DEGREE PROJECT

Wastewater Treatment at Kraft Pulp Mills

Effect of temporary effluents and mitigation measures

Hodda Shariatmadari

Natural Resources Engineering, master's
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Luleå University of Technology
Department of Civil, Environmental and Natural Resources Engineering

LULEÅ UNIVERSITY OF TECHNOLOGY

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Abstract

Large amount of water is used in the pulp-and-paper industry. Consequently, large amount of wastewater is produced in the various production processes. In general, the pollutants of concern involve organic compounds, nutrients, including nitrogen and phosphorous, suspended solids, and chlorinated compounds. Temporary effluents from the production processes often have increased concentrations of these contaminants and there is a risk of overloading the wastewater treatment, which then further increases the risk of discharge of insufficiently treated water to receiving water bodies. The aim of this study was to investigate the effect these temporary, temporary effluents from Kraft pulp mill processes have on the wastewater treatment, with the objective to develop an action plan with measures to address and remedy the problems that occur (to handle them in the best way possible in the future). This study has been conducted through interviews to collect the experiences from personnel working in Kraft pulp mills located in Sweden.

The results of the study from the interviews showed a total of 16 different types of temporary effluents. The results also showed that the most common incidents occurring in the mills were incidents connected to planned or unplanned maintenance stops, and the most common temporary effluents experienced were liquors from the different process steps and chlorate mainly from the bleaching plant. All results are compiled, in both Swedish and English for easier use. The most important measure for mitigating the effect of the temporary effluents was identified to be optimum conditions for the favorable microorganisms in the biological wastewater treatment, such as neutral pH, mesophilic temperature range (20 - 40°C), and sufficient oxygen and essential nutrients for the microorganisms to grow and reduce the contaminants. However, it should be considered that the measures for the different types of effluents can vary significantly depending on the incidents and the cause of the effluents, as well as the type of wastewater treatment implemented, and some measures are specific for each particular mill.

Sammanfattning

Det är mycket vatten som används i papper- och-massaindustrin. Följaktligen produceras det även mycket avloppsvatten i de olika processerna. Generellt består de vanliga föroreningarna av organiskt material, närsalter (kväve och fosfor), suspenderat material, och föreningar som innehåller klor. Vid ’onormala utsläpp’ riskerar halten av föroreningar att öka, och reningsverket riskerar överbelastas, vilket i sin tur leder till en ökad risk för föroreningar till recipienten. Syftet med studien var att undersöka effekten av de onormala utsläppen från processerna i sulfatmassabruk har på reningsverket, med målet att utveckla en åtgärdsplan med åtgärder för att undvika och minska påverkan när incidenter sker (för att kunna hantera de på bästa möjliga sätt). Denna studie har utförts genom intervjuer med anställda på sulfatmassabruk i Sverige och har fokuserat på deras erfarenheter av onormala utsläpp.

Resultaten av intervjuerna visade på totalt 16 olika typer av onormala utsläpp. Resultaten visade även att de vanligaste incidenterna som inträffar är incidenter i anslutning till planerade eller oplanerade underhållsstopp, och de mest vanliga utsläppen som sker vid sulfatmassabruk är utsläpp i form av lut från processerna och klorat från blekeriet. Resultaten sammanställdes både på svenska och engelska för att underlätta användning. De viktigaste åtgärderna, dock med viss variation, är att se till att den biologiska reningen uppehåller optimala förhållanden för de mikroorganismerna som är viktiga för reningen, som exempelvis neutralt pH, mesofila temperaturförhållanden (20 – 40°C), och tillräckligt med syre och livsnödvändiga närsalter till mikroorganismerna för att de ska kunna växa och reducera föroreningarna. Det är dock viktigt att notera att åtgärderna för utsläppen kan variera signifikant beroende på vilken typ av incident det handlar om och vad som orsakar utsläppen, samt även vilken typ av reningsverk som finns implementerad i bruket. Vissa åtgärder måste därför anpassas till bruket i fråga.

Preface

This study has been conducted as a degree project within the Master Program in Natural Resources Engineering with an orientation in water and environmental science consisting of 30 credits (30 hp), at Luleå University of Technology (LTU) in cooperation with AFRY.

Completing this study would not have been possible without the opportunity and support from my supervisors Thérèse Johansson and Åsa Sivard at AFRY, and I would like to issue a special thanks for all the great help and support, stimulating discussions, and for being my mentor during this time – I could not have done this without you. Thank you to Tomas Ericsson, senior consultant/advisor at AFRY, also for participating in the workshops and for the discussions we have had during the course of the project. I would also like to thank my supervisor at LTU, Inga Herrmann for all the support along the way and for always being there answering all my questions, and for my examinator Annelie Hedström for the additional support. Finally, to the personal at the mills who have participated in the interviews – thank you for taking the time although your busy schedules to answer my questions and contributing to the basis of the study. It has been very interesting, and I have learned a lot from this project so thank you to everyone who has supported me and made this possible.

Glossary

English	*Swedish*	*Description*
Black liquor	*Svartlut*	Residue liquor after cooking process, containing wood substances and byproduct chemicals
-Heavy black liquor	*Tjocklut*	Evaporated (thin) black liquor (i.e., high solid content)
-Thin black liquor	*Tunnlut*	Contains unwanted residues from the wood chips and chemicals
ECF bleaching	-	Elementary chlorine free bleaching, using chlorine dioxide as bleaching agent
Green liquor	*Grönlut*	Consists of sodium sulfide and sodium carbonate
Kraft pulp	*Sulfatmassa*	Chemical pulping where the pulp is attained from cooking wood with alkaline cooking liquor
Lime sludge/Lime mud	*Mesa*	Consists of insoluble calcium carbonate
Sulfite pulp	*Sulfitmassa*	Chemical pulping where the pulp is attained from cooking wood with acidic cooking liquor
TCF bleaching	-	Totally chlorine free bleaching, using ozone and hydrogen peroxide as bleaching agent
White liquor	*Vitlut*	Cooking chemical, consisting of sodium hydroxide and sodium sulfide

Abbreviations

Abbreviations	*Swedish*	*English*
AOX	*Halogenerade organiska föreningar*	*Adsorbable Organically bounds halogens*
AS	*Aktivslam*	*Activated sludge*
ASB	*Luftad damm*	*Aerated Stabilization Basins/Aerated Lagoon*
BAS	-	*Biofilm Activated Sludge*
BOD	-	*Chemical Oxygen Demand*
COD	-	*Biological Oxygen Demand*
ECF	-	*Elementary Chlorine Free*
MBBR	-	*Moving Bed Biofilm Reactor*
LAS	*Långtidsluftad aktiv slamanläggning*	*Long-term Activated Sludge*
RAS	*Returslam*	*Return Active Sludge*
SS	*Suspenderat material*	*Suspended Solids*
TCF	-	*Totally Chlorine Free*
TOC	-	*Total Organic Carbon*
TSS	*Totalt suspenderat material*	*Total Suspended Solids*
WAS	*Överskottsslam*	*Waste Activated Sludge*
WWT	*Avloppssrening*	*Wastewater Treatment*
WWTP	*Reningsverk*	*Wastewater Treatment Plant*

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1 Introduction

Water is an essential part of life. All things living need water to function and survive, and it is a key function in everyday life. In the same way, water plays a crucial role in the industry sector and is one of the most important raw materials there is, used in almost all processes including washing manufactured goods, cooling, and used in the preparation of chemicals as a solvent or diluting agent among others. These processes require a large quantity of water. Consequently, these processes will also produce a large amount of wastewater.

In general, the pulp-and-paper industry produces the third largest amount of wastewater, right after agriculture and primary metals and chemical industries (Ashrafi, Yerushalmi, & Haghighat, 2015), and is the sixth largest polluter (after oil, cement, leather, textile, and steel industries) due to the environmental impact of the discharges (Singh & Tripathi, 2020). The greatest environmental concerns of pulp-and-paper industry regard the usage of fresh water, the wastewater production and composition that is released to receiving water bodies, along with the greenhouse gases, including carbon dioxide and methane, emitted from the processes, and the high nutrient content of sludge that is produced as an effect of the wastewater treatment (Ashrafi, Yerushalmi, & Haghighat, 2015).

These grave concerns have taken a larger part in modern days compared to the hand-made factories they were in the beginning, or the pulp-and-paper industries during the industrialization in the 19th century. The 20th century, however, where the Swedish and pulp-and-paper production faced revolutionary changes that made them into the industries we know today, with the advancement of new technology such as the steam engine and soda recovery boiler. These advancements also entailed that the environmental problems intensified (Jerkeman & Norrström, 2017).

Environmental laws and regulations did not apply until around 1960s and 1970s, after the environmental movement where environmental issues started blossoming up and it became of great importance to regulate air and water pollution. The industrialization led to a substantial increase in the production of pulp and paper, resulting in an increase in the emissions and effluents. This increase cumulated however before it started decreasing in 1960 with new environmental procedures and technology advancements. Accordingly, the emissions today are around the same amount as they were in the late 19th century despite the great increase in production (Jerkeman & Norrström, 2017).

Nowadays, these concerns mostly regarding air and water pollution and raw water use are becoming more and more of a staple in the sustainability work of pulp-and-paper industries, and circular economy thinking is of importance to achieve this. About $60\ m^3$ of water is required to produce a ton of paper, generating at least $50\ m^3$ of wastewater (Singh & Tripathi, 2020). Reusing and recycling water and process chemicals are therefore the key in order to reduce the amount of used water. Treatment of

wastewater and minimizing the left-behind-contamination are essential for decreasing the environmental impact as well as assuring secured surface water quality in the future.

Generally, the common discharges of concern from the paper- and pulp-industries involve organic compounds, nutrients including nitrogen and phosphorous, suspended materials, and chlorinated compounds (Cabrera, 2017). The occurrence of temporary effluents, those that occur when something goes wrong in the mill processes or during ‘unnormal’ periods, can give a rise of these parameters as well as causing other toxic elements such as chlorate emitting. If these are not detected and prevented in time, they will overload the wastewater treatment, further allowing increasing effluents to affect the receiving water body. Therefore, temporary effluents are important to detect and prevent before they might affect the wastewater treatment processes and risk overloading it, resulting in the possibility of being further released to receiving water body.

1.1 Aim and Focus with the Study

The aim of this study was to investigate and analyze the occurrence of temporary, temporary effluents from the pulp-and-paper industry processes, focusing on Kraft pulp mills, and the effect these discharges have on the wastewater treatment plant and eventually the receiving water body. The objectives were to:

(1) analyze the experiences of previous process incidents causing temporary influents to the wastewater treatment at pulp-and-paper industries, using interviews,
(2) investigate the effects of these temporary effluents on the following wastewater treatment processes with the help of interviews, workshops with experts as well as the literature, and
(3) develop a guide with suggestions about how to address and remedy the problems that occur with these temporary effluents in the future to handle them in the best way possible.

The focus of the study was on Swedish Kraft pulp mills and the discharges that could have an effect on the treatment plant and risks affecting the capacity of the treatment that in return will have a negative impact on the receiving water body, i.e., only discharges treated in the treatment plant were focused on. This excludes accidental effluents from e.g., cisterns that overflows and thereby reach the receiving waters directly through storm water drains and manholes located in the facilities.

The biological treatment and how it is affected was the primary interest and focus of this thesis because of its sensitivity and importance, although other treatment processes are also discussed.

2 Background

2.1 Pulping Mill Processes

The chemical components of wood vary depending on the wood type, hardwood or softwood for example, but can also vary a lot within the same type of wood. In general, wood is approximately composed of 40% cellulose, 30-35% hemicellulose, 20-30% lignin, and about 4% extractive substances (ÅF-IPK, 1999). Lignin is the component binding together the fibers in the wood and moreover exists in the fiber walls thus contributing to the compressive strength of the wood together with the hemicellulose. The purpose with the pulping mill and paper production is to separate the fibers from the lignin and cellulose in the wood in order to obtain pulp that is much better suitable for further production of paper. High lignin content contributes to a stronger pulp, but it also causes the paper to weaken and discolor more rapidly, and therefore it is of interest to remove as much as possible in the pulping process (ÅF-IP, 1999). The lignin content obtained depends on the quality of paper required, for e.g., cardboard boxes, or tissues (soft paper) among others. There are three main processes in which the separation of lignin from the fibers can be accomplished by: mechanical production, chemical production or through a combination of both treatments (Borg, 1989).

There are several ways to obtain mechanically produced pulp, but the main idea is based on using a form of mechanical energy to separate the fibers from the wood for producing the mechanical pulp, e.g., by crushing or grinding wood or wood chips. Chemical pulp is produced by “boiling” or “cooking” the wood chips at high temperature and pressure together with chemicals in order to break down and dissolve the lignin. Chemical pulping consists of two main processes, that are based on the chemicals used in the process and the type of pulp desired to produce: Kraft process (sulphate process), and sulphide process. The cooking liquor in Kraft pulp processes is alkaline and consists of sodium hydroxide and sodium sulphide, whereas sulphide mills usually use a more acidic cooking liquor that consists of a range of different sulfites or bisulfite chemical compounds (Borg, 1989).

Popa (2013) reported the yield from mechanical pulp being as high as 95-98 %, while chemical pulping only has about 45-55 % yield. The difference is due to the lignin being removed and thus diminishing the pulp yield in the chemical pulping process. Despite this fact, chemical pulp is much more vastly produced around the world and in Sweden, specifically Kraft pulp which is shown in Figure 1. This is due to mechanical pulping having a very high energy consumption and produces a weaker, lower quality paper production. New technologies have further advanced re-using the major part of the used cooking chemicals, making the chemical pulping more profitable (Popa, 2013). Sulphide pulp is brighter than sulphate pulp and provides a somewhat higher yield although weaker. It used to be the dominant chemical pulp production type but due to the longer cooking time and the weaker paper mass produced,

and the fact that bleaching has advanced to brighten the brownish sulphate mass, sulphide pulping has diminished in use and today there are only a few still in operation (Borg, 1989). Due to these reasons and the large use of the pulp from Kraft pulp mills, the emissions from these are of more interest and will therefore be the continued focus of this thesis.

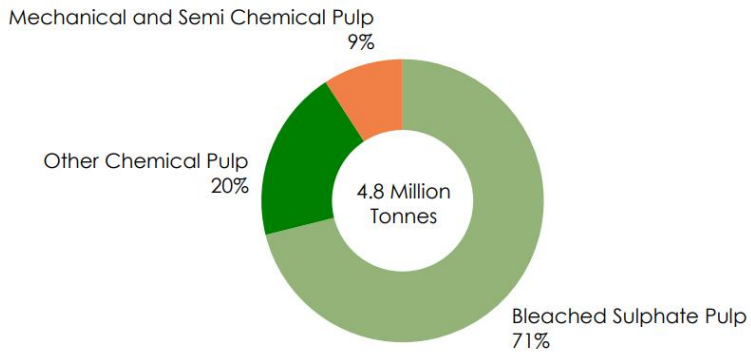

Figure 1. Production distribution of market pulp in Sweden 2021 (Swedish Forest Industries, 2021).

2.2 Kraft Pulp Mills

The main processes of a Kraft pulp mill consist of wood preparation, cooking, washing and screening, pulp bleaching, and recovery treatment for the cooking chemicals (see Figure 2). This can be divided into two key parts; the fiber line, where pulp is made from the wood, and the recovery system, where the chemicals used in the fiber line is recovered and used again in the pulp production.

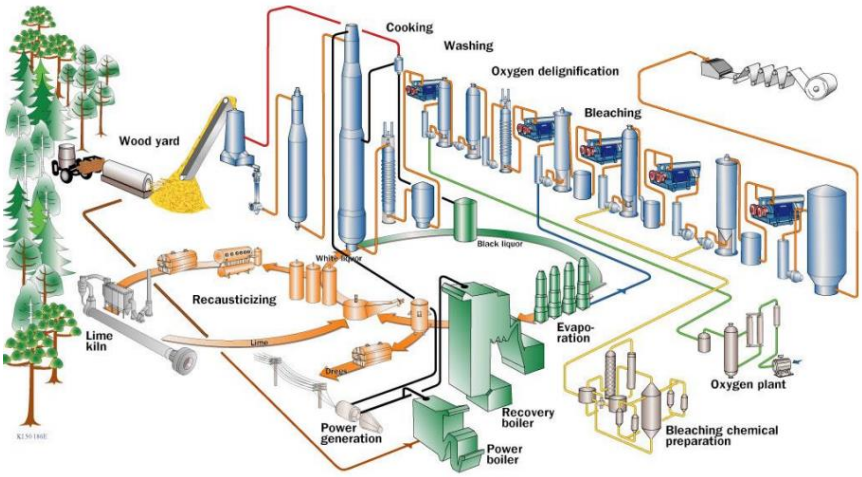

Figure 2. Overview of Kraft pulp mill (Andersson, 2014).

The process waters, or *liquors* as they are called, have different names depending on which process they are discharged from, and the concentration and composition of the liquors differs as well. White liquor, green liquor, and black liquor are the most common liquors in Kraft pulp mills, the latter being the most abundant in variations. Kraft liquors are characteristically alkaline, and Kraft black liquor also has a

high organic content as well as high load of suspended solids, low degradability, and containing toxic chemicals (Tran & Vakkilainnen, 2016). These liquors are processed and used in the fiber line and in the recovery system and conclude a part of the wastewater effluents.

2.2.1 The Fiber Line

After the wood has been prepared into smaller fragments (chips) by debarking and crushing or grinding, the cooking process begins. This is done in either a discontinuous or continuous digester with high temperature and high pressure. The wood chips are mixed in the digester with the alkaline cooking liquor, that is called *white liquor* and contains of sodium hydroxide and sodium sulphide which are the active reagents. These chemicals will then react with the lignin in the wood, resulting in them degrading and dissolving in the cooking liquor (Popa, 2013).

The formed pulp is then further separated from the remaining cooking liquor, and the extracted liquor is now called *thin black liquor* and contains unwanted residues from the wood chips and chemicals. This is done by firstly removing the debris with screening, i.e., filtering out the (larger) particles, and then washing the pulp with water to separate the black liquor. The black liquor is then further transported to the recovery system (Mattsson, 2006).

The last step in the pulping process is bleaching. Because the remaining Kraft pulp is brownish, bleaching needs to be done to attain a brighter and cleaner pulp. The bleaching also dissolves the remaining lignin that the cooking could not remove (Borg, 1989). This is done in several steps and there are two main types of bleaching methods that can be done; totally chlorine free (TCF) and elemental chlorine free (ECF), where the pulp is bleached with chlorine dioxide (ClO_2) without any molecular or gaseous chlorine involved (Cabrera, 2017). TCF bleaching uses ozone and hydrogen peroxide. There is a slight difference when it comes to the organic matter content in the bleaching effluents of each method, however, compared to other parameters, it is neglectable and the (biological) treatment of the effluents are similar to each other (Cabrera, 2017).

When the pulp has been finally processed, it is either dried at the site for further transportation where the mill sells the pulp off or the pulp is pumped directly to a paper mill, if the mill is integrated, meaning the mill consisting both of a pulp and paper production industry.

2.2.2 The Recovery System

The purpose with the recovery treatment is to minimize the environmental impact from the pulp process by recovering and recycling the chemicals in the black liquor and using the dissolved organic matter in the liquid for steam and energy production (Tran & Vakkilainnen, 2016). A figure of the process is shown in Figure 3.

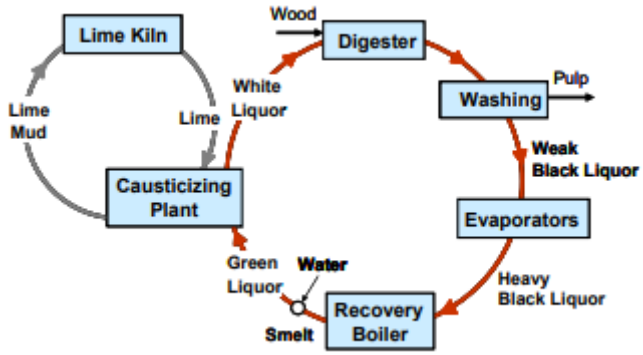

Figure 3. A simplified view of the Kraft recovery process (Tran & Vakkilainnen, 2016).

The first step in the recovery process after the wood has been digested and washed into pulp is evaporation. This is done to increase the solid content of the black liquor, in preparation for the burning for the next step in the recovery boiler, to about a solid content of 65-85 % (Tran & Vakkilainnen, 2016). Water is the main liquid evaporated from the substance, but also some organic compounds (mainly methanol) are evaporated. The water can then further be reused as washing water for the pulp or for preparation of the white liquor in the pulp processes (Mattsson, 2006). The remaining substance after the evaporation is called *heavy black liquor* or *thick liquor*, and it can be used to extract compounds such as turpentine and crude tall oil in a separate tall oil refinery at the site (Andersson, 2014).

The remaining heavy black liquor is further processed in a recovery boiler where it is burned in an anoxic environment. Sodium and sulphide are recovered in this process in the form of a smelt containing sodium sulphide and sodium carbonate. Both chemicals are used in the pulp processing, sodium sulphide in the same form but sodium carbonate needs to be processed and formed into sodium hydroxide. This smelt is then combined with water, and the formed substance is called *green liquor*. Further, the green liquor is sent to the causticizing plant where the sodium carbonate reacts with lime (CaO) to form sodium hydroxide, the other chemical needed in the cooking process to form pulp, which forms the rest product lime sludge or lime mud, and consists of insoluble calcium carbonate ($CaCO_3$). By further burning this, lime can be extracted which then can be further used in the process (Tran & Vakkilainnen, 2016).

After the causticizing plant, the remaining liquid containing mostly sodium hydroxide and sodium sulphide is then called white liquor again and is reused in the pulping as cooking liquid. In addition to the extraction of chemicals, the black liquor can also be used in the production of steam from combustion of the organic material in the liquid, which then can be further used for generating electricity (Tran & Vakkilainnen, 2016).

2.3 Quality of Process Water from Kraft Pulping

Water is an essential part in the pulping mill and is involved in all the main steps throughout the mill processes. Consequently, wastewater is also produced in the various stages. Singh and Tripathi (2020) described that a large amount of water is needed for the pulp-and-paper processes, between 60-230 m^3 water per ton of paper production, resulting in a large amount of wastewater being produced in the process.

The composition of the process waters, i.e., the content of the liquors from the pulp mill processes, depends on the processes and chemicals being used. In general, the major contaminants to be taken into account are high loads of organic matter, TOC (BOD and COD), total suspended solids in the water, adsorbable organic halides, phosphorous, and nitrogen (Cabrera, 2017). The loads from these effluents vary also depending on the source, see Table 1, and affect the treatment processes differently.

Table 1. Effluent loads from Kraft pulp mill and their sources (Cabrera, 2017). Unit is in kg per air-dry ton (kg/ADt), except for phosphorous where the unit is g per air-dry ton (g/ADt).

Source	*Mass flow*	*TSS*	*BOD*	*COD*	*AOX*	*N*	*P*
[Unit]	kg/ADt	kg/ADt	kg/ADt	kg/ADt	kg/ADt	kg/ADt	g/ADt
Debarking	2.5	4	2	5	0	0.2	20
Washing and Screening	0.5	3	1	2	0	0.015	1
Bleaching	31	2	10	35	1.2	0.075	47
Condensates	1	0	1	3	0	0	0
Others	3	4	4	10	0	0.002	7
Total	38	13	18	55	1.2	0.3	75

Due to these contaminations, the wastewater from these different processes needs to be treated in a wastewater treatment plant to reduce these contaminants and eliminate the effect of the pollutants before the water can be discharged into the receiving water body. Further, the contaminants will be described in terms of where they originate from in the mills, what they (may) cause, and how it would affect the receiving water body if they were released.

2.3.1 Common Contaminants

TSS

Suspended solids (SS), or total suspended solids (TSS), is mainly caused by wood and its residues and particles from debarking and washing, and includes bark particles, fiber pigments, dirt, grit, BOD, and COD (Kamali & Khodaparast, 2015). TSS are the main reason behind the dark color and high turbidity of a water which, if released into a receiving water body, can affect the transparency of the water as well

as causing blanketing which can further result in a reduction of photosynthetic activity prompted by oxygen and sunlight deficiency in water bodies (Singh & Tripathi, 2020).

TOC, BOD, and COD

Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are both parameters to determine the amount of organic matter in a water, and it is often used to measure environmental impact. BOD measures the amount of (dissolved) oxygen needed in biologically degrading organic matter, i.e., the amount of (dissolved) oxygen microorganisms need to break down the organic matter present in the water. BOD only comprise of easily degradable substances. The COD represents the amount of (dissolved) oxygen consumed to break down organic matter by chemical oxidation and include both substances that are easy and difficult to decompose (Mattsson, 2006).

The total organic carbon (TOC) is a parameter that is becoming of greater use in the pulp-and-paper industry and refers to the direct measurement of inorganic and organic carbon, thus providing the organic substance in a water.

AOX and Chlorinated Substances

Adsorbable Organic Halides (AOX) are substances that contain carbon and hydrogen where one or more hydrogen atoms have been replaced by a halogen. AOX is used to measure the presence of organically bound halogens in a sample (Naturvårdsverket, n.d.). The replacing halogen is often chlorine with AOX in association with the pulp and paper industry.

Chlorine dioxide used in the ECF-bleaching process is the main source of chlorate (ClO_3^-), which is an unwanted byproduct from the ECF-bleaching in the pulp-and-paper processes through a set of different reactions with the bleaching effluent containing inorganic substances such as chlorite (ClO_2^-), chloride (Cl^-), chlorine dioxide (ClO_2) and hypochlorous acid ($ClOH/HClO$), a weak acid formed when chlorine is dissolved in water (Ni, Kubes, & Van Heiningen, 1993).

Generally, chlorinated organic compounds are genotoxic and very toxic if they are released untreated because of their damaging effects and high persistence in nature and, resulting in migration and accumulation through ecosystems (Singh & Tripathi, 2020).

Nutrients (N, P)

Nutrients, such as nitrogen (N) and phosphorous (P), are essential for organic substances, e.g., aquatic plants and algae, and for their growth and survival. This is then essential for all the aquatic life as aquatic plants and algae provides living space but also food to a lot of water-living fauna. High concentrations of nutrients present in the water can however cause eutrophication, where an overgrowth of organic

substances occur in the water, causing algal bloom which then leads to oxygen and sunlight accessibility reducing, affecting the living conditions for the aquatic life.

The main source of nutrients in the pulp-and-paper industry comes from the wood itself. Although high concentrations can occur, nitrogen and phosphorous are usually not the main problem in the wastewater treatment and often needs to be added to the wastewater in order to provide the nutrients for organic substances to grow in the biological treatment (Mattsson, 2006).

2.4 Wastewater Treatment in Pulp Mills

Physicochemical and biological wastewater treatment methods are combined in the wastewater treatment plant to obtain and increase the efficiency of the removal of contaminants with the purpose of recycling and reusing the water and/or releasing the water to the recipient with a good quality. The treatment processes are divided into different steps; primary, secondary, and tertiary treatments, each with a different purpose. A schematic figure over the treatment plant for a typical pulp-and-paper mill is shown in Figure 4.

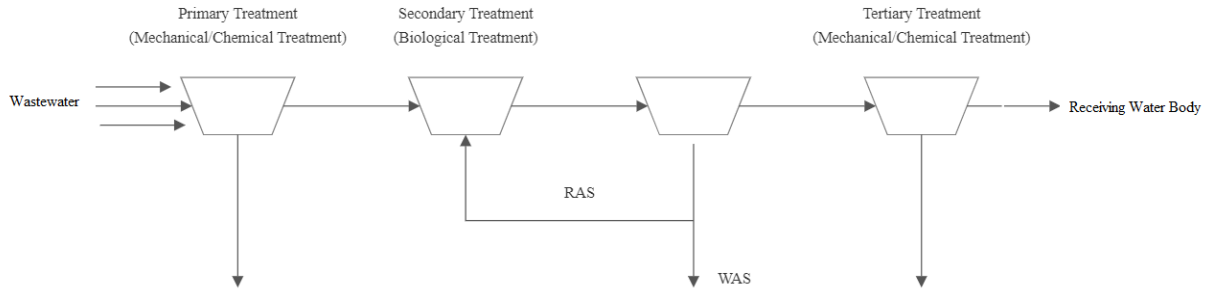

Figure 4. A schematic figure of the wastewater treatment plant and processes involved.

Generally, a preliminary treatment is done first to remove any larger materials, oils or debris from the water, thus preventing it from overloading or damaging further treatment processes. Next, the primary treatment takes place as a form of mechanical process, usually sedimentation, with the purpose of removing the suspended solids. Secondary treatment often consists of biological processes where the aim is to reduce the amount of organic material in the water, i.e., reducing BOD and COD, but also removing nitrogen and phosphorus, as well as chlorinated compounds including AOX and chlorate. Tertiary treatment is not always applied, depending on the type of contaminants that are present in the wastewater. Usually, it involves chemical processes in order to remove contaminants in the form of metals or reducing lingering effluents from previous treatments/steps such as COD, phosphorus, and nitrogen. An additional step with sedimentation or filtration is also fairly common (Mattsson, 2006).

Sludge is formed as an (unwanted) residual product in the wastewater plant, typically in the biological processes, but also from the sedimentation. The purpose of the wastewater treatment is mainly to settle

unwanted particles into a waste, i.e., a sludge, that can be dealt with using other methods. There are different methods for reducing the volume of sludge produced in the wastewater treatment processes. Return activated sludge (RAS) is one method where the sludge is returned to the biological treatment where it can undergo treatment again with the purpose of reducing the amount of sludge and at the same time allowing further reduction of COD and improving sludge settling quality. The objective with the sludge treatment is to reduce the volume of the sludge for disposal, i.e., the waste activated sludge (WAS), through dewatering (Mahmood & Elliott, 2006).

The treatment processes used for the wastewater vary and depend on the type of process used in the pulp mill, i.e., the quality of the water and contaminants present from each process. Main contaminants from the pulp-and-paper industry consists of suspended solids and organic compounds, and the main purpose with the wastewater treatment plant is to remove the contaminants through a combination of different treatment processes, such as physiochemical and biological processes, before it can be reused or released back into the environment.

2.4.1 Physicochemical Processes

Physicochemical processes are comprised of a combination of mechanical and chemical treatments and is mainly used to remove the solid particles in the water, including suspended solids, colloidal particles, toxic compounds, and color from the wastewater which is caused by the particles. Choosing the type of physicochemical process for the treatment plant is, described by Ashrafi et al. (2015), depending on the composition of the water and contaminants present as well as the water quality that needs to be obtained. This treatment is usually done in one or several steps throughout the treatment plant, typically in the primary and/or tertiary stages of the treatment (Ashrafi, Yerushalmi, & Haghighat, 2015).

Mechanical methods can be used more or less directly to remove solid contaminants in the water while chemical methods use chemicals to form flocks from dissolved material that occur in the water, before using mechanical methods to remove the flocs. Physicochemical treatments involve screening, ultra-filtration, sedimentation, flotation, coagulation, flocculation, ozonation, electrolysis, ion exchange, and activated carbon filtration. The continued focus of this study will be solely on the commonly used wastewater treatment processes for pulp-and-paper industries applied in Sweden.

Mechanical Treatment

Mechanical treatment methods can be divided into two groups; filter and gravimetric systems. Filter systems include screening and membrane filtration (ultra-filtration), and commonly used gravimetric systems in treating wastewater in pulp-and-paper industry are sedimentation and flotation. Sedimentation involves settling of particles on the bottom of the sedimentation basin, thus separating

them from the water, while flotation is the opposite where the separation is accomplished by making the particles float using dissolved air.

Sedimentation or flotation are often used as a primary treatment for the wastewater with the purpose to reduce the high concentrations of suspended solids and floating matters (Ashrafi, Yerushalmi, & Haghighat, 2015). In order to achieve even greater efficiency in the removal of particles, e.g., lignin residues, primary treatments such as screening and/or sand traps can also be done before the sedimentation and flotation. According to Singh and Tripathi (2020), sedimentation is reported to reduce 80 % of TSS from the wastewater, and even greater reduction of the total solids is reported from Kraft black liquor, 60 % respectively 87 %, when it is used in combination with adsorption and ultrafiltration. Ultra-filtration, however, is not commonly used despite its high efficiency due to the high operation cost (Singh & Tripathi, 2020).

Chemical Treatment

The chemical treatment methods commonly used in wastewater treatment are chemical precipitation, coagulation, and flocculation, and they are usually applied in the tertiary stages in the plant. The purpose of this treatment is to reduce and remove remaining contaminants after both the mechanical and biological treatment, consisting e.g., of remaining BOD or COD, TSS, metal ions, and color. Coagulation and flocculation are used together in succession where metal salts (e.g. alum, ferric salt, calcium) and polymers (e.g. polyamine) are used to generate larger flocs from small particles (Kamali & Khodaparast, 2015). Chemical coagulation and flocculation followed by sedimentation is widely used in the tertiary treatment processes for pulp-and-paper wastewater treatment to reduce the suspended solids (Singh & Tripathi, 2020).

The reported COD removal from chemical treatments has an efficiency that varies between 20-96 %, depending on the characteristics of the wastewater, and the color removal had an efficiency of 80 %, making the treated water suitable for reuse in the mill. Aside from the removal efficiency of the color, these methods should be combined with biological treatments because they are not efficient enough in removing COD and BOD on their own (Ashrafi, Yerushalmi, & Haghighat, 2015).

2.4.2 Biological Processes

The aim with the biological treatment is mainly to reduce the organic material in the wastewater with the use of microorganisms such as bacteria, fungi and algae that can produce enzymes responsible for lignocellulose degradation (Kamali & Khodaparast, 2015). Certain bacteria are more favorable than others in the reduction of contaminants. These favorable microorganisms refer to the ones that has the ability to form flocks, thereby being able to settle the contaminants and reducing them (Kamp, 2016). These are the wanted bacteria in the biological wastewater treatment processes, and because they only

live within certain living conditions, these conditions are referred to as ‘optimal conditions’ for the bacteria, see further down in this section. In addition to these more favorable microorganisms, there are also other bacteria that exists in the biological basin, e.g., so called Filamentous bacteria or Filaments that live among the flock-forming bacteria. The goal is to obtain a good mixing between these two different bacteria in order to optimize the reduction (Kamp, 2016).

An anoxic zone is usually implemented in the aerobic processes with the aim to reduce the chlorate emissions through chlorate reduction. Toivakainen (2011) reports how this is done similarly as denitrification process, by chlorate-respiring microorganisms in anaerobic or anoxic conditions, the latter meaning there is no free oxygen although oxygen may still be present in other forms. The chlorate is reduced to chlorine dioxide by the chlorate functioning as an electron acceptor instead of oxygen through a set of reactions where the chlorate (ClO3-) is firstly reduced to chlorite (ClO2) by the denitrifying microorganisms and then further converted to chloride (Cl-) and oxygen (Toivakainen, Laukkanen, Jokinen, & Dahl, 2011).

Biological processes are usually used as a secondary treatment as a complementary treatment to physicochemical in order to reduce the BOD and COD in the wastewater. Commonly biological treatments in pulp-and-paper plants are aerobic or anaerobic processes, or a combination of both.

Aerobic Processes

Aerobic treatment involves the degradation of oxygen demanding organic matter by microorganisms in the presence of oxygen (Kaur & Sharma, 2018). This occurs according to Equation 1.

$$Orgaic\ material + \ O_2 \leftrightarrow CO_2 + H_2O + energy \quad (1)$$

The degradation of organic matter will increase by aerating the wastewater, thus reducing BOD and COD, and the production of new biomass. As a result, carbon dioxide is also emitted through this process. Often times, nutrients, i.e., nitrogen and phosphorus have to be added as well to fulfill the Redfield ratio (C:N:P ratio, where the optimum ratio is 106:16:1) between the nutrients and the organic matter in order to maintain best possible yield for the process (Kamali & Khodaparast, 2015).

Commonly used aerobic treatment methods in paper-and-pulp wastewater treatment plants consist of activated sludge (AS), and aerated lagoons (also called aerated ponds) or aerated stabilization basins (ASB). The most commonly used biological processes in Swedish Kraft pulp mills consist of another variant of the activated sludge process, translated to “long-term aerated active sludge”, shortly called LAS, as well as aerated lagoons, and MBBR (Moving Bed Biofilm Reactor) techniques implemented in the biological wastewater treatment process. BAS also exists, which is short for ‘biofilm activated sludge’ and is a biological wastewater treatment where both MBBR and activated sludge are implemented consecutively.

Kaur and Sharma (2018) desbribes the wastewater treatment in aerated lagoons being carried out by active microorganisms and mechanical aeration, making it easy to operate. Disadvantages with this method is the large area the basin requires, along with the residency of 5-7 days and the high energy consumption required for the aeration. Other disadvantages include the high energy consumption required for the aeration (Kaur & Sharma, 2018). For the activated sludge process, the wastewater is first treated with a high concentration of microorganisms and an aeration facility for a few hours or a day. Further, the water is separated from the sludge in a sedimentation basin before the sludge re-circulates to maximize the reduction of organic compounds (Kaur & Sharma, 2018).

Aerobic treatment methods are usually more preferable than anaerobic ones due to their lower cost and minimum operation demand. The disadvantage of aerobic processes is the high sludge production (Singh & Tripathi, 2020). Ashrafi et al. (2015) desbrices how investigations have shown how the active sludge process effectively can decrease the concentrations of COD, BOD, and AOX with a reduction efficienty of 70%, 90%, and 60%, respectively, as well as reducing chlorinated compounds. Correspoding, aearated lagoons removal efficiency was 30-40% COD and 50-70% of BOD, although the removal of chlorinated compounds were lower, while at the same time requiring a lower amount of nutrients added to the wastewater. With these efficiencies in mind, aerobic processes have considered to be suitable processes for wastewater treatment despite their high sludge production and their dependecy on nutrients for the high effiency (Ashrafi, Yerushalmi, & Haghighat, 2015).

Anaerobic Processes

Similar to the aerobic process, the anaerobic process main function is the degradation of organic material of microbes, however without any oxygen but through hydrolysis and acidification. Consequently, the anaerobic reaction leads to the emission of methane gas, see Equation 2.

$$Organic\ material \leftrightarrow CH_4 + energy \quad (2)$$

Methane gas has a much greater impact on global warming than carbon dioxide. Unlike carbon dioxide however, methane gas can be further put to use by being recovered and used as an energy source, thus diminishing the environmental impact. Anaerobic processes emit slightly less greenhouse gases than anaerobic treatments due to the lower volume of sludge production (Kaur & Sharma, 2018).

Anerobic treatment are not as commonly used as aerobic processes although it is applied in a few wastewater treatment plants. Up-flow anaerobic sludge blanket (UASB) reactor and fluidized-bed reactor (FBR) are two anaerobic processes that have been used in the treatment of pulp-and-paper wastewater. Studies treating bleached and unbleached Kraft mill wastewater showed a high removal efficiency of COD and chlorinated organic compounds at 79-82% respectively 71-99% (Ashrafi, Yerushalmi, & Haghighat, 2015). Despite the fact they are not commonly used, they hold several advantages against aerobic processes. The volume of the sludge production is about 30-70% less,

possible biogas production with the emitted methane gas, design simplicity, and the area requirements are smaller than with aerobic treatment basins (Kamali & Khodaparast, 2015). However, anaerobic prosses uses microorganisms that are more sensitive to toxic material in the water and low pH which may influence the removal efficiency of contaminants in the wastewater (Singh & Tripathi, 2020).

The majority of the biological process in this study consists of the different aerobic processes, and it is primarily these that will be the continued focus in the study.

Parameters affecting the Biological Wastewater Treatment

Because biological treatment is done with the help of living microorganisms, it makes the method sensitive to several factors that affect the microorganisms living conditions and functioning, the most important factors including temperature, pH, dissolved oxygen, available nutrients such as phosphorous and nitrogen needed for the growth of microorganisms, and low or no concentration of toxic materials (Mattsson, 2006). This causes the potential of constant change in the biological basin depending on the living conditions, where microorganisms with advantages will grow while others will be outrivaled and outlived (Kamp, 2016). Thus, if these parameters would alter, the biological activity of these favorable microorganisms will be inhibited and reduced significantly.

pH

pH is an important parameter that affects the activity of microorganisms, and the optimal pH is around neutral pH (6,5 -7,5) for aerobic processes (Kang, Wang, & Xiao, 2009). Sudden changes of pH that is common with some temporary effluents, that are common with alkaline or acidic effluents, is therefore not optimal for the bacteria, and alterations of pH may lead to reduction of the biological activity, which will then further affect the effluent out from the WWTP.

Temperature

The more favorable microorganisms thrive in mesophilic temperature conditions, i.e., in temperatures varying between 20 °C and 40 °C are the most optimal temperature conditions for these microorganisms (Samer, 2014). If the temperature is too low, the biological activity of the microorganisms will slow down, meaning the reduction in the biological WWT will not be as effective compared to the residence time in the basin. Van Dyke et. al. (2003) survey showed that temperature had a crucial role in the nitrogen removal in aerated lagoons specifically, and during colder months, the nitrogen removal decreased due to temperature being the most important factor affecting the microbial nitrification of ammonia (Van Dyke, Jones, & Ong, 2003).

If the temperature is higher than the microorganisms optimal however, studies carried out by Tripathi & Allen (1998) has shown that not only will higher temperatures cause a microbial reduction change

that is more selective and narrow, but that COD reduction as well as sludge settling rates decreases significantly at higher temperatures than over 45 degrees.

Nutrients

In addition to the microorganisms need of organic matter (carbon), nutrients such as nitrogen and phosphorus are essential as well in order for the microorganisms to grow and for the production of new bacteria in the basin, thus meaning that the Redfield ratio need to be fulfilled for the best possible conditions for the microorganisms (Kamali & Khodaparast, 2015).

As mentioned before in section 2.3.1, nutrient deficiency is a common problem in pulp-and-paper WWTP compared to municipal wastewater due to the smaller amount of nutrients compared to organic matter in the wastewater, and sometimes need to be added to meet the conditions for the microorganisms.

In addition to this, there are also other parameters that may affect the activity and efficiency of the microorganisms and thereby the biological WWT, such as activated sludge age and retention time. These will however not be closer discussed in this study.

3 Methods

The key element of this study has been based on interviews with personnel from different Kraft pulp mills situated around Sweden (see Appendix 1) where the interviewees experiences concerning common temporary effluents, the incidents which causes these, as well as the effect they had on the treatment processes was in focus. This methodology was used in interest to collect data to base the study on the experiences of Kraft pulp mills regarding the effluents that occur in practice, as opposed to the theoretical/possible effluents from literature alone. The interviewing target was environmental engineers mainly in charge of the wastewater treatment for each mill, and 13 out of 21 of all Kraft pulp mills in Sweden participated in the study, empowering well enough data for the research from different parts of the country, as well as different types of mills and a variety of wastewater treatment plant processes (see Appendix 1).

In preparation for the interviews, risk analyses on various situations from different Kraft pulp mills were studied as well as environmental reports from the mills that participated in the interviews, and an extensive literature study was carried out which the interviews were based on. Questions for the interview were developed in discussion with experts from AFRY in a scheduled workshop with expert senior consultants (see Table 2). The original interviewing questions in Swedish are compiled in Appendix 2.

Table 2. Interview questions, translated to English.

1.	Have you experienced temporary effluents during these past years that have affected the wastewater treatment plant?
2.	What type of effluents have it been?
3.	How have they affected the wastewater treatment plant?
4.	What types of common incidents caused these effluents?
5.	How did the incidents occur?
6.	How often do they occur?
7.	What precautions did you take when they occurred? Did it work?
8.	Have you drafted a measure/action plan?

Further, the interview results were compiled based on the common temporary effluents the interviewed mills had experienced in Excel, together with the incidents that caused them and measures to mitigate the effects if these had been mentioned. Additional parameters that had an effect on the treatment processes were also included in the survey due to their important effect on the treatment processes. Another workshop was scheduled together with expert senior consultants in order to discuss the effects of all the effluents as well as measures for managing them. All the results and discussions were then compiled together in the form of an action plan (a handbook) in both Swedish and English in Appendix 3 for easier use.

4 Results

The results of the study have been conducted and compiled with a basis of the interviews. Initially, the interviews were analyzed in quantitatively with emphasis on the common temporary effluents as well as commonly occurring incidents among the interviewees. Further, the effects of the common temporary effluents observed, if there had been any, were compiled along with action plans, i.e., what has been done when these occur. Lastly, additional parameters are also included with the interviewees experience of the effect of these.

The common temporary effluents from the Kraft pulp mills will be further referred to only as ‘common effluents’. Note that the normally occurring effluents, i.e., emissions that occur on a normal basis from the mills, are not included in this study. The same applies to the incidents causing the effluents, referred to as ‘common incidents’.

4.1 Common Effluents and Incidents

The results from the common effluents and incidents are represented in Table 3 below.

Table 3. Common (temporary) effluents derived from the experiences of the 13 interviewed mills are presented sorted by their frequency of occurrence. A description of the effluents is given if one was provided by the interviewees, together with the incidents or the sources that caused the effluents in these cases.

Common effluents	*Description*	*Source of effluents*	*Occurrence*
Liquors	*Mainly black and white liquors (washing liquors and chemical liquors)*	Stoppage/Maintenance stop Overflow Unknown	12/13
(Sodium) chlorate	*Base chemical for bleaching chemical preparation, usually a rest-product from the bleaching chemicals*	Bleaching plant incidents Stoppage/Maintenance stop	4/13
Fibrous water	*From cardboard-machine*	Unknown	3/13
Condensate (unclean)	*Evaporation condensate*	Unknown	2/13
Chlorine dioxide	*Bleaching chemicals*	Bleaching plant incident (dosage of bleaching chemicals)	2/13
Raw water	*Incoming water that accidentally mixed with wastewater*	Overflow Problems with equipment	1/13
Bark Press Water	*From cleanery, ends up in sewage system by pump errors*	Problem with equipment	1/13
Sodium bisulfite **Magnesium bisulfite**	$NaHSO_3$ $Mg(HSO_3)_2$ *Base chemicals in sulfite pulp mills*	Problem with equipment	1/13
Hydrogen peroxide	*H2O2* *Bleaching agent*	Bleaching plant incidents	1/13
Lime sludge	*Insoluble calcium carbonate (CaCO3)* *Rest product from causticizing plant*	Overflow Stoppage/Maintenance stop	1/13
Tall oil	*Extracted from heavy black liquor/soap in a refinery at site*	Unknown	1/13
Soap	*Separated from heavy black liquor in a refinery at site*	Overflow Stoppage/Maintenance stop	2/13
Turpentine	*Extracted from heavy black liquor*	Unknown	1/13
Methanol	*Extracted from heavy black liquor*	Unknown	1/13
Hydraulic oil	*Used in machinery at site*	Unknown	1/13
Starch	*From cardboard-machine*	Unknown (chemical preparation emission)	2/13

The most common emission to WWTP, which has occurred in 12 out of the 13 mills participating in the interviews, consist of liquors in various forms (e.g., black liquor and white liquor). The source of these was also similar in all the mills, caused either by emissions from the bleaching plant or during stoppage/maintenance stops, both planned and unplanned ones. These effluents were also the most frequented occurring, with at least 1-2 discharges per year. Other effluents varied depending on which type of mill was asked as well as the other processes they exercised at the facility, e.g., if the mill is integrated, what type of bleaching is applied, or if there is a tall oil refinery at the site. Additional common effluents (occurring in more than one mill) include chlorate, fiber-rich water, condensate, and other chlorinated compounds from the bleaching plants such as chlorine dioxide and chlorate.

Similarly, the most common incidents or sources that caused the temporary effluents (Figure 5) were in general similar between the mills, and the most commonly occurring were emissions from the bleaching plants or effluents caused by both planned and unplanned maintenance stops. Even overflowing (of e.g., cisterns), causing the content to lead straight to the wastewater treatment plant through sewage drains, is a highly occurring incident. A list consisting of all possible incidents that may occur (based on the interviewer's experiences) is listed in Table 3. These are also presented in Figure 5 below, displaying the distribution of all the experienced incidents.

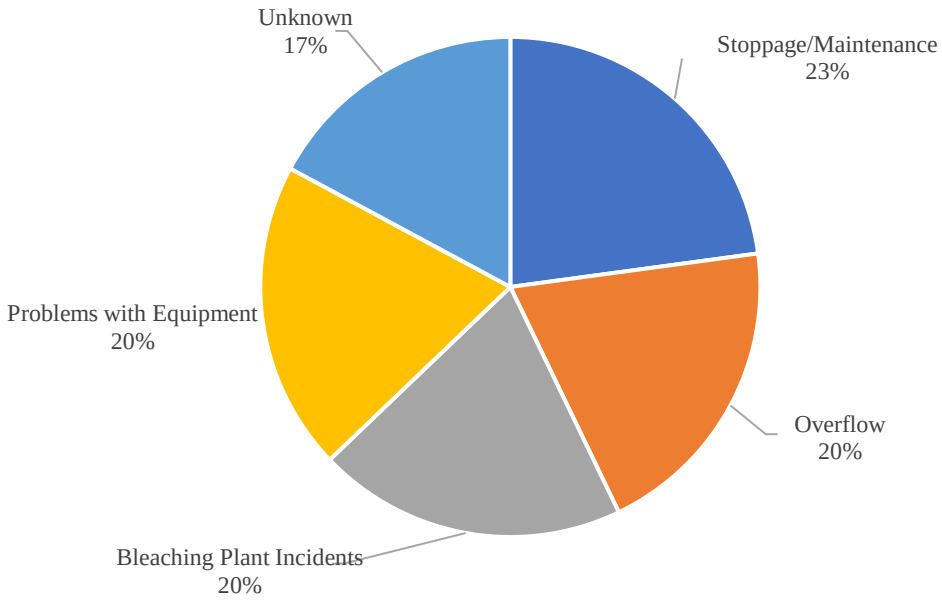

Figure 5. Most occurring temporary incidents or sources of effluents compiled from the interviewees.

Unknown incidents were also common among the mills. The Kraft pulping mill process is a highly complex system with many crucial components intertwined, therefore the cause or source of a problem is often hard to pinpoint. Many of these incidents presented in Figure 5 can also be related to each other for that reason, and therefore be hard to categorize. For example, it is common that stoppages, whether planned or unplanned ones, cause overflow of substances such as liquors (the most common effluent).

4.2 Effect of Common Effluents on WWTP and Applied Measures

Depending on the mill as well as the type of biological process operated, the effect of different effluents can vary. The results from what the mills have generally practiced and experienced are compiled in Table 3. Where no effect is given, either the mills did not experience any effect due to the small quantity of the effluent or no effect on the treatment process was detected until the discharge from the treatment had been released. The latter does not suggest no effect was present, since the various effluents were shown on the discharge from the treatment plant on to the receiving water body, e.g., by higher emissions

of various parameters such as suspended solids or nutrients, thus signaling something had altered in the treatment processes. The lack of effect could also be due to a lack of response from the interviewee for various reasons.

Table 3. The effect of the common effluents on the wastewater treatment processes, as reported by the interviewed mills' as well as the measures taken when these temporary effluents occurred. The WWTP mainly referred to is the biological process treatment, unless otherwise specified for the effect of the effluents. Empty cells in the table displayed as "-", indicate a lack of result, i.e., no answer was received from the interviewees, due to effect not observed at the mill or measures not taken.

Common effluents	*Description*	*Effect on WWTP*	*Measures/Action plan*
Liquors	*Alkaline*	pH increases Foam and soap(?) formation Risk of harming microorganisms	Neutralize the alkalinity with acidity, e.g., sulphuric acid Adding nutrition (N, P) Aeration
(Sodium) chlorate	*Strong oxidant*	Risk of harming microorganisms	1. Reduce the unbound oxygen in the basin 2. Add organic material 3. Add nutrients (N, P)
Fibrous water	-	Fibers instead of sludge Risk of overloading sedimentation (not working properly) A lot of fibers to biological basin	Added extra help with excavator to remove fibers from the sedimentation
Condensate (unclean)	-	-	-
Chlorine dioxide	*Oxidizing agent*	Subverted in the biological process Risk of harming microorganisms	-
Raw water	*Incoming water to the mill* *Colder than the wastewater*	Temperature impact Risk of harming microorganisms	-
Bark Press Water	*Contains high COD and weakly degradable substances*	Risk of harming microorganisms	-
Sodium bisulfite **Magnesium bisulfite**	*Acidic*	pH decreases Risk of harming microorganisms	-
Hydrogen peroxide	*Oxidizing agent*	Subverted in the biological process Risk of harming microorganisms	-
Lime sludge	*Suspended material increases*	-	-
Tall oil	*Floats on the water surface (has lower density than water)*	-	-
Soap	*Composition is a combination between liquors and tall oil*	-	-
Turpentine	*High organic content*	-	-
Methanol	*Low toxicity* *Easily biodegradable* *High organic content*	-	-
Hydraulic oil	*Similar to methanol, although more toxic*	-	-
Starch	-	-	-

Most of the common effluents have the potential to harm microorganisms in the biological treatment process, thereby reducing the biological activity which can lead to higher emission out from the treatment plant, which further may lead to negative effects in the receiving water body.

The overall results show that similarly to the incidents or the sources of the common effluents, the effect of the effluents were often only detected 'too late' when the effluents from the WWTP already show increasing concentrations. This is one of the reasons these studies are important, to compile the effluents and the effect they tend to have if they should occur, including the measures to take if or when they occur. In section 5.2, there will be a survey of possible effects of all the common effluents listed and how they affect the treatment processes.

Measures that have been practiced when these effluents have occurred have in some cases been specific and related to the effluent at hand, and some cases either the mills did not take any actions at the time of the emissions or did not mention it. In some cases, the effect may have not been detected in time, and as a result of this circumstance, no measures were taken. The situations where no action plan was applied will be further discussed in section 5.2, along with measures for all the listed common effluents as well as discussing both the action plans already practiced and additional possible ones.

4.3 Additional Parameters Affecting WWTP

In addition to common effluents experienced by the mills participating in the interviews, there are some other parameters to take into account when investigating WWTP. In this regard/survey, in particular the biological treatment, which is based on the biological activity of microorganisms such as bacteria and therefore also are especially sensitive. Some parameters are essential to sustain a habitable environment for the microorganisms in order for them to 'clean the water', and these parameters were reported (by the interviewees) to be temperature, pH, and nutrient balance, as well as organic balance in their living environment (Table 4). Ranges of these outside the optimal may risk inhibiting and/or harming the microorganisms, thus causing problems in the WWTP (primarily in the biological process).

The overall experience of the mills with the changing of these parameters are listed in Table 4 below.

Table 4. A list of parameters that may affect the biology in the biological treatment process along with what can cause a variation of these as well as what the effect will be on the WWTP (biological process primarily) if these parameters are changed.

Occurrence	*Parameters affecting biology*	*Incidents/Causes*	*Effect on WWTP*
5/13	Temperature	Season variations Problems with equipment	Risk of inhibiting microorganisms
-	pH	Incidents involving pH changing substances	Risk of harming and inhibiting microorganisms
-	Nutrient deficiency	-	Cause floating sludge Risk of inhibiting microorganisms

Temperature was a parameter that the mills experienced differently from each other, therefore the only occurrence given is for the mills who specifically had problems related to temperature influence. Some mills stated they did not experience any seasonal variation of the temperature impact. The effect of these parameters could also alter significantly depending on the type of biological wastewater treatment process implemented in the mill. All microorganisms may work differently, but in general, the optimal temperature is between 25 – 40 °C (Samer, 2014), usually between 35 – 37 °C for the pulp-and-paper industry because of the normally high temperature of the wastewater. The occurrence in the table therefore suggests mills that experienced a seasonal variation (due to temperature changes) and thereby had more problems related to their biological treatment depending on the season.

5 Discussion

In this section, the results from the interviews are discussed as well as possible sources of error in the survey. Further, the results are analyzed with regard to both the practical experiences reported by the mills as well as against the background of relevant literature to explain the effects on the WWTP. Lastly, these analyses and investigation results are compiled in a guideline or action plan.

5.1 Common Effluents and Incidents

Liquors are one of the most abundant substances in the processes of the Kraft pulp industries, both in the fiber line but also in the recovery system, which can be an explanation to why almost all the interviewees in the survey experienced some incidents involving liquors, resulting in liquors being the most common temporary effluent among the Kraft pulping mills. Liquors are derived from many different processes and can therefore comprise of many different compositions, such as white liquor, also called ‘washing liquor’, black liquor (heavy or thin), and green liquor (restoration chemicals). A typical characteristic of the Kraft liquors is that they are alkaline.

The main incidents causing the liquor emissions were due to maintenance stops and overflows (along with unknown reasons), see Table 3. Maintenance stops, including both planned and unplanned ones, are the most occurring incident in the mills, all the mills having reported at least one scheduled maintenance stop per year to look over the functions of the machinery and maintain them. This makes stoppages statistically more likely to occur, explaining why they are the most common type of incident. Everything does not function properly or as it should during these stops, which is why the risk of incidents increases. This also makes incidents occurring at stops more important to try to prevent, as well as trying to minimize the occurrence of effluents at these stops, or in best case scenario, know how to remedy such effluents. Singh & Tripathi (2020) reported bleaching plants being the main source of contaminants in Kraft pulp mills effluents, which is in agreement with the results of this study where the experiences of the interviewees show that bleaching plant incidents were a highly reoccurring incident (Figure 5).

Additionally, the extent of the survey needs to be considered when discussing the common effluents and incidents listed in section 4.1 and 4.2. The results in this thesis are based on the experiences of 13 (out of a total of 21) Kraft pulp mills in Sweden. The mills that did not participate are not represented and may have different experiences. For the continuation of the study as well as the discussions however, the results from the 13 out of 21 interviewees will be considered representing the majority of Kraft pulp mills.

5.2 Effects of Common Effluents on Treatment Processes and Possible Measures

The type of effect a discharge has or may have on the wastewater treatment processes varied considerably depending on the type of treatment implemented at the mill (Table 4). In particular, the type of biological treatment is a factor that influences the effects, and thereby also the type of remedy measure. This can also mean that there might not be a (measurable) effect in the biological process efficiency at certain types of processes. Some mills participating in the interviews did not observe any effects of some or all of their effluents/water emissions. Other mills, in contrast, experienced many and significant effects because of the more sensitive biological process they have implemented, see Table 4.

Sedimentation is also an important process, and if not functioning effectively, it may lead to increasing emissions to the biological wastewater treatment (WWT), i.e., risk harming and/or inhibiting the activity of the microorganisms. The main objective with the sedimentation basins is to reduce the amount of suspended particles by letting them settle and forming a sludge that is then removed mechanically (Ashrafi, Yerushalmi, & Haghighat, 2015). This is done as a primary treatment in order to make the wastewater more suitable for the biological treatment process. As reported by Singh and Tripathi (2020), the content of total suspended solids in the wastewater is reduced by 80 % in the sedimentation, which is usually done both before and after the biological WWT. This means that if these components do not function as they should, the repercussions would be that the large amount of suspended particles originating mainly from the wood but also from some forms of temporary effluents, instead will flow through the sedimentation process and further to the biological treatment. The suspended particles may then continue to not settle; thus risk being released into the environment without further treatment.

The key function of the biological treatment processes is the microorganisms for treating the wastewater. When temporary effluents occur, the aim is firstly to reduce the possible toxic trait of the effluent, i.e., reducing the impact on the wastewater treatment plant, before continuing to apply measures to ensure the growth and activity of the favorable microorganisms. These are microorganisms that have the ability to form flocks and thereby reducing the contaminants in the wastewater (Kamp, 2016), and these are mainly monitored through the parameters that affect their living conditions (see section 2.4.2 *Parameters affecting the Biological Wastewater Treatment*). If these parameters would change due to occurring emissions and not remain optimal, other microorganisms than the more favorable ones for treating the wastewater might take over instead, leading to a reduction in biological activity which then further leads to the risk of effluents being released to the receiving water body.

Further in this section, how the experienced temporary effluents effect the WWTP will be discussed for each effluent as well as possible measures for these, with the aim of discussing and assessing the results from the interviews (Table 4 in section 4.2). These are also represented in Appendix 3 compiled for the effects and measures of all the effluents, both in English and Swedish for easier use.

Liquors

The optimum conditions for a well-established biological activity is, among others, a pH close to neutral in the wastewater (Samer, 2014). This means that the bacteria will grow faster at this pH, but will reduce their microbial activity significantly the further the pH deviates from the optimum. The majority of the liquors from Kraft pulp mills are alkaline with a pH over 10, which is above the optimum pH and therefore risk altering the conditions for the bacteria in the biological processes if not neutralized.

Black liquors also contain possible toxic substances and a high load of organic material, e.g., tall oil, soap, and methanol (Andersson, 2014), that can also reduce the bacterial activity of the microorganisms. In addition, liquors also have a tendency for foam formation which can physically affect the basin, and devices such as meters that monitor parameters such as pH, temperature, and conductivity in the basin.

One of the first and most important measures if liquor emissions occur is to add defoamer as well as adjusting the pH in the water, which is often done by adding sulphuric acid to counteract the effect of the alkaline liquors. Further, depending on which type of liquor is emitted as well as the composition, additional measures need to be taken. This is especially relevant for black liquor that also contains a high content of organic matter. Then, the conditions of the bacteria need to be monitored and perhaps adjusted by for example increasing the aeration and add nutrients including nitrogen and phosphorous, to optimize the growth rate of the microorganisms. The type of nutrient that may be needed to add varies among the mills, and depends on e.g., the type of wood that is used and the processes and reduction in the WWTP. The temperature of the wastewater can be monitored as well. The optimum temperature for the favorable biological activity lays around 37°C (Samer, 2014), whereas the temperature of the liquors usually is very high. This can alter the overall temperature in the biological processes, and if the temperature increases too much, it may risk inhibiting or even harming the microorganisms.

Last but not least, liquor emissions often occur along with incidents involving maintenance stops so one of the most important measures to take is to secure a plan in order to prevent these effluents at the stops. This can be in the form of cisterns to store the liquor during such stops as well as a form of spill pond or detention pond with sufficient retention time to avoid the wastewater treatment being overloaded. When implemented these contingency plans will also be of use in the case of unplanned stoppages, although they are more difficult to control.

Chlorinated Compounds

The chlorinated compounds mainly originate from the bleaching plant and mills that use ECF-bleaching, and these compounds constitute of chlorate and chlorine dioxide. These are derived from the ECF-bleaching processes; chlorine dioxide as a bleaching agent and chlorate formed from reactions between

bleaching agents such as chlorite and hypochlorous acid (Ni, Kubes, & Van Heiningen, 1993). Chlorine dioxide is more reactive than chlorate, with a risk of being disintegrated in the biological processes, thus increasing the risk of harming the microorganisms (Cabrera, 2017).

Due to the toxicity of the chlorinated compounds and the long-term harm they can cause for microorganisms if released, Kraft pulp mills always have an implementation of chlorate reduction in their biological treatment process during anoxic conditions in the form of an anoxic zone where chlorate is reduced to chlorine by chlorate-respiring microorganisms (Toivakainen, Laukkanen, Jokinen, & Dahl, 2011). Within aerated lagoons and activated sludge processes, this chlorate reduction occurs in an anoxic zone usually in the first steps of the biological wastewater treatment. This is due to the slightly higher TOC the chlorate reduction entails. Therefore, if this anoxic zone was to be implemented at the end of the biological wastewater treatment, there would be an additional need for aerobic microbial activity/processes after this step to reduce the organic content yet again. In WWT processes with MBBR, the anoxic zone is usually a part of the biofilm reactors where the reduction of chlorate occurs inside the anoxic parts of these.

When emissions of these compounds occur, especially chlorate, one priority is to make sure the environment the chlorate-respiring microorganisms live in is anoxic. Chlorate is a strong oxidant, and the chlorate reduction relies on chlorate functioning as an electron acceptor instead of oxygen (Toivakainen, Laukkanen, Jokinen, & Dahl, 2011), meaning that the presence of oxygen would disturb this reduction and the chlorate would remain in the wastewater untreated. Other measures that need to be taken is making sure the conditions for the microorganisms are optimal. This includes the Redfield ratio (which is the ratio between the organic matter and chlorate/nutrients) being met, as well as making sure the mixing is efficient and even and the temperature and pH of the wastewater are optimal to obtain optimum conditions for the chlorate reducing bacteria. Condensate and methanol, both described in Table 3, are good sources of additional organic matter for the microorganisms, and nutrients, nitrogen in particular, should be added in the form of ammonium, if needed. This is due to nitrate also having the capacity of functioning as an electron acceptor (instead of the chlorate) when free oxygen is not available.

The measures for chlorine dioxide emissions are similar to the ones with chlorate. Additional measures to take is temporarily to temporarily stop the return active sludge (RAS) to make sure that the chlorate or chlorine dioxide are not recirculated into the system again, and also preventing the accumulation of these in the process in order for a faster recovery for the wastewater treatment.

The chlorate-respiring bacteria are more sensitive than the other microorganisms and grow slower as well. This will result in the recovery time being longer for these if the parameters of the biological WWT are not optimal or if they alter, i.e., chlorate effluents are a risk-factor to be considered if the risk of harming the microorganisms increase with temporary emissions.

Other Chemical Compounds

In this category, the remaining chemical compounds used as bleaching agent or in other processes will be discussed, including hydrogen peroxide, bisulfites (consisting of sodium and magnesium bisulfite), and lime sludge.

Hydrogen peroxide

Similarly to chlorine dioxide and chlorate, hydrogen peroxide originates from the bleaching plant processes, but unlike them, hydrogen peroxide is a bleaching agent in the TCF-bleaching process. Hydrogen peroxide is also an oxidizing agent, and similar to chlorine dioxide, it is biodegradable in the wastewater and produces hydroxyl radicals (OH) which are very reactive and cause damage on the cells of microorganisms, i.e., risks harming them and potentially killing them (Mahaseth & Kuzminov, 2018). This is especially of concern at larger emissions, when the risk of negative impact on the biological process increases.

In addition, hydrogen peroxide effluents cause foam formation in the wastewater. Consequently, the formation of foam increases in the sedimentation processes as well (usually before the secondary biological treatment). Excessive foam formation will create so called 'caps' on the sedimentation caused by the increased sludge formation, which will lead to the sedimentation not functioning properly and the fibers that are supposed to settle will float on the surface instead and subsequently flow with the wastewater to the biological process. This will then be mixed with the sludge in the biological processes and weaken the favorable microorganisms by the resulted dilution in the biological treatment, thus decreasing the reduction of organic matter in the process.

When hydrogen peroxide is emitted to the wastewater treatment processes, addition of defoamer may prevent the aforementioned effects. Other measures for this effluent include making sure the conditions for the bacteria in the biological WWT are optimal as well as encouraging their growth.

Bisulfites

Both sodium bisulfite ($NaHSO_3$) and magnesium bisulfite ($Mg(HSO_3)_2$) are chemicals used in the sulfite pulp process which are acidic, in contrast to the alkaline Kraft pulping chemicals. This means that they may have similar effect on the wastewater treatment with the risk of affecting the optimum living conditions, more specifically decreasing the pH in the wastewater to below neutral in this case, thus risk harming the microorganisms. This is done when the bisulfites react with the available oxygen and form sulfuric acid (H_2SO_4), a very acidic compounds that may decrease the pH considerably.

Therefore, pH neutralization with an alkaline product will be the foremost measure to take when these effluents occur. Sufficient aeration is also important to prevent hydrogen sulfide formation due to sulfate-reducing microorganisms.

Organic Compounds/Substrates

In this section, soap, tall oil, turpentine, methanol, hydraulic oil, excessive organic material, and starch will be discussed in terms of effect on the WWTP and measures to prevent any negative effects. These organic compounds have similar characteristics, although some differences occur.

Soap

Heavy black liquor is used to extract soap, which is then further processed in a tall oil plant to extract tall oil (Andersson, 2014). The characteristic of soap is similar to a combination of liquors and tall oil, and contain high concentrations of COD. Similar to liquors, soap tends to foam which can cause similar problems in the biological basin as well as in the sedimentation. Applying defoamer is therefore of interest when suspecting emissions of this kind.

Additional measures to take when soap is leaked into the biological WWT is to make sure to circulate and aerate the wastewater to maintain the bacterial activity. Similar to the chlorinated compounds, stopping or reducing the RAS would eventually be a good measure as well with the purpose of decreasing the risk of accumulation, and increasing the chances of removing the contaminant from the WWT processes.

Tall oil

Because of the higher density of water compared to oil, tall oil will float on the surface and does not mix with the wastewater. Tall oil is highly toxic to aquatic life and microorganisms (Sunpine AB, 2020), and there is always a flame risk associated with compounds such as tall oil.

The first and foremost action to take with these effluents is to try to separate and collect the tall oil as fast as possible, preferably before it reaches the biological process, in the primary sedimentation treatment process. If the discharge would reach the biological basin, it is important to make sure the conditions for the favorable microorganisms are optimal and the wastewater is circulated. RAS should be stopped here as well for the same reasons as mentioned before.

Hydraulic oil

Hydraulic oil is used in the machines at the site with the purpose of making sure the machines in the pulp-and paper processes are working properly, and can evidently leak to the WWTP in the event of

incidents. Hydraulic oil is comparable with tall oil, although more toxic if emitted to the WWTP. Therefore, the measures for this kind of effluent are very similar to the ones for tall oil.

Methanol

Methanol is extracted from black liquor and is, like the hydraulic oil, very similar to tall oil except for the fact that methanol is classed as low toxicity for aquatic organisms and easily biodegradable according to its safety data sheet. On the other hand, methanol give rise to increased organic material in the wastewater, i.e., an increased stress on the biological WWT. The basins are usually only dimensioned for a certain capacity, and if the biological treatment is overloaded beyond this capacity, the microorganisms will not be able to clean the wastewater. This will then result in the emission of high organic content into the environment.

The aim with the biological WWT process is to reduce the organic matter content using microorganisms that break these down, see Equation 1. Hence, the microorganisms should be able to reduce an increasing organic load as well, given that the increase occurs within the dimensioning of the (biological) basin. If emissions of this type arise, the most important precautions to take is making sure the conditions in the basin are good, and the parameters optimal to alleviate the stress for the bacteria. This includes neutral pH, ideal temperature for the microorganisms, and well enough nutrients for the organisms to grow. Aeration is important as well to make sure the microorganisms can reduce the organic material.

Turpentine

Turpentine is an organic viscous liquid substance that is separated from the produced condensate from the Kraft pulp process and, like methanol, consist of a high load of organic matter. It is classified as very toxic to aquatic life with long-lasting effects (Sunpine AB, 2020). Thus, a discharge of this kind risks having an effect on the receiving water body and the organisms living there, it may also harm the microorganisms in the biological WWT for this reason.

Measures for this effluent is the same as previously mentioned for methanol.

Starch

Starch is an important raw material in the paper manufacturing and is used for a large number of applications, including as a flocculant and retention aid and the use as a surface-sizing agent, i.e., improving the water and abrasion resistance (Maurer, 2009). The effluent of starch does not contain any toxic traits for the microorganisms in the biological WWT, although it will give a rise in COD in the wastewater. Starch also has a tendency to trigger the non-favorable bacteria, e.g., filamentous bacteria, i.e., bacteria that cause floating bio-sludge. They are thereby ineffective when the goal is to reduce the organic material in the wastewater by letting sludge settle on the bottom of the basin.

Due to the higher load of organic compounds in the biological WWT from this effluent, the measures are the same as previously mentioned for methanol.

Others

Lime sludge

Lime sludge consists of insoluble calcium carbonate ($CaCO_3$). Similar to tall oil, lime sludge does not mix with the wastewater (although it sinks unlike tall oil), and should therefore be easy to gather up in the primary treatment processes step, i.e., the sedimentation, to prevent it from affecting the biological WWT process by e.g., overloading the sedimentation.

Condensate (unclean/foul)

The condensate is a byproduct of the Kraft pulp process from the digester and evaporation, from which turpentine can be generated. 'Foul' condensate, i.e., unclean condensate, generally contains volatile compounds such as methanol and sulfur compounds (Milet, 1997). For example, condensate can give arise to hydrogen sulfide (H_2S), a toxic gas that attacks cell tissues, which is why it should be handled with care if emitted.

Similar to turpentine, condensate contains a high load of organic content which can overload the biological WWT. Most of the Kraft condensate can be reduced with aerobic biological treatments, although addition of nutrients may be necessary for healthy biological growth (Milet, 1997). Aeration is also important because the of the high organic load, the bacteria demand oxygen to be able to reduce these, see Equation 1.

Fibrous water

A possible source for wastewater containing high amounts of fibers is larger emissions of fibrous water from the paper production within integrated mills, although other sources are also possible. The high-content fibrous water is likely to strain the sedimentation mainly, causing overloading which might result in the sedimentation not being able to fulfill its purpose of reducing the particles if they do not settle. If the fibers are too much for the primary treatment to remove, this will lead to an increased load of particles into the biological WWT, similar as the effect of hydrogen peroxide mentioned earlier. The measures that can be taken for this effluent is therefore also similar to those of hydrogen peroxide aforementioned.

Raw water

The term 'raw water' suggests the incoming water that have not yet been used in the Kraft pulp process and technically does not account as an effluent. Incidents where raw water has accidently reached the WWTP and mixed with the wastewater has occurred, therefore this will be included and covered as well.

Raw water does not contain toxic substances naturally because its lack of contact with the production process. The effect it may have on the biological WWT is due to the difference in temperature conditions of the wastewater and the colder raw water mixing. The most important measure to apply then is to monitor the temperature of the wastewater and make sure it stays the optimal. If the emission of raw water is significantly large, it may also risk diluting the wastewater.

Bark press water

Bark press water is a rest-product from the bark press, where the purpose is to increase the dryness or dry matter of the wet bark, and is a part of the wastewater emitting from the wood handling. Bark press water may contain very toxic substances derived from the wood/bark, and high COD (a lot of organic matter).

In order to avoid any interference/repercussions in the biological WWT, the most important measure is to aerate the biological basin as well as making sure the conditions are optimal, similar to the applied measures of methanol effluents.

5.3 Effects on Receiving Water Bodies

The emissions from the wastewater treatment plant at Kraft pulp mills have the potential of disrupting the structure and functioning of natural ecosystems (Singh & Tripathi, 2020). How large this potential is depends strongly on the type of receiving water body at each and every mill, and how resilient it is. Some water bodies are very sensitive to even the smallest of emissions of a contaminant and the effect can be seen almost immediately, whereas no noticeable changes are shown for others according to several of the interviewees. In the long term, however, it is important to decrease the emissions of contaminants to all receiving water bodies in order to avoid accumulation of them, which can very well lead to destructive behavior on ecosystems over longer periods of time.

The risk of an temporary effluent affecting receiving water bodies occurs mainly when the WWTP is overloaded, and the contaminants are released with the water, and how they risk affecting the environment is dependent on the effluent. Further, the effects are divided into three categories; increased suspended material, toxic trait, and contaminants with high organic content. These categories are mainly based on the effect the common temporary effluents risk have (Appendix 3).

Fibrous water and lime sludge are effluents that mainly risk increasing the amount of suspended material in the wastewater, if the effluents are large enough to overload the sedimentation and the biological WWT. If water with high content of suspended material is released, it causes dark color and high turbidity of the water. This further risks causing blanketing on the surface of water bodies (relevant for the floating particles), resulting in a reduction of sunlight and available oxygen in the water (Singh &

Tripathi, 2020). This may have a very negative impact on the aquatic life conditions, altering the living conditions for the present marine flora and fauna.

Some effluents contain toxic substances (see Appendix 3), and the main source of most of them is the bleaching plant. Examples for these substances include chlorate, chlorine dioxide, and hydrogen peroxide. These can be very toxic, mutagenic, persistent, and accumulate in ecosystems with a significant risk of disturbing it, as well as causing a variety of abnormalities in fish for example, along with detrimental impact on marine flora (Singh & Tripathi, 2020). Even compounds such as tall oil contain compounds that are highly toxic to aquatic organisms. Tall oil also floats on the surface of the water and may cause direct harm to especially marine fauna if they are exposed. However, how much this affects aquatic life depends on how much is emitted and how the marine flora and fauna will react, i.e., on the ecosystem's sensitivity.

Contaminants containing high organic content increase the BOD and/or COD in the water and thus contribute to depletion of the available dissolved oxygen in the receiving water body (Singh & Tripathi, 2020). This further risks affecting the ecosystem, e.g., reducing the available oxygen for the fauna present in the water body.

6 Conclusions

Preventing incidents and temporary effluents to occur will always be the best alternative, with the help of e.g., contingency plans and general careful planning for common site incidents. If and when incidents do occur, the next best thing is to know the measures to take to mitigate the effect, thus preventing potential effects on the environment. The results of this study showed that the most common temporary effluents that occurred from the processes were liquors followed by chlorate, and the most common incidents that caused these effluents were incidents correlated to both planned and unplanned maintenance stops. The most important measure in each case of the effluents, although with some variations, is to ensure the biological basin sustains in optimal conditions such as neutral pH, mesophilic temperature ranges by cooling the wastewater with high temperature, and to ensure enough oxygen and nutrients for the microorganisms. In most cases, these measures will lead to a minor or no effect in the wastewater treatment plant (WWTP), thus having no effect on the receiving water body either.

Overall, the assessment of the common temporary effluents experienced from the interviewed personnel at mills provided a wide overview of the more common effluents that occur in Kraft pulp mills, although they varied significantly across the different mills. This assessment provided a good basis for further investigations of the effect of these on the WWTP as well as possible measures to take if and when these occur. However, the results do not represent the common temporary effluents from all Kraft pulp mills in Sweden (13 of 21 pulp mills participated), but they provide a good basis for further guidelines to similar effluents. It should also be considered that the action plans and measures could vary considerably depending on the type of incident and the causes of the effluents, as well as the wastewater treatment processes implemented. The results from this study can therefore be seen as general, and some modifications must be applied for each particular mill as well as the different kinds of temporary effluents.

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Appendices

Appendix 1

Table 6. List of Kraft pulp mills in Sweden and their applied bleaching method. Mills that are integrated consist both of a Kraft pulp mill and a paper mill within the same facility.

	Kraft Pulp Mill	*Integrated*	*Unbleached*	*ECF-bleached*	*TCF-bleached*
1.	Billerud, Frövi	X	X	X	
2.	Billerud, Gruvöns Mill	X	X	X	
3.	Billerud, Karlsborgs Mill	X		X	
4.	Billerud, Korsnäsverken	X	X	X	
5.	Billerud, Skärblacka	X	X	X	
6.	Holmen AB, Iggesunds Mill	X		X	
7.	Metsä Board, Husums Mill	X		X	
8.	Mondi Dynäs AB	X	X		
9.	Munksjö Paper, Aspa Mill		X	X	
10.	Munksjö Paper, Billingsfors	X	X		
11.	Nordic Paper Bäckhammars Mill AB	X	X		
12.	Rottneros AB, Vallviks Mill AB		X	X	
13.	SCA, Munksund	X	X		X
14.	SCA, Obbola	X	X		
15.	SCA, Östrands Pulp Mill			X	X
16.	Smurfit Kappa Piteå	X	X		X
17.	Stora Enso, Skoghalls Mill	X	X	X	
18.	Stora Enso, Skutskärs Mill			X	X
19.	Södra Cell AB, Mönsterås Mill				X
20.	Södra Cell AB, Mörrums Mill			X	
21.	Södra Cell AB, Värö			X	

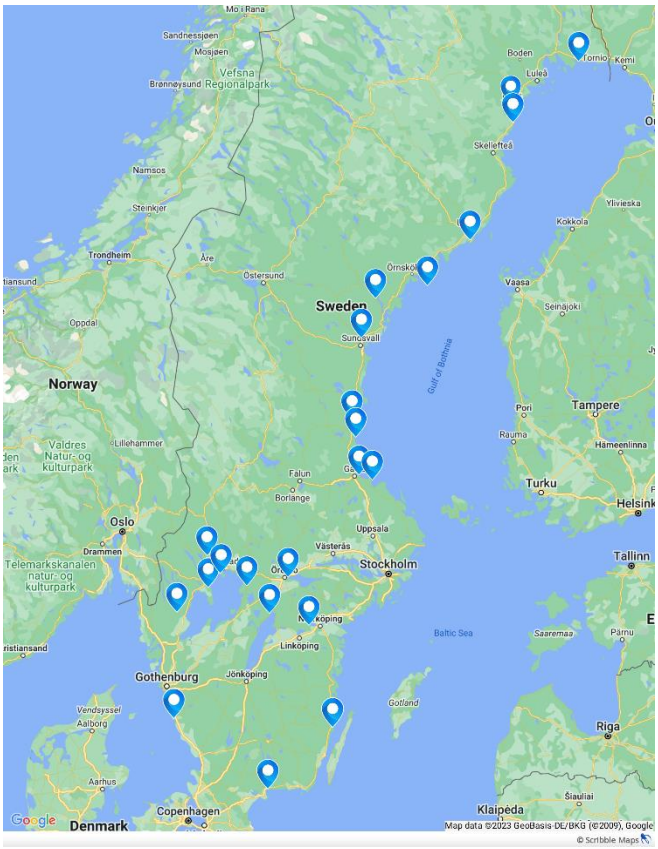

Figure 6. Map of Kraft pulp mills and their location around in Sweden.

Appendix 2

Table 7. Interview questions in Swedish.

1.	Har ni under de senaste åren haft några onormala utsläpp från fabriken som har stört reningen?
2.	Vad har det varit för utsläpp? (utsläpp som når rening)
3.	Hur har det påverkat reningen?
4.	Vad brukar vara vanliga typer av incidenter som brukar ske? (som orsakar tillfälliga/onormala utsläpp)
5.	Vad brukar de bero på/vad orsakas de av?
6.	Hur ofta har det skett under de senaste åren?
7.	Vad vidtog ni för åtgärder vid de incidenterna? Funkade det?
8.	Har ni tagit fram en åtgärdsplan?

Appendix 3

Table 8. Effect and measures for the common temporary effluents in English.

Common effluents	*Description*	*Effect on WWTP*	*Measures/Action plan*
Liquors	*Alkaline*	pH increases Foam formation Risk of inhibiting or harming microorganisms	* pH adjustment/neutralization (add acidic compound, e.g., sulphuric acid) * Add defoamer * Aeration and addition of nutrients (relevant for highly organic black liquor) * Monitor temperature of wastewater * Have a good contingency plan (relevant for incidents involving maintenance stops)
(Sodium) chlorate	*Strong oxidant*	Risk of inhibiting or harming microorganisms	* Ensure the environment is anoxic * Add nutrients, especially nitrogen in the form of ammonium * Make sure conditions in the basin are optimal, addition of organic material may be needed * Maintain good circulation * Monitor temperature and pH
Fibrous water	-	Sedimentation overloaded (not working properly) Fibers instead of sludge in the biological WWT A lot of fibers to biological basin	* Addition of extra help in order to remove the fibers from the sedimentation, e.g., with an excavator
Condensate (unclean)	-	Increases organic matter in the wastewater	*Aeration * Addition of nutrients
Chlorine dioxide	*Oxidizing agent*	Subverted in the biological process and kills off bacteria Risk of harming microorganisms Increase AOX formation	* Stop the RAS (if applicable) * Add nutrients * Make sure conditions in the basin are optimal, addition of organic material may be needed * Ensure sufficient mixing * Monitor parameters (temperature, pH etc.)
Raw water	*Incoming water to the mill (Colder than the wastewater)*	Temperature impact	* Monitor temperature
Bark Press Water	*Contains high COD and weakly degradable substances*	Risk of harming microorganisms	*Aeration * Addition of nutrients * Make sure conditions in the basin are optimal
Sodium bisulfite Magnesium bisulfite	*Acidic*	pH decreases Risk of harming microorganisms	* pH neutralization (add alkaline compound) * Aeration * Make sure conditions in the basin are optimal
Hydrogen peroxide	*Oxidizing agent*	Subverted in the biological process, may produce hydroxyl radicals Risk of harming microorganisms Foam formation Risk of overloading sedimentation	* Add defoamer * Same measures as the chlorinated compounds
Lime sludge	*Suspended material increases*	Overloading sedimentation	(Same as tall oil)

Tall oil	*Floats on the water surface (has lower density than water)* *Toxic to aquatic life*	Risk of harming microorganisms	* Separate and collect as fast as possible (preferably in the primary sedimentation, before the biological process) * If it reaches the basin, make sure to circulate/stir the wastewater if possible and eventually reduce RAS *Make sure conditions in the basin are optimal
Soap	*Composition is a combination between liquors and tall oil*	Foam formation Risk of harming microorganisms	* Add defoamer * Stop the RAS (if applicable) * Aeration and good circulation * Strive for optimal conditions
Turpentine	*High organic content*	Increases organic matter in the wastewater	(Same as methanol)
Methanol	*Low toxicity* *Easily biodegradable* *High organic content*	Increases organic matter in the wastewater	* Aeration * Strive for optimal conditions (neutral pH, ideal temperature, nutrients) * Addition of nutrients may be needed
Hydraulic oil	*Similar to methanol, although more toxic*	Risk of harming microorganisms	(Same as tall oil)
Starch	-	Increases COD in the wastewater May trigger non-favorable bacteria	* Aeration * Strive for optimal conditions

Table 9. Effect and measures for the common temporary effluents in Swedish.

Vanliga utsläpp	*Beskrivning*	*Påverkan på rening*	*Åtgärdsplan*
Lut	*Alkaliska*	pH ökar Skumbildning Riskerar att skada mikroorganismer	* Justera pH (tillsätt syra, ex. svavelsyra) * Skumdämpare * Lufta och tillsätt närsalter (relevant vid utsläpp av svartlut som innehåller mycket organiskt material) * Kontrollera temperatur * Planera inför stop för att minska påverkan (relevant för incidenter som involverar driftstopp)
Natriumklorat	*Starkt oxiderande*	Riskerar att skada mikroorganismer	* Kloratbakterier trivs anoxiskt * Tillsätt närsalter, speciellt kväve (som ammonium) * Upprätthåll optimala förhållanden i bassängen, tillsätt organiskt material vid behov * Bra omrörning * Se till att ha bra och jämn temperatur
Fiberhaltigt vatten	-	Sedimentation överbelastad Fiber istället för slam till den biologiska reningen Ökad fiberhalt till den biologiska bassängen	* Använd extrahjälp för att få bort överflöde av fibrer i sedimentationen, exempelvis med hjälp av en grävare
Kondensat (orenat)	-	Ökar organiska innehållet i avloppsvattnet	* Lufta * Tillsätt närsalter

Klordioxid	*Oxiderande*	Bryts ner i den biologiska reningen Dödar bakterier och ökar bildar AOX Riskerar att skada mikroorganismer	* Stoppa RAS (om tillämpligt) * Tillsätt närsalter * Upprätthåll optimala förhållanden i bassängen, tillsätt organiskt material vid behov * Bra omrörning * Kontrollera parametrar (temperatur, pH etc..)
Råvatten	*Inkommande vatten till bruket (Kallare än avloppsvattnet*	Temperaturpåverkan	* Kontrollera temperatur
Barkpressvatten	*Innehåller högt COD och svårt nedbrytbara ämnen*	Riskerar att skada mikroorganismer	* Lufta * Tillsätt närsalter * Upprätthåll optimala förhållanden i bassängen
Natriumbisulfit och magnesium-bisulfit	*Sura*	Ökning av pH Riskerar att skada mikroorganismer	* Justera pH (tillsätt basiskt ämne) * Lufta * Upprätthåll optimala förhållanden i bassängen
Väteperoxid	*Oxiderande*	Bryts ner i den biologiska reningen	* Tillsätt skumdämpare * Samma åtgärder som klorat och klordioxid
Mesa	*Suspenderat material*	Överbelastar sedimentationen	(Samma som tallolja)
Tallolja	*Flyter på vattenytan (har lägre densitet än vatten)* *Giftigt för vattenlevande organismer*	Riskerar att skada mikroorganismer	* Separera och samla upp så snabbt som möjligt (helst innan sedimentationen, innan den biologiska reningen) * Om det når biologiska reningen, se till att ha bra omrörning och eventuellt stoppa RAS *Upprätthåll optimala förhållanden i bassängen
Såpa	*Liknar en blandning mellan lut och tallolja*	Ökar skumbildning Riskerar att skada mikroorganismer	* Tillsätt skumdämpare * Stoppa RAS (om tillämpligt) * Lufta och ha god cirkulation * Upprätthåll optimala förhållanden
Terpentin	*Hög halt av organiskt material*	Ökar halten av organiskt material i avloppsvattnet	(Samma som metanol)
Metanol	*Låg giftighet för vattenlevande organismer* *Lättnedbrytbar* *Hög halt organiskt material*	Ökar halten av organiskt material i avloppsvattnet	* Lufta * Upprätthåll optimala förhållanden (neutral pH, bra och jämn temperatur, närsalter) * Tillsätt närsalter vid behov
Hydraulolja	*Likt metanol, men mer toxisk*	Riskerar att skada mikroorganismer	(Samma som tallolja)
Stärkelse	-	Ökar COD i avloppsvattnet Triggar trådbakterier	* Lufta * Upprätthåll optimala förhållanden