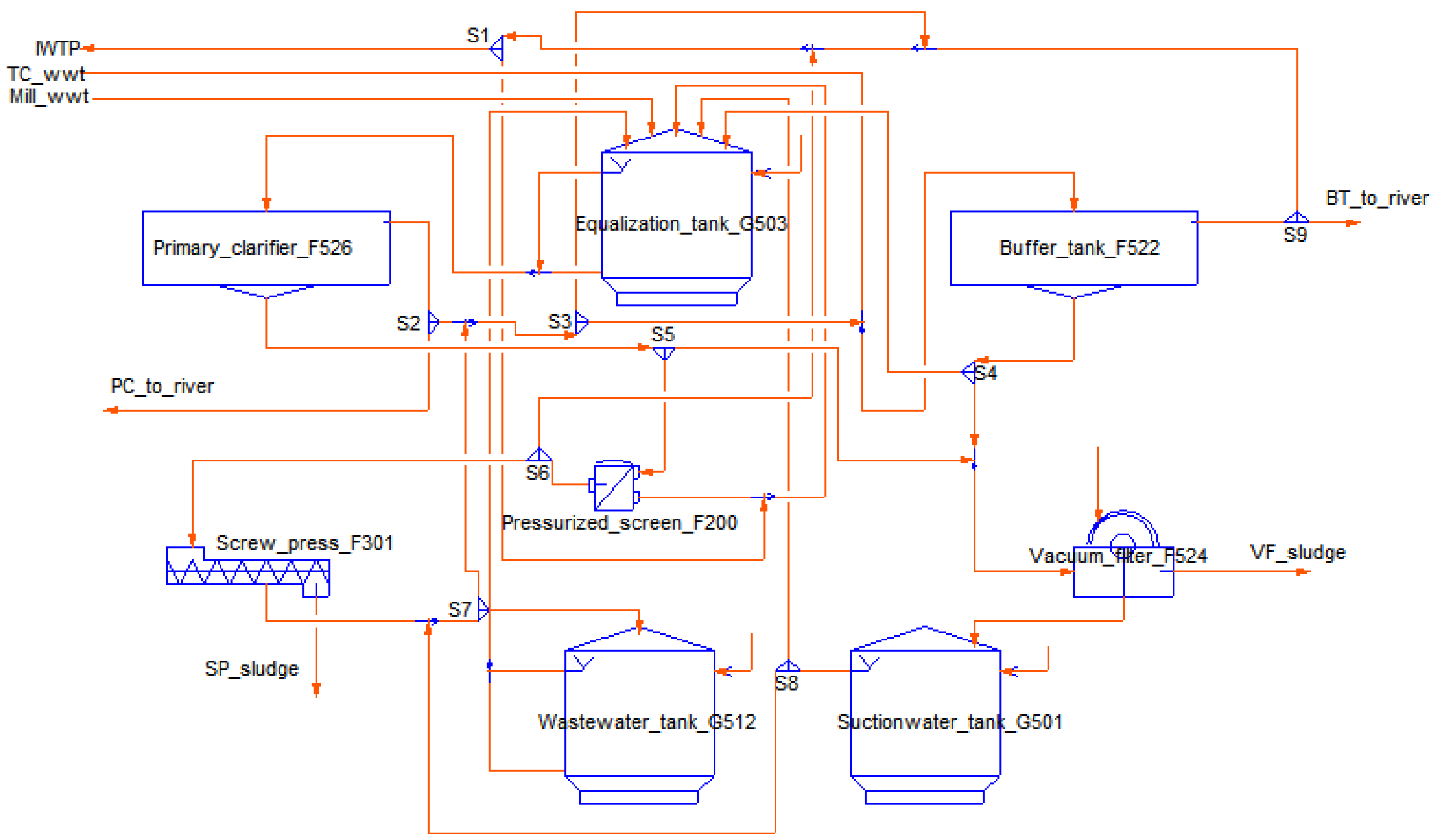


Figure 20 A Flosheet model of the Case mill wastewater treatment plant for the BALAS simulation. IWTP stands for Integrate wastewater treatment plant, TC_wwt for test center wastewater, Mill_wwt for mill wastewater, PC for primary clarifier, BT for buffer tank, SC for screw press and VF for vacuum filter.

The streams are classified as wastewater or water streams. The wastewater streams consist of water and sludge. The fractions are defined for all feed streams. The feed stream definitions are presented in Table XV.

Table XV BALAS simulation feed stream classification and components. Mill wastewater is presented as Mill_wwt, test center wastewater as TC_wwt and vacuum filter wastewater as Washwater_vc.

Stream	Stream class	Components	Fractions
Mill_wwt	Wastewater	Sludge (19.3 MJ/kg) Water	0.003 0.997
TC_wwt	Wastewater	Sludge (19.3 MJ/kg) Water	0.0005 0.9995
Washwater_vc	Water	Water	1

The used unit operations are listed in Table XVI with the used calculation modules and input parameters.

Table XVI BALAS simulation unit operations and their definitions. (* input value changed during simulation)

Unit	**Calculation module**	**Input parameters**	**Input values [%]**
Primary_clarifier_F526	Simple separation module	Reject consistency Temperature drop Recovered components: sludge	4 0.5 85
Buffer_tank_F522	Simple separation module	Reject consistency Temperature drop Recovered components: sludge	0.001* 0.2 98
Pressurized_screen_F200	Simple separation module	Reject consistency Temperature drop Screened components: water	10 0.2 98
Screw_press_F301	Press	Dry content Solids loss Temperature drop	40 5 1
Vacuum_filter_F524	Dewatering element	Web consistency Temperature drop Recovered components: sludge	15 0 30

The settings of the simulation are presented in Table XVII. Splitters were used in the simulation for convenience to have easy access between the cases. In real life, there are different valves for this purpose. The normal drive in the Table XVII presents the situation where the wastewaters are led to the integrate wastewater treatment plant. The splitters S7 and S8 are marked as insignificant, because the sludge is led to the integrate treatment plant line with the aid of splitters S5 and S6.

Table XVII Simulation settings for the flow guiding splitters.

SPLITTER	DESCRIPTION	NORMAL DRIVE	CASE 1	CASE 2
S1	Partial return flow from the integrate treatment plant line	0.9	*insignificant*	*insignificant*
S2	Primary clarifier overflow to the integrate treatment plant (1) or the river (0)	1	1	1
S3	Primary clarifier overflow to buffer tank (1) or the integrate treatment plant line (0)	1	1	1
S4	Buffer tank sludge to equalization tank (1) or to vacuum filter (0)	1	1	0
S5	Primary clarifier sludge to pressurized screen (1) or to vacuum filter (0)	1	1	0
S6	Pressurized screen accept to integrate treatment plant (1) or to screw press (0)	1	0	*insignificant*
S7	Screw press filtrate to wastewater tank (1) or to mix with the primary clarifier overflow line (0)	*insignificant*	1	*insignificant*
S8	Suctionwater tank's waters to equalization tank (1) or to screw press' filtrate line (0)	*insignificant*	1	1
S9	Buffer tank overflow to the integrate treatment plant (1) or to the river (0)	1	0	0

In Table XVII, Case 1 represents the operational model where the wastewater effluents are led to the river after clarification and the sludge is treated on-site with the screw press. Therefore, the splitter S1 is insignificant, as there is no flow to the integrate wastewater treatment plant. Case 2 shows the model where the wastewaters are treated on-site with effluents led to the river. The sludge is in this model treated with the vacuum filter. Therefore, the splitters S6 and S7 are marked as insignificant as they relate to the screw press operation.

8. Results and discussion

8.1 Simulation results

Simulation of the wastewater treatment plant mass balances were done with a simulation tool BALAS. The object of this simulation was to determine the proper flow levels for the primary clarifier and buffer tank and to examine the effect of wastewater flow fluctuation to the plant.

The simulation was firstly tested with the inflow rate of 78 kg/s to test the simulation tool and to get an insight of what needs to be done in the following steps. There were two cases tested each time, case 1 for the screw press sludge dewatering and case 2 for the vacuum filter sludge dewatering. The simulation results for the cases 1.1 and 2.1 are presented in Table XVIII in terms of in- and outflow as well as the wastewater flows around the primary clarifier and the buffer tank. More in-depth results are presented in Appendix I.

Table XVIII Simulation results in terms of in- and outflow, primary clarifier and buffer tank flow rates for the cases 1.1 and 2.1.

	CASE 1.1	CASE 2.1
INFLOW	**Flow L/s**	**Flow L/s**
Mill wwt	73.00	73.00
TC wwt	5.00	5.00
OUTFLOW		
IWTP	0.00	0.00
Screw press sludge	0.46	0.00
Vacuum filter sludge	0.00	0.93
PC overflow to river	0.00	0.00
BT overflow to river	77.54	77.07
PRIMARY CLARIFIER		
Inflow	77.75	84.19
Overflow	72.79	72.63
Sludge	4.96	11.55
BUFFER TANK		
Inflow	77.79	77.63
Overflow	77.54	77.07
Sludge	0.25	0.56

It can be seen from the first simulation case's results that with the normal inflow rate of 78 L/s and normal flow routing the inflows to the primary clarifier and buffer tank are both approximately 77.7 L/s. As the wastewater flow to the integrate treatment plant is blocked, the treated wastewaters exit the system as overflow from the buffer tank.

The simulation results of case 1.2 and 2.2 are presented in Table XIX. The difference between cases 1.1 and 1.2 as well as for cases 2.1 and 2.2 is the increased return flow from the buffer tank to the primary clarifier through the equalization tank. This was executed in the simulation by lowering the wanted sludge consistency from 0.01 % to 0.0005 %. As the buffer tank wastewaters originate from the primary clarifier overflow and the test centre wastewaters, the sludge consistency is low in the real case as well. This return flow increase can be implemented for example with the sludge pumps in real life.

Table XIX Simulation results in terms of in- and outflow, primary clarifier and buffer tank flow rates for the cases 1.2 and 2.2.

	CASE 1.2	**CASE 2.2**
INFLOW	**Flow L/s**	**Flow L/s**
Mill wwt	73.00	73.00
TC wwt	5.00	5.00
OUTFLOW		
IWTP	0.00	0.00
Screw press sludge	0.46	0.00
Vacuum filter sludge	0.00	0.93
PC overflow to river	0.00	0.00
BT overflow to river	77.54	77.07
PRIMARY CLARIFIER		
Inflow	227.56	251.72
Overflow	222.60	240.17
Sludge	4.96	11.55
BUFFER TANK		
Inflow	227.60	245.17
Overflow	77.54	77.07
Sludge	150.07	168.09

A simulation was run to imitate the real maximum flow which is restricted by the buffer tank sludge pumps. There are two sludge pumps that have the flow capacity of 16.67 L/s. Used parallel the maximum sludge removal capacity is 33.34 L/s. In simulation case 1.3 and 2.3 a single pump was added to the simulation with the flow rate set to 33.34 L/s to simulate the restricted sludge removal. The results for the case 1.3 and 2.3 simulation are presented in Table XX.

Table XX Simulation results in terms of in- and outflow, primary clarifier and buffer tank flow rates for the cases 1.3 and 2.3.

	CASE 1.3	**CASE 2.3**
INFLOW	**Flow L/s**	**Flow L/s**
Mill wwt	73.00	73.00
TC wwt	5.00	5.00
OUTFLOW		
IWTP	0.00	0.00
Screw press sludge	0.46	0.00
Vacuum filter sludge	0.00	0.92
PC overflow to river	0.00	0.00
BT overflow to river	38.09	22.15
PRIMARY CLARIFIER		
Inflow	110.82	116.91
Overflow	105.88	105.42
Sludge	4.94	11.49
BUFFER TANK		
Inflow	110.88	110.42
Overflow	36.09	22.15
Sludge	33.34	33.34

Finally, the peak flows were studied in the simulation. The inflow for the peak flow simulation was set at 250 L/s. Case 1.4 and 2.4 are simulated with this inflow rate while keeping the same settings for the simulation as in the case 1.2 and 2.2. The results are presented in Table XXI.

Table XXI Simulation results in terms of in- and outflow, primary clarifier and buffer tank flow rates for the cases 1.4 and 2.4.

	CASE 1.4	**CASE 2.4**
INFLOW	**Flow L/s**	**Flow L/s**
Mill wwt	245.00	245.00
TC wwt	5.00	5.00
OUTFLOW		
IWTP	0.00	0.00
Screw press sludge	1.55	0.00
Vacuum filter sludge	0.00	3.11
PC overflow to river	0.00	0.00
BT overflow to river	248.45	246.89
PRIMARY CLARIFIER		
Inflow	500.10	832.96
Overflow	483.45	794.20
Sludge	16.65	38.77
BUFFER TANK		
Inflow	488.45	799.20
Overflow	248.45	246.89
Sludge	240.00	552.31

As seen from the simulation results in the Table XXI, the inflows to the primary clarifier and buffer tank are significantly increased during peak flows. This can cause overflow in the tanks, if the plant has not been prepared for the peak flow.

8.2 Operating model

The key of the operation of the case mill wastewater treatment is to ensure that the primary clarifier is working properly. One of the main problems in the treatment plant has lately been the formation of H_2S. In this chapter the possible changes of the primary wastewater treatment operating model are discussed.

The primary clarifiers are usually designed based on the SLR values. As previously mentioned, the desired SLR value for a primary clarifier is 0,8 – 1,2 m/h. The SLR and DP values are calculated in Table XXII for the current average inflow rates. The inflow rates are defined for primary clarifier and buffer tank inflows based on the simulation case 1.

Table XXII The calculated detention period and surface loading rate based on the current approximate flow rates to the primary clarifier and the buffer tank.

	Inflow [L/s]	**DP [h]**	**SLR [m/h]**
Primary clarifier	77.7	16.7	0.29
Buffer tank	77.8	12.6	0.33

As seen from Table XXII, the wastewater flow to the primary clarifier has not been on a level that ensures the proper functioning of the process. The surface loading rates and detention periods are much too high at these flow rates. To solve this problem, it has been suggested that the operating model should be changed to have return flow from the buffer tank to the primary clarifier. There is no pipe line straight from the buffer tank to the primary clarifier, so the recycle flow should be done via the buffer tank sludge pumps.

To have a better understanding of the maximum return flow from buffer tank, the SLR and DP values were calculated based on the case 1.3 and 2.3 simulation results. The calculated values are presented in Table XXIII.

Table XXIII The calculated inflow and detention period rates for the primary clarifier and buffer tank based on the simulation results in cases 1.3 and 2.3.

CASE 1.3	**Inflow [L/s]**	**DP [h]**	**SLR [m/h]**
Primary clarifier	110.82	11.7	0.41
Buffer tank	110.88	8.8	0.47
CASE 2.3	**Inflow [L/s]**	**DP [h]**	**SLR [m/h]**
Primary clarifier	116.91	11.1	0.44
Buffer tank	110.42	8.9	0.46

Compared to the SLR and DP values for the current average flow rates in Table XXII, maximizing the return flow from the buffer tank improves the overall situation. However, as the desired SLR value is 0.8 – 1.2 m/h and DP 3 – 6 h, the return flow maximization with the sludge pumps is not enough.

To prevent the long detention times for the primary clarifier sludge, it would be an option to recycle part of the sludge back through the equalization tank to the clarifier feed. This is a possible operating model as this can be executed with the existing piping. However, there is need for an additional control valve that keeps the return sludge flow at a steady level.

Table XXIV shows the calculated inflow rates and DP values based on the desired SLR values. The flow rates are calculated from the Formula 3 and the detention times from Formula 4.

Table XXIV The calculated inflow and detention period rates for the primary clarifier (PC) and buffer tank (BT) based on the desired SLR values.

SLR [m/h]	$\dot{v}_{in,PC}$ **[L/s]**	DP_{PC} **[h]**	$\dot{v}_{in,BT}$ **[L/s]**	DP_{BT} **[h]**
0.8	213.8	6.1	190.1	5.2
1.0	267.3	4.8	237.6	4.1
1.2	320.7	4.0	285.1	3.4

As seen from the Table XXIV, the calculated flow rates vary between 190 and 320 L/s and the detention periods between 3.4 and 6.1 hours. For a primary clarifier, the detention periods are normally between 3 and 6 hours, so it can be assumed that these calculations are correct. Based on the desired SLR values, the flow rate to the primary clarifier should be 214 – 321 L/s. As the average flow rate is approximately 78 L/s, the flow rate should be increased three times to reach the proper SLR and DP rates.

The detention times should be monitored more carefully in the future. For example, a daily average detention time calculator can be added to the mill operating software including alarm limits. Detention time monitoring can also help with predicting the H_2S formation in the treatment plant, which increases process safety.

Preparing for the large wastewater quantities of production breaks is key for ensuring the proper operation. The buffer tank surface level can be lowered close to the minimum surface level height, so that the buffer volume is large enough to take up the increased wastewater quantities without any overflow to the nature water bodies. During production breaks, the wastewater quality is often remarkably different from normal driving conditions. The wastewaters are less fibrous as the wastewaters originate mostly from the washing waters, so the emphasis is then on the flow control instead of the separation of dry matter.

8.3 Process improvement suggestions

In this chapter the previously mentioned suggestions for the primary wastewater treatment and sludge handling improvements are presented.

8.3.1 Primary wastewater treatment

There have been problems with hydrogen sulphide formation in the case mill treatment plant. Anaerobic conditions aid the H_2S formation. Thus, the first step in solving the H_2S problem should be ensuring aerobic conditions throughout the treatment plant. Anaerobic conditions can be ensured with comprehensive mixing or aeration in the clarifiers as well as with flow control. With flow rates high enough and steady, the process functions properly and the clarifiers' detention times are on good levels. Long detention times aid the anaerobic condition formation.

The flow rates to the primary clarifier can be increased with a return flow from the buffer tank. This can be done in two ways:

1) Build a new pipe line from the buffer tank sludge line before the sludge pumps to the primary clarifier feed line.
2) Replace the existing buffer tank sludge pumps and pipe lines with ones that fit the increased flow rates.

The primary clarifier detention time should be more carefully monitored. This is taken into consideration in the operating model and guide. The results from the primary clarifier detention time reduction can be seen with the ORP analysis as it states the disinfection potential in the wastewater. Shorter detention time ensures the aerobic conditions in the tank, and the presence of more oxygen increases the ORP value.

The odours and septic conditions in the buffer tank can be prevented with additional aeration equipment installed at the bottom of the tank. Thorough aeration ensures the aerobic conditions in the tank. The hydrogen sulphide can also be removed, or the formation can be prevented with different chemicals. Additional chemical use must be taken into consideration, if the H_2S presence continuously forms a safety hazard and prevents the normal operation of the treatment process.

Another factor in the hydrogen sulphide problem is the ventilation system in the wastewater treatment building. The air intake is located next to the buffer tank's rising sludge chute. It should be taken into consideration to move the air intake position so that the odours and formed H_2S are not passed to the building from the buffer tank's rising sludge.

8.3.2 Sludge handling

There is no need for more mechanical capacity in sludge treatment. The existing sludge dewatering units can handle the sludge removed in the primary treatment. The emphasis should be on the dewatering quality. The usage of a pre-dewatering treatment should be taken into consideration. For example, as previously mentioned the addition of cyclodextrins to a polymer can significantly boost the dewatering results while being economically feasible.

Screw press is an efficient sludge dewatering method, as it can produce high DSC for a feed sludge with low dry matter content. The only disadvantages of a screw press are its high energy and space requirements. Still, it is preferable to have a higher DSC in the final disposed sludge firstly because of the transportation matter and secondly for the freezing problem during the winter. Instead of trying to boost the functioning of the vacuum filter, it may be better to focus on the screw press.

The sludge is in many positions diluted with clean water to improve its movement in the pipes. However, it is possible to save clean water by using the filtrate water from the drum vacuum filter or from the screw press. Especially for the feed sludge dilution of the drum vacuum filter it is preferable to use the filtrate water.

9. Conclusions

This thesis was done to evaluate the operation and performance of the wastewater treatment plant of a Finnish board mill. The object was to determine the problems and malfunctions in the wastewater treatment process and to propose solutions for these problems. The wastewater characteristics and flow data were collected from the Savcor Wedge process analysis programme and analysed with MS Excel to get a general view of the process and to detect possible changes in the data. A simulation was done to examine the wastewater treatment plant mass balances using the VTT BALAS simulation tool.

The Case Mill is a part of an integrate that is comprised of a wood handling, debarking and grinding section, a power plant, paper mill and a wastewater treatment plant. In normal conditions the wastewaters generated at the Case Mill are treated in the integrate wastewater treatment plant. In that case the function of the Case Mill treatment plant equalizes the wastewater flow to the integrate treatment plant.

The Case Mill wastewater treatment plant consists of a primary clarifier, a buffer tank, a screw press and a rotary drum vacuum filter. When it is for some reason not possible to lead the wastewaters to the integrate's treatment plant, the wastewaters must be treated on-site with the existing primary treatment and sludge handling unit.

The primary clarifier design is based on the surface loading rate and the detention period. It was found that the surface loading rate and detention period for the primary clarifier and the buffer tank have not been on the level that ensures the proper wastewater treatment and operation conditions. The SLR rates should be in the range of 0.8 – 1.2 m/h for clarifiers. With the average inflow, 78 L/s, the SLR is 0.29 m/h for the primary clarifier and 0.33 m/h for the buffer tank. Also, with the average inflow, the detention period in the primary clarifier is approximately 17 hours and in the buffer tank 13 hours. The normal detention period for a clarifier is 3 – 6 hours.

Too long detention periods result in operational problems such as the formation of anaerobic conditions. Anaerobic conditions in a clarifier or tank cause unwanted odours, septicity and boost the formation of hydrogen sulphide, H_2S. The presence of H_2S is a significant process safety risk. The hydrogen sulphide can be removed from the process with the aid of chemicals, such as ferric sulphate ($Fe_2(SO_4)_3$). Although in the long run instead of just treating the H_2S the object should be to solve the reason behind the formation.

The solution to reduce long detention times is to increase the inflow rates to the unit. The desired inflow rates to the primary clarifier and the buffer tank were calculated based on the normal SLR rates. The calculations showed that the inflow rates should be at least 214 L/s to the primary clarifier and 190 L/s to the buffer tank. The increase of the inflow rate should be done with a return flow from the buffer tank through the equalization tank to the primary clarifier. This can be done via the existing buffer tank sludge pumps and by utilizing the existing pipe lines. However, the capacity of the sludge pumps is not enough to meet the desired inflow rates and the pipe lines are not big enough for this kind of flow rates. So, there are two possible ways to implement the return flow increment:

1) Build a new pipe line from the buffer tank sludge line before the sludge pumps to the primary clarifier feed line.
2) Replace the existing buffer tank sludge pumps and pipe lines with ones that fit the increased flow rates.

In addition to the flow control changes, the detention period monitoring should be implemented to the mill operating software.

The sludge dewatering is at the moment done with either a screw press or a rotary drum vacuum filter. The screw press is more efficient in terms of dewatering, while the vacuum filter has significantly higher capacity. As the sludge is transported for incineration to the integrate power plant, it is preferable to have sludge that is further dewatered. Chemical conditioning can be implemented to boost the dewatering results. Improved dewatering leads to sludge with higher dry matter content. This lowers the transportation costs and ensures the sludge conveyor operation during winter months.

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APPENDIX I 1(1) Simulation results

	CASE 1.1	CASE 1.2	CASE 1.3	CASE 1.4	CASE 2.1	CASE 2.2	CASE 2.3	CASE 2.4
INFLOW	**Flow L/s**							
VJA	80	73	73	245	73	73	73	245
IK1_VJA	19	5	5	5	5	5	5	5
Makeup_G503	0	0	0	0	0	0	0	0
Makeup_G512	0	0	0	0	0	0	0	0
Makeup_G501	0	0	0	0	0	0	0	0
Washwater_eimco	0	0	0	0	0	0	0	0
OUTFLOW								
VJA_AP	0	0	0	0	0	0	0	0
Sludge_screw_press	0.01142	0.46184	0.46184	1.5497	0	0	0	0
Sludge_vacuum_filter	0	0	0	0	0.001794	0.92756	0.92756	3.1125
Overflow_pc_to_river	0	0	0	0	0	0	0	0
Overflow_bt_to_river	98.989	77.538	77.538	248.45	77.982	77.072	77.072	246.89
OTHER								
Feed_pc	80.236	77.749	227.56	500.1	74.583	84.185	251.72	832.96
Overflow_pc	80.114	72.788	222.6	483.45	74.471	72.633	240.17	794.2
Overflow_pc_to_iwtp	0	0	0	0	0	0	0	0
Overflow_pc_to_bt	80.114	72.788	222.6	483.45	74.471	72.633	240.17	794.2
Sludge_pc	0.12267	4.9606	4.9606	16.646	0.11264	11.552	11.552	38.768
Sludge_pc_to_vf	0	0	0	0	0.11264	11.552	11.552	38.768

APPENDIX I 2(2) Simulation results

Feed_pressurized_screen	0.12267	4.9606	4.9606	16.646	0	0	0	0
Accept_pressurized_screen	0.12169	4.921	4.921	16.513	0	0	0	0
Reject_pressurized_screen	0.00098	0.03969	0.03969	0.13317	0	0	0	0
Reject_ps_to_equalization_tank	0.00098	0.03969	0.03969	0.13317	0	0	0	0
Accept_ps_to_iwtp	0	0	0	0	0	0	0	0
Feed_screw_press	0.12169	4.921	4.921	16.513	0	0	0	0
Filtrate_screw_press	0.11027	4.4591	4.4591	14.963	0	0	0	0
Filtrate_sp_to_equalization_tank	0.11027	4.4591	4.4591	14.963	0	0	0	0
Wastewater_tank_to_equalization_tank	0.11027	4.4591	4.4591	14.963	0	0	0	0
Feed_bt	99.114	77.788	227.6	488.45	79.471	77.633	245.17	799.2
Overflow_bt	98.989	77.538	77.538	248.45	77.982	77.072	77.072	246.89
Sludge_bt	0.12497	0.25011	150.07	240	1.4885	0.56031	168.09	552.31
Sludge_bt_to_vacuum_filter	0	0	0	0	1.4885	0.56031	168.09	552.31
Sludge_bt_to_equalization_tank	0.12497	0.25011	150.07	240	0	0	0	0
Feed_vacuum_filter	0	0	0	0	1.6011	12.113	179.65	591.08
Suctionwater_vacuum_filter	0	0	0	0	1.5832	11.185	178.72	587.96
Overflow_suctionwater_tank	0	0	0	0	1.5832	11.185	178.72	587.96
Suctionwater_tank_to_equalization_tank	0	0	0	0	1.5832	11.185	178.72	587.96
Suctionwater_Tank_to_wastewater_tank	0	0	0	0	0	0	0	0