CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Proposal of Water Purification Technologies for Contaminated Water from a Pulp Company, Lake Toba region of North Sumatra, Indonesia

BACHELOR'S THESIS

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Declaration

I hereby declare that I have written this thesis entitled “Proposal of Water Purification Technologies for Contaminated Water from a Pulp Company, Lake Toba region of North Sumatra, Indonesia” independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to citation rules of the FTA.

In Prague ….

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Dagmar Václavíková

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Abstract

Lake Toba and its outflow the Asahan river are located in the region of North Sumatra, Indonesia. Over the last few decades, the quality of the local environment, including water sources, has been very badly affected since Indonesia is one of the world's largest pulp and paper producers, which generates both an environmental and a social burden. The main cause of pollution is attributed to a pulp and paper factory, now called Toba Pulp Lestari. This bachelor's thesis addresses this controversial pulp mill, which is a major source of water and air pollution that has been causing several illnesses in the local indigenous population and nearby communities, as well as serious degradation of the environment. The area most affected by pollution is located near the mill and its waste dumping location, where several people living close to the factory experience symptoms and health problems such as skin redness, respiratory issues, and eye irritation, among others. Therefore, the main target of this bachelor's thesis was to design appropriate technologies and strategies for purification of wastewater from the pulp mill. Improvements were proposed for each stage of wastewater treatment: primary (application of flotation) and secondary treatment (addition of returned sludge device). In addition, a tertiary wastewater treatment section was newly designed in the form of membrane filtration technologies and an ozone device. This should prevent the release of contaminated water from the factory into the environment, which would improve the quality of life for the population residing in the region, together with preserving the natural environment.

Keywords: Wastewater treatment, pulp and paper industry, environmental/community impacts, conventional wastewater treatment, membrane filtration, ozonation.

Contents

List of tables

List of schemes

List of figures

List of the abbreviations used in the thesis

AOX – Adsorbable organic halides

AS – Activated sludge

AR – Asahan river

BOD – Biological oxygen demand

COD – Chemical oxygen demand

EU – European Union

IIU – Inti Indorayon Utama

km – kilometre

km^2 – kilometre square

LT – Lake Toba

m – metre

MF – Microfiltration

mg/l – milligrams per litre

m^3/s – cubic meter per second

NF – Nanofiltration

NGO – Non-governmental organization

nm – nanometre (1×10^{-9} m)

pH – potential of hydrogen

P&P – Pulp and Paper

RO – Reverse osmosis

TPL – Toba Pulp Lestari

TSS – Total Suspended Solids

UL – Ultrafiltration

μm – micrometre (1×10^{-6} m)

1. Introduction

Nowadays, in developed world is being taken for granted the luxury to have access to potable and safe water in every household. An absolutely different situation could be found in developing countries of Global South. In most places there is no water coming from the tap and people are dependent on open sources of ground water in the form of streams, rivers, lakes, or wells with underground water. Water from the river is used for everyday activities such as washing food, dishes, clothes, fishing, a water source for animals, irrigation for agriculture crops, etc.

Such a traditional way of life would not be an issue in very remote mountain areas of Central Asia which are upstream; however, the situation around Lake Toba is very different thanks to significant intervention in the pulp and paper industry by a corrupted government and influential people who are willing to make as large of a profit as possible. Due to inappropriate wastewater treatment technology used by a local pulp mill, this kind of acting causes extensive water and air pollution in the local environment and affects local inhabitants as well. This subsequently harms both people's health and the environment around a pulp mill named Toba Pulp Lestari. This is a very common problem in most developing countries worldwide.

2. Aims of the Thesis

This bachelor's thesis describes the area around Lake Toba and highlights the environmental and social burden caused by the pulp producing factory Toba Pulp Lestari (TBL) in the surroundings. The major focus of this thesis is the insufficiently treated wastewater that is generated by the factory and the possibly contaminated effluent which goes back to the environment. The main aim is the design of several wastewater technologies commonly used in the pulp and paper industry, in addition to some advanced methods possibilities for achieving the best quality of water and avoiding any harmful substances.

3. Methods

The information collected in this bachelor's thesis was predominantly obtained and further analysed from scientific journals, periodicals, and databases searched at Science Direct, Web of Science, and Google scholar. The paper literature sources used, such as textbooks, as well as electronic sources were found in the Czech National Library of Technology. The most prevalent part of materials used for the literature review were in the English language with a minor share of sources in the Czech language.

Part of the bachelor's thesis methods were visitations to the pulp mill PT Toba Pulp Lestari Tbk in North Sumatra, Indonesia, and the paper mill JIP Větřní in South Bohemia, Czech Republic, which provided more comprehensive information that has been used in designing suitable final wastewater treatment solutions.

4. Literature Review

4.1. Background of Toba province

The area surrounding Lake Toba (LT) has significant functions and a highly intensive rate of utilization at the local, national, and international levels representing a very important multi-sectoral role. The location is highly valued for its hydrological, ecological, and economical aspects such as fresh water, agriculture, diverse forest culture, and fishing activities, and is most commonly utilized for cage aquaculture (Lukman 2019). Other uses of the lake are for the essential needs of local inhabitants and their households, like inter-village water transportation and especially tourism, which is becoming more popular lately (Hehanussa 2000). The indigenous population was significantly affected by the construction of the factory Inti Indorayon Utama (IIU) in 1989, later renamed as Toba Pulp Lestari (TPL 2019), which discharges its wastewater effluents into the Asahan river. The river is used as a source of drinking water, simultaneously with water for bathing, washing, and fishing. (Quina 2014). Asia Development Bank (2016) reported that 37 % of the urban population and 31% of the rural population was lacking access to improved water supply.

In TPL's case is a waterway usage limited by industrial wastewater outflow into the Asahan river. Subsequently, a huge stress is put on quality and utility of heavily polluted upstream river bringing contaminated water all the way to downstream, which finishes in the Malacca strait. Since the human activity in LT's surrounding area is very high, the risk of potential threats to the lake's environment could break the natural balance.

4.1.1. Geography and Location

Lake Toba (LT), visible in Figure 1 (1), represents a unique natural asset of global significance situated in the province of North Sumatra, Toba Samosir, in Indonesia. LT is the world's largest volcanic lake with a water area of 1129 km^2 and a normal water level at 905 m above sea level with seasonal fluctuation not exceeding 3 m. It is the largest lake in Indonesia with a maximum depth of 585 m (Hehanussa 2000), maximum length of 80 km, and width of 35 km (Hehanussa 1995). The Asahan river (see Figure 1(2)) origins in LT and it is a major outflow for the lake with an average water discharge of 80 m^3/s, flowing in a north-eastern direction, finishing in the Malacca strait (Berga et al. 2006; Quiona 2014; ADB 2016). The length of the Asahan river is about 150 km long (Latitude. to 2020). On the upstream of the Asahan river, where it flows out from the Lake Toba, TPL (see Figure 1(3)) operates.

Figure 1: Lake Toba (1) and the Asahan river (2) from its upstream to downstream with TPL factory (3) (Latitude. To 2020).

Figure 2: Map of Lake Toba in the North Sumatra Province of Indonesia (World Bank 2018).

4.1.2. Agriculture and aquaculture

Water sourced from LT is used for traditional agriculture production around the lake, mainly dry land farming with agricultural crops covering 27% of the catchment area, 11% belonging to plantations, and another 10% covered with wet rice fields. In remaining catchment area can be found forest (20%) and other natural cover like grasslands, shrubs, etc. (see Figure 3). Cattle and pigs are most commonly used for animal husbandry. However, Lukman (2019) stated that cage fishery production remains the dominant sector in the surrounding areas of LT. Small-scale aquaculture was first popularized in 1996 in the north-eastern part of LT, Haranggaol Bay. Subsequently, two large-scale aquacultures PT Aquafarm Nusantara in 1998 and PT Suri Tani Pemuka in 2012 conditioned the quality of water in the lake, resulting in the amount of phosphorus doubling between the years 2012 and 2016. The amount of waste produced by the fisheries would equal 2.3 million people living in the LT catchment area; however, the real population is only half a million. Intensive aquaculture generates a loading of phosphorus and nitrogen mainly caused by fish feed, manure, and dead fish bodies resulting in water pollution (The World Bank 2018).

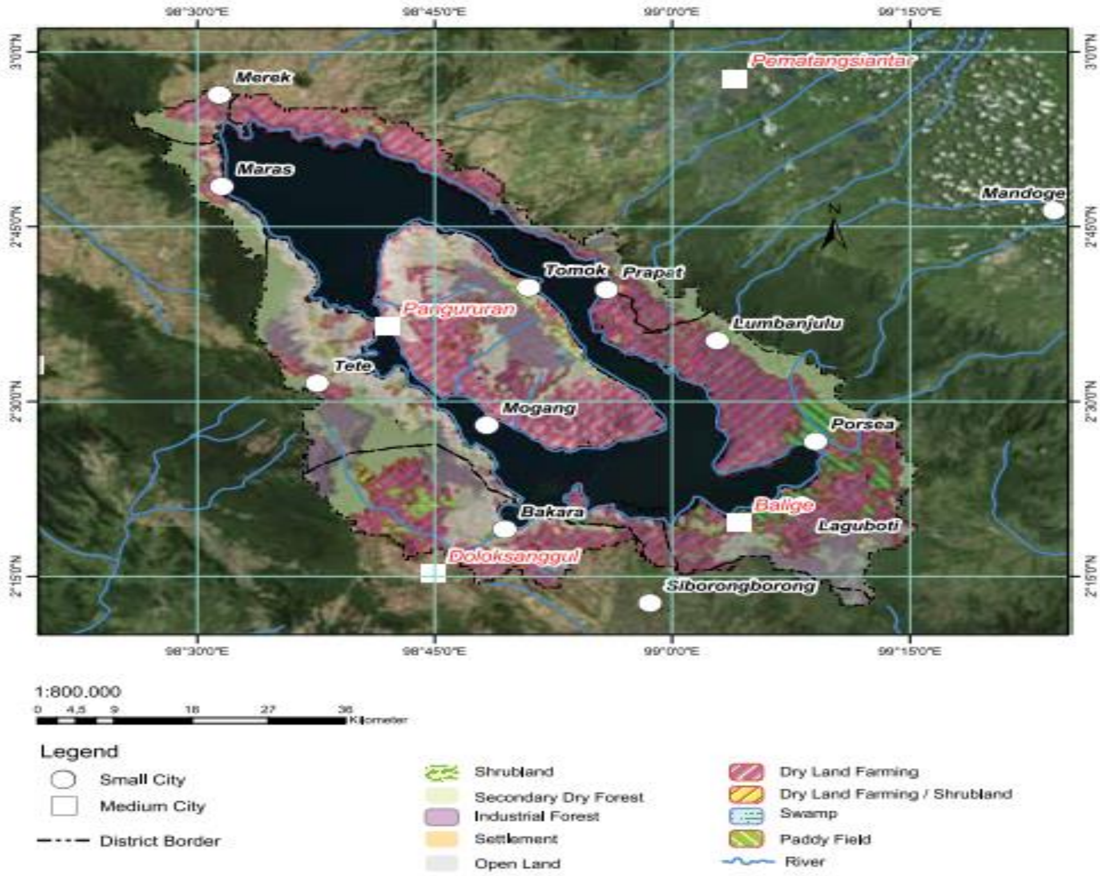


Figure 3: Land use in the Lake Toba catchment (World Bank 2018).

4.2. Pulp and paper industry

Paper has been part of human development since ancient times. It all began with Egyptian papyrus followed by the expanding of Chinese papermaking technologies thousands of years ago, to Gutenberg and modern paper machines. Nowadays, paper is contributing in everyday human activities and is used in households, schools, offices, etc. According to World Wildlife Fund (2020) 40% of global trade is with industrial wood manufactured for pulp and paper (P&P) production used for office and catalogue glossy paper, tissue, and paper-based packaging.

Today, Indonesia has the world's 10th largest (WPM 2020) production which has been dramatically expanding since the 1980s and is made from Indonesia's P&P industry the fastest growing industrial giant and world-class player, that is also very capital intensive (Dijk v M 2005). Indonesia was experiencing a massive boom in pulp production, which is clearly visible in Figure 4, when it has rapidly grown from 167,000 tonnes in 1983 to 1.3 million tonnes in 1993 and paper production increased from 377,000 to 2.6 million tonnes (Lohmann L 1996). In 2013, pulp and paper production reached 8.8 million tonnes from approximately 84 pulp and paper mills all around the country, which ranked Indonesia as the third largest P&P manufacturer in Asia at the end of 2014 (Rizaluddin et al. 2016). The P&P industry is ranked as one of the major industries in the world and it is one of the oldest manufacturing sectors in Indonesia. On average, one ton of paper requires 7800 gallons of water, which makes the pulp and paper industry one of the most water demanding (Ecolab 2019). The industry is also ranked among the top five in terms of environmental pollution and quantity of generated toxins per a unit of output (Herbert-Copley 1999). Due to the rapid extending of industry around the country, enormous expenditures of energy, raw resources, and water are required, resulting in generating large amounts of waste (Rizaluddin et al. 2016).

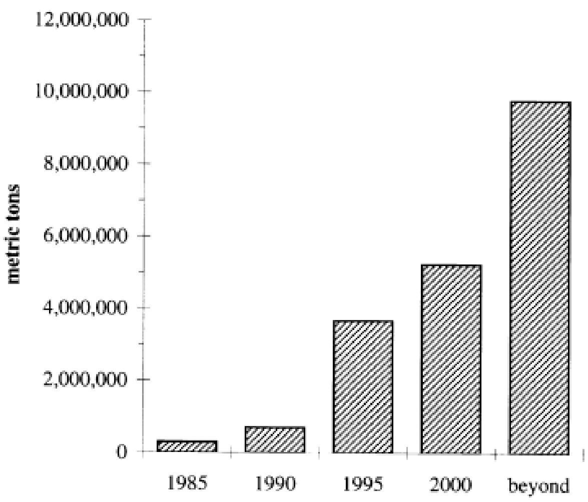


Figure 4: Indonesia: growth in pulp production, 1985+ (Sonnenfeld 1998).

Because of globalization of wood fibre production, more demanding consumers, and development of international trade with companies from developing countries, the global wood fibre market has increased. Moreover, the prices for pulp are strongly influenced by Southern exporters (Lohmann 1996).

According to ADB (2016) the industrial sector in Indonesia contributes the largest share to national GDP with 26.38%. The red highlighted rectangle in Table 1 clearly shows the importance of the P&P industry for the country, together with the wood industry. In addition are estimated water demand and number of workers employed in the industry within Indonesia.

Table 1: Industry sectors with relative water demand (ADB 2016).

Sector	% Share in Economy	Number of Plants	Water Demand	Number of Workers
Oil and gas	3.81		High	8,700
Agro industry, food, and beverage	7.49	6,000	Very high	832,000
Textile	2.08	2,853	Very high	478,000
Wood	1.43		Low	222,000
Paper and pulp	1.09		Very high	104,000
Chemicals	2.90		High	227,000

4.3. Toba Pulp Lestari (TPL)

Toba Pulp Lestari is a eucalyptus pulp factory located near Porsea village, on the southeast part of LT, close to the upper stream of AR (TPL 2019). TBL is an exact example of an advanced factory using large installed technologies constructed in a very remote area of the tropical region of North Sumatra, with wood and labour cost advantages. Due to the rapid expansion of Indonesia's P&P industry, the environmental and social aspects in the area around LT were damaged. Quina (2014) reported lacking an official in TPL with Indonesia's administrative environmental law background as one of the reasons.

4.3.1. Factory's history of problems

The factory was established in 1989 and called Inti Indorayon Utama (IIU) during the P&P industry boom in Indonesia. The end of 20th century created many issues regarding IIU's operation. Later renamed as TPL, it was the first pulp and rayon company in Indonesia's history. It caused not only several health problems to inhabitants living nearby, but also strongly disregarded sustainable development in the area and neglected the political right of local people which resulted in long-lasting social conflict, which led to temporary closure of the factory (Nomura 2009).

4.3.1.1. Pollutants discharging

Since the start of factory operation, TPL has faced circumstances related to environmental burden in the form of water and air pollution caused by intentional release of chemical toxins into the nearby environment and contaminating waterways with oxygen hungry effluents and chemicals (Lohmann 1996). Releasing toxic substances into a water source leads to the death of zooplankton and local fish like jurung, mas and asa-asa (Situmorang 2003), as well as dangerous affecting of terrestrial land is inevitable (Pokhrel & Viraraghavan 2004). In 1989, 1993 and 1994, artificial tanks full of liquid waste full of chemicals and contaminants ruptured and polluted water flowed into AR. Regarding these cases was stated that IIU was accused for irresponsible controlling of pollutants released to the AR resulting in bad smell, unsafe drinking water and devastation of aquaculture and agriculture production, which is usually the only and most important source of living and significant marketable price. The data of water samples from AR indicated serious changes in aquatic ecosystem which stated river water no more usable for drinking. Furthermore, it caused several health diseases and illnesses to local communities near the mill and waste dumping location (Situmorang 2003; Rizaluddin et al. 2016). Several authors such as, Mandal & Bandana (1996) and Bhagawati & Shivayogimath (2017) reported that major health problems caused by pulp and paper mill discharged contaminated wastewater into the environment are diarrhoea, vomiting, nausea, headache and eye irritation. This was affirmed by Situmorang (2003) in addition, skin diseases like reddish- coloured skin were developed, problems with a respiratory tract like shortness of breath, dry throat, loss of voice etc., following with dizziness and optic sparkles. Resulting consequences threatened factory's employees following local communities living nearby. Large number of people even fled their houses.

As a result, for the effort putted into several demonstration and protests organized by the local community in nearby Porsea village, which was supported by Indonesia non-governmental organization (NGO) called Indonesia Forum for the Environment (Walhi), was IIU in March 1999 officially shut down for a short term. In 2003 was decided to reopen the factory again and rename it to Toba Pulp Lestari, but with more requirements concerning the quality of wastewater discharged back to the AR (Situmorang 2003 & Rizaluddin et al. 2016).

The negative background of P&P industry boom at the turn of the millennium in Indonesia is showed in Figure 5, where is presented water pollution in total BOD emissions generated by P&P industry. The fact behind TPL's enormous pulp mills is, that it is hold by the biggest, powerful and most notorious business families whom gain their wealth through connections with politically important and influenceable people with no concern about environmental regulations that are pushed to the side.

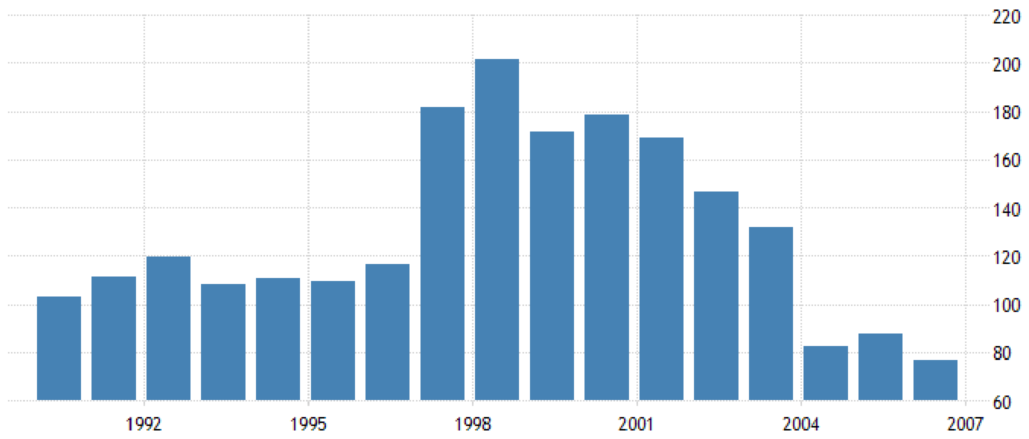


Figure 5: Indonesia – Water Pollution, Paper and Pulp Industry (% Of Total BOD Emissions) (Trading Economics 2020).

4.3.1.2. Land tenure

Almost every giant pulp mill must be supplied by natural timber in its initial stage. Wood, as the major raw material needed in P&P industry requires huge hectares of land, meanwhile plantation fibre has grown in importance relative to fibre gained from natural forest resulting in substitution of original tree species by vast monocultures of fast-growing and less land demanding eucalyptus. The issue of monocultures is that they are very vulnerable to erosions, it causes different distribution of water and nutrients in the soil, thus it monopolized the biosphere. The chopped forest is very vulnerable and affected by irreversible ecological changes (Lohmann 1996). Due to expansion of P&P industry in Indonesia over the last few decades, the issue regarding ownership and use of land have arisen. The P&P industry incudes several operational steps. To start from the initial process in order to get a raw material, which is used for generating pulp, large areas of forests have been cut down and the land further used for eucalyptus plantations. The land was taken away from the owners, usually farmers, which must have been displaced, even forced to dwindling frontiers of their holding. For these smallholders the natural forest represents an important or the only source of their livelihoods, moreover in a case of seizure of an agriculture land with even more serious impacts. The location surrounding LT is home for indigenous Batak people, which must have been displaced because of enlargement of Indorayon's clear-cutting of natural forests and growing new monoculture plantation, building new roads etc. (Situmorang 2003). The company IIU had been causing issues such as blocking a road to common pastures needed for buffalo-raising, placing eucalyptus plantations on an ancestral graveyard, drought caused by logging resulted in decrease of rice yield (Lohmann 1996). Another constraint stem from logging related issue is that Batak people have been collecting, cultivating and traded benzoin tree for at least ten centuries. The containing benzoin components are greatly valued, used in medicines, perfumes, incense for traditional ceremonies, and fragrant cigarettes (Ginting 2010). Since local people in LT’s area have an emotional tie to this area and their culture is deeply embedded in traditional customs, such irresponsible acting has been leading to disrupted livelihoods of indigenous Batak people and gave arise to severe social conflicts and protests.

4.4. Operational process

The pulp manufacture involves a long production chain, ranging from forestry following with several steps of processing in a factory to convert logs of wood into pulp, and final products. According to Dijk van M (2005) and Al-Aisri (2012) is pulp manufacturing process ordered as follows:

1. Raw material preparation
2. Pulping
3. Bleaching
4. **Chemical recovery (wastewater treatment process)**

Innovation development in chemical pulping permitted manufacturing of short fibred hardwood such as eucalyptus tree at the end of 1960's. Since then, the new technology let rapidly grow the P&P industry in Indonesia. The crucial step in the industry is to obtain a pulp from timber during the wood processing. After cutting, washing and screening of wood logs to woodchips are further sent to digester for process of pulping. According to Hurter (2006), woodchips delivered contain about 50% of water, 25% of cellulose fibre, which is the major component to make a pulp. The remaining share of 25% in a woodchip belongs to lignin which is a natural glue that holds the wood fibre together, therefore the first step is to remove lignin from wood fibre. Nowadays, chemical pulp making process, also called "Kraft process", is the most utilized refers to the process that is held in digester with an addition of cooking chemicals such as sulphate or sulphite to convert eucalyptus wood or any other raw materials into pulp. After cooking process is lignin washed away and cellulose fibres continue to bleaching stage, wherein chlorine dioxide is used in order to get rid of any remaining lignin and to assure a white colour of pulp/cellulose (Dijk v M 2005 & Al-Aisri 2012). The effluents from the bleach plant in a pulp mill are adsorbable organic halides (AOX), phenols and very toxic chlorinated organic compounds, in order to convert pulp, usually to desirable white colour demanding by customers. Natural wood-based compounds rich in toxins are likely to occur, for instance acids, alkaloids, waxes, fats etc. (Toczyłowska-Mamińska 2017). The operational process of P&P mill is graphically illustrated in Figure 6.

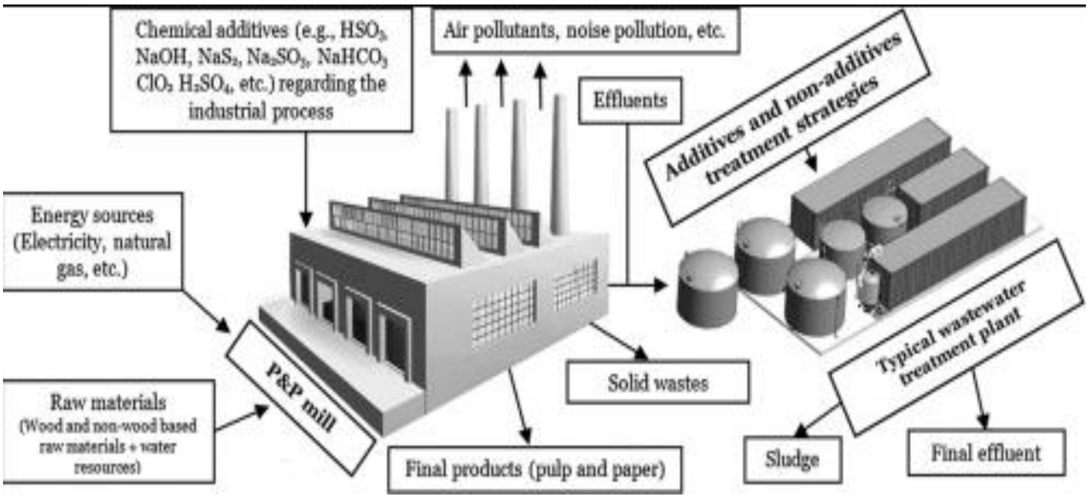


Figure 6: Graphical abstract of the P&P factory (Kamali M 2019).

It is important to mention that TBL is not a paper producing factory, however a pulp manufacturing factory which means that paper as a final product is not produce there. Pulp generates from the TBL is dried, bailed and eventually exported to final paper manufacturing company in Indonesia or to oversees.

4.4.1. Role of timber

Indonesia is listed as the top producer in pulp and paper industry, also by reason of its geographical location near the equator. The hot and humid climate with enough sunshine all the year boosts a growth of trees and it allows three times more harvesting of wood on lesser land, compare to countries located in temperate zones (Rizaluddin et al. 2016; Lohmann 1996). The mature time for eucalyptus tree is about seven years long which significantly shorter time for harvesting (Dijk v M 2005).

In the pulp and paper industry must be taken to consideration the type of raw material used. It can be classified many kinds of wood like softwood, hardwood etc. Hard wood has many advantages compare to softwood like higher specific weight, higher pulp output, lower costs and less energy and chemical consumption. In the pulp of hardwood is recognized better bleach ability and lower chemical demand, that means lesser amount of pollutants discharged into environment (Al-Aisri 2012). TBL factory operates with a hard type wood from evergreen eucalyptus trees which are grown from seedlings in TBL's forest nursery (see Figure 7) close by the factory. When eucalyptus trees are grown enough, they are transported to final eucalyptus plantations.

Figure 7: TBL's Forest Nursery (Author 2018).

4.4.2. Role of water

In manufacturing process in P&P industry, water is being utilized for its operations in almost every stage; it is ranked as the world's third most wastewater generating industry, after metals and chemical industries. Toczyłowska-Mamińska (2017) reported that P&P manufacturing demands 42% of total industrial wastewater in the world. The average paper mill in developing country consumes the volume in the range 100-250 m^3 fresh water per ton of paper (Bhagawati & Shivayogimath 2017; Younas et al. 2018). In comparison with developed countries is volume of incoming water significantly reduced due to better operational process and organization, therefore the water consumption in the advanced paper mill typically ranges from 10-50 m^3 per 1 ton of paper (Toczyłowska-Mamińska 2017). This statement was confirmed by the paper mill JIP Větřní in the Czech Republic, where is the average water consumption 20 m^3 per 1 ton of paper.

Water source located close by to factory plays essential role in paper and pulp industry, thus the water is the lifeline in the pulp making process, considered as medium to transport pulp and moving product throughout the mill, conduct and retain heat inside the boilers to generate steam and to cool machinery water, form final product and remove contaminants. In the end of pulp making activity is water returned into a river, therefore it is important to keep the water circulation unpolluted after the industry processing and implementation of appropriate wastewater treatment technologies is necessary facility.

4.4.3. Wastewater

The P&P industry is highly water intensive industry demanding enormous amounts of water for its operations. Moreover, it has been considered as one of the biggest effluent generators worldwide, that would be able to cause numerous serious pollutions if left untreated (Cabrera 2017). Approximately, the volume of 75-225 m^3 wastewater per ton products is generated during pulping and bleaching (Bhagawati & Shivayogimath 2017). Especially in developing countries remains a big problem that the inflow water to the factory is discharged back to the environment in relatively large volume of not properly treated wastewater. The pollution level of outflow from the factory can be characterized by major types of pollutants generated mainly from pulping and bleaching pulp manufacturing process (Toczyłowska-Mamińska 2017), described in more details in the chapter 4.4 "Operational process", that could lead to serious environmental problem.

4.4.4. Sewage Treatment Parameters

There are several parameters for measuring water quality of effluent from the P&P mill. As the most important ones are biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), pH, toxicity, colour, foam, temperature and odour which determine some of the key contaminates in water such as high chlorinated organic compounds and nutrient loadings, chemical toxicants, synthetic chemicals and absorbable organic halides (AOX) (Situmorang 2003; Al-Aisri 2012; Bhagawati & Shivayogimath 2017; Younas et al. 2018).

BOD – Biological oxygen demand describes the amount of organic water pollutants presented in water that refers to amount of oxygen that bacteria need for digesting waste. Measuring BOD is standard way of testing water for the presence of dissolved organic pollutants. Rising BOD parameters leads to increase level of water pollution which might cause decrease of soluble oxygen needed by aquatic life (Situmorang 2003 & BMS 2013).

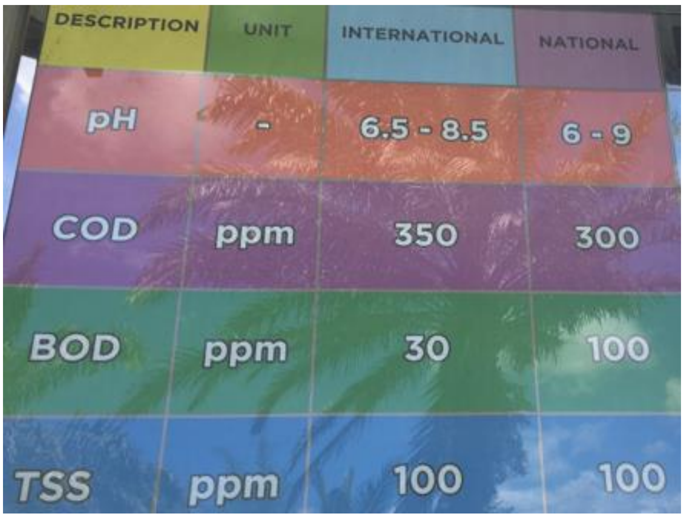
COD – Chemical oxygen demand is closely related to BOD testing referring to the level of organic matter that can be chemically oxidised instead of biologically based oxidation, in case of BOD testing. It has been seen when higher COD is measured, then more polluted water is, as well as in BOD example (BMS 2018).

TSS –Total Suspended Solids are undissolved suspended materials, including organic and inorganic, that is possible to trap by a filter (Alar 2016). The clarity of wastewater is affected by turbidity (EPA 2020).

ph – is an indicator of acidity or alkalinity at the scale from 0 to 14, whereas a neutral water has a pH of seven. A rising number signify an alkaline water while decrease on the scale means more acidic water (EPA 2020).

According to Butler Manufacturing Services (2013), each company must comply with certain discharged water standards set by the government. It has been seen differences in BOD, COD and TSS parameters between Indonesia, considered as a developing country, and the developed world, example from the Czech Republic. Table 2 indicates the international norms compared with Indonesian national norms, where is clearly visible a considerable difference in range of BOD. 30 mg/l of BOD is applied within international standards, while national one escalates to 100 mg/l of BOD. This parameter table was photographed directly in the TPL factory in 2018. Furthermore, in comparison with the Czech Republic, Správní právo (2015) stated, that the maximum allowed industrial water effluents from P&P industry depending on pulping process, are ranging between 300-400 mg/l of COD parameter and 25-40 mg/l of BOD which corresponds with the column "International" in Table 2 below.

Table 2: Comparison of national (Indonesian) and international effluents standards (Author 2018).



DESCRIPTION	UNIT	INTERNATIONAL	NATIONAL
pH	-	6.5 - 8.5	6 - 9
COD	ppm	350	300
BOD	ppm	30	100
TSS	ppm	100	100

4.5. Water Treatment Process

P&P industry is a heavy producer of pollutant generated during its operational process, beginning in wood debarking and chopping, pulp washing and screening, bleaching, including machine operating too. In order to mitigate any potentially dangerous effluents from TPL's pulping and bleaching processing, the wastewater must go through several water treatment stages. The conventional wastewater treatment often combines preliminary and primary treatment, where is the main aim solid particles removal, following secondary water treatment based on biological reactions. In order to improve previously mentioned methods and increase the quality of water discharged back to the environment, the conventional treatment is supplemented with, namely "tertiary" or so-called "advanced" treatment. Wastewater management system faces variety of challenges referring to demanded purity of wastewater treated, which depends on different uses and required quality, same as different country's standards for effluent from the P&P industry (Hubbe et al. 2016 & Younas et al. 2018).

Traditional widely implemented system of industrial wastewater treatment station from P&P mill is described in Figure 8 below. It consists from primary clarification facilities, following with secondary aerobics biological section. According to Younas et al. (2018), combination of primary and secondary treatment together will provide 58% removal of BOD and suspended solids. This is an ideally selected technology in case of already incurred facility, where the effluents can meet with wastewater quality parameters required at relatively low cost of P&P mill operation (Hubbe et al. 2016). This kind of wastewater system is commonly used in developing countries, including Indonesia. However, a risk of not properly treated water discharge from factory might be under consideration.

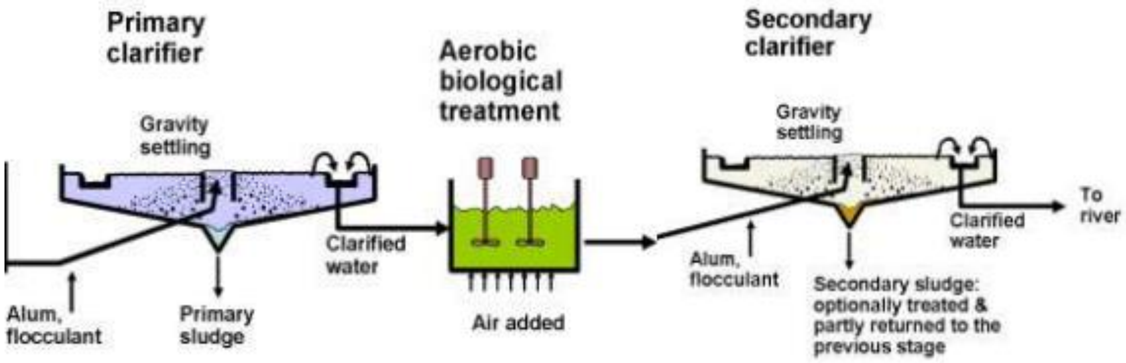


Figure 8: Conventional typically utilized wastewater treatment system from P&P industry (Hubbe et al. 2016).

Figure 9 below presents different stages of wastewater treatment plant for P&P mill. As the preliminary step are processes of screening and grit removal, following with primary treatment where is water cleaned by sedimentation and/or flotation. Next stage is secondary treatment based on biological decomposition of undesirable organisms. For clear summarization, preliminary, primary and secondary treatments have been already described in previous paragraph as "Conventional wastewater treatment system", which is also illustrated in Figure 8 above.

In last stage in wastewater treatment processes, that continue after conventional wastewater treatment, is tertiary or advanced water treatment technologies used for possible enhancing a quality of effluents discharged into a river. In this stage have been purposed membrane filtration and/or ozonation.

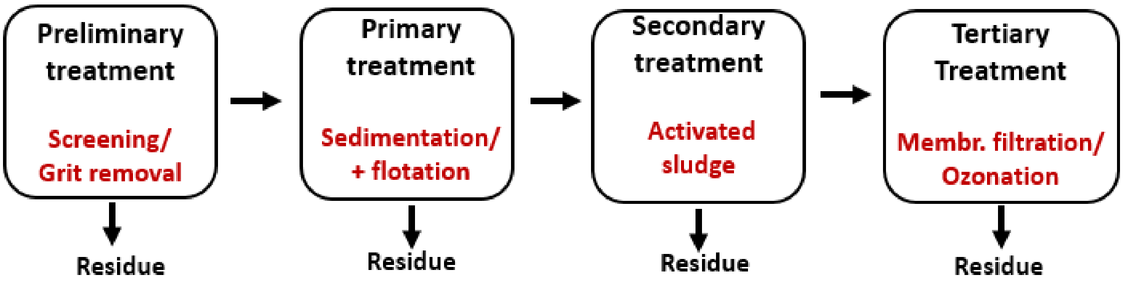


Figure 9: Conventional wastewater treatment processes with "tertiary" or "advanced" treatment introduced (Author 2020).

As shown in Figure 9, pulp mill does not generate only liquid waste but also solid waste accumulated form every single stage of water treatment. Standard residues during primary and secondary treatment is solid sludge, generally, that is further dewatered, dried and landfilled, burned for energy recovery or recycled into a product, which can find its utilization in board industry for instance (CANMET 2005; Monte etc. 2009; Younas etc. 2018). For example, paper mill JIP Větřní supplies a brickyard with its solids waste (see Figure 10). Also, combustion and anaerobic digestion are very favourable ways for energy production.

Figure 10: Dewatered pile of residues after water treatment in JIP Větřní (Author 2020).

4.5.1. Primary treatment (physical)

Primary treatment is usually associated with utilization of physicochemical methods for water purification. The most important aim in this process is to remove suspended particles, materials and colours. Also, one- third of BOD, which is contained in wastewater is possible to eliminate in primary treatment (Younas etc. 2018). For primary treatment are designed two technologies; the first one represents commonly used process of sedimentation frequently implemented in conventional wastewater treatment systems. The second one can be done either by addition of flotation technology or comprehensive substitute solution of flotation instead sedimentation in wastewater treatment.

4.5.1.1. Sedimentation

Sedimentation has been widely implemented in P&P industry after preliminary treatment in order to remove suspended solids and separating sludge from wastewater. The main instrument in the process represents the gravity, which allows heavier solid particles to settle down and to create a sludge, that is removed further on (Younas et al. 2018).

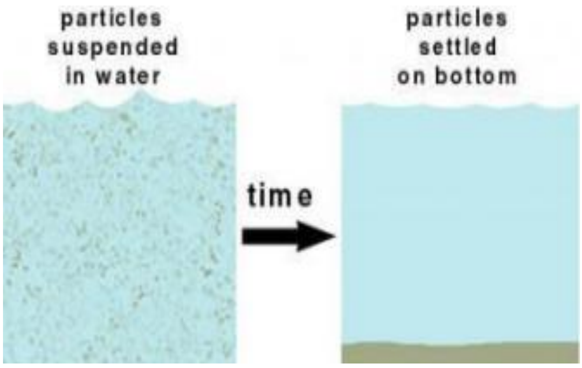


Figure 11: Sedimentation Process (Younas et al. 2018).

4.5.1.2. Flotation

In order to enhance an effectiveness of primary treatment is possible to apply a technology, that can be a promising approach called flotation instead of sedimentation. Flotation is a key method for particles separating in water, that have same or similar phase density. In this case, small air bubbles are injected into water in order to break down the elements. By adhering a flocculant and air bubbles to suspended matter, the elements with lower density called hydrophobic, showed like orange ones in Figure 12, float to the surface of the water where is froth formed into dissolved air flotation units like fats, oils, grease and suspended solids, while hydrophilic particles stay in the bottom of tank. Float skimming mechanisms remove the froth from the surface of the tank, that have joined together to form a froth and sludge. Hydrophilic particles do not adhere to air bubbles.

Therefore, they are let to settle down at the bottom of a tank. Similar skimming device like on the top of the tank operates at the bottom to remove all impurities. Compare to sedimentation, is flotation method more successful with particles removing. In general, flotation is likely to implement in the last tertiary, so called advanced or polishing treatment in P&P industry, even though it might be utilized in primary stage as well (Younas etc. 2018).

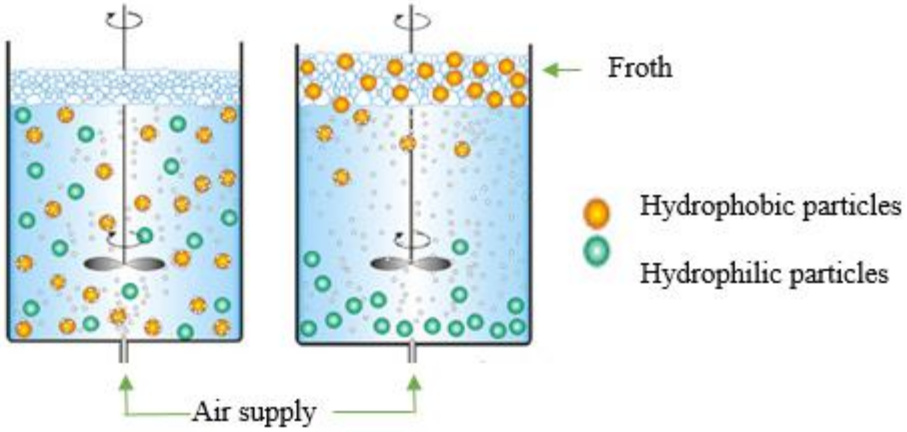


Figure 12: Mechanism of flotation (Laboratoř flotace 2014).

In Figure 13 and 14 is clearly distinguishable skimming mechanisms in two wastewater treatment technologies implemented in the paper mill JIP Větřní. During sedimentation process a sludge settles to the bottom of the tank from where is removed afterwards. Contrary to flotation, where the skimmer arm collects sludge from the surface.

Figure 14: Sedimentation tank in JIP Větřní (Author 2020).

Figure 13: Flotation tank in JIP Větřní (Author 2020).

4.5.2. Secondary treatment (biological)

The secondary treatment is based on aerobic biological methods with assistance of bacteria in comparison to primary treatment. It is essential to eliminate any biodegradable organisms and organic matter remaining in the water. Secondary treatment represents an important role in removing of BOD and toxicity from wastewater treatment. As widely demonstrated technology in secondary stage in conventional management has been utilized an activated sludge (Thompson et al. 2001; Kostamo & Kukkonen 2003; Younas etc. 2018).

4.5.2.1. Activated sludge

Activated sludge (AS) is a process used not only in the P&P industry, but generally it is dealing with sewage and industrial wastewaters. As the main actors are being utilized microorganisms in order to eliminate any remaining pollutants and toxins in the water. Theobald (2014) stated that about 85-95% of BOD is possible to mitigate by activated sludge technology. For solids contained in the wastewater is recognized about the same percentage range as for BOD. However, Graves and Joyce (1994) reported AS being not much successful in colour removing. The sludge also contains microorganisms which has developed during wastewater treatment, hence the conversion to carbon dioxide, water and other inorganic mixes is essential (Younas et al. 2018).

In AS operation is necessary an action called recirculation, which returns a part of sludge already used, back to the intake. This model is demonstrated in Figure 15. It provides higher stability during treatment, because of returned activated sludge have become acclimatized with the environment. Moreover, the returned AS enhance diversity in microorganisms and speed up the

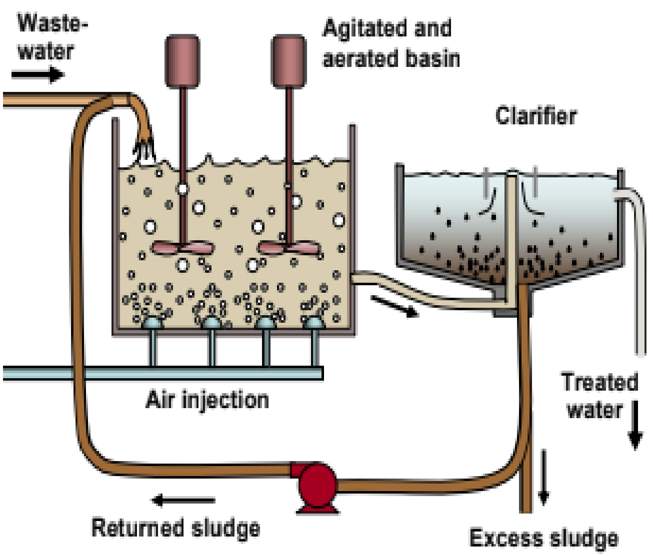


Figure 15: Schematic model of recirculation in AS wastewater treatment (Hubbe et al. 2016).

process of decomposition (Hubbe et al. 2016). According to Graves & Joice (1994) and Hubbe et al. (2016) and Younas et al. (2018), the process of aeration is essential for microorganism's cultivation and efficient operation of activated sludge. Necessary facilities are oxygen blowers and sludge pump, which must keep the aerobic environment stable, therefore constant energy supply is needed. The oxygen blowers spread the air bubbles through the waste inside a reactor, following with strong fluid division. Water continue to clarifier (see Figure 16), where is used a sedimentation process, similarly as in primary treatment, where is employed a skimmer arm for moving a sludge to outlet pipe.

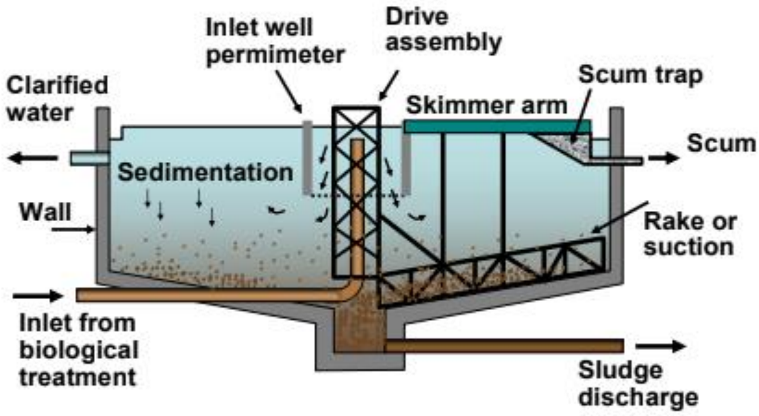


Figure 16: Detailed illustration of clarifier, commonly used after aerated tank, in activated sludge (Hubbe et al. 2016).

The activated sludge differs in several ways referring to location and environmental conditions of wastewater treatment plant, concerning the environmental conditions like temperature, precipitation and existence of toxins or chemicals used by factory during pulp manufacturing. Also, environmental law requirements and parameters for effluents discharged must be considered well (Younas etc. 2018).

Activated sludge treatment ability is based on biological capacity of mixed microorganism to absorb pollutants from P&P industry operation. The major microorganisms mixed in wastewater treatment plant are bacteria accompanied with protozoa, fungus and the largest in size rotifers. Aerobic bacteria are considered as being responsible for removing of organic nutrients from wastewater. Protozoa serves as a remover and digester of suspended solids and some bacteria, which provides higher clarity of effluent from treatment plant. Rotifers have a crucial role as being primarily affected by toxic loads and they maintain a clarity of water as well as protozoa. Fungus and algae are presented generally in the older sludge and they appear in case of pH changes for instance, that can indicate issues in the water balance and becoming problems (Theobald 2014; Hubbe et al. 2016).

The main goal is to consume undesirable bacterial matter in the sludge and to achieve clean water effluent from operational process. One of the most critical attributes for microorganisms living in activated sludge is a constant supply of oxygen (air) during the aerobic treatment. Mahmood and Elliot (2006) stated that the cultivation time, also retention time has an impact on protozoa and rotifers development and cell division, depending on how long they stay in activated sludge. Extending of aeration time promotes the forming of wider range of organisms, moreover it can reduce a volume of final sludge produced attributed to a greater level of biodegradation, because of improved metabolic processes of organisms. Another important aspect in keeping favourable condition in activated sludge process are temperature and pH, which are key factors for optimal growth and proliferation for living organisms (Hubbe et al. 2016).

It should be always put emphasize on accurate controlling the balance of microorganisms in mill wastewater effluent for the optimization of successful biological treatment. Utilization of activated sludge as s secondary treatment in P&P industry is a promising and very effective approach how to break down some of the hard-to-biodegrade organic compounds and removing possible toxicity from mill's wastewater.

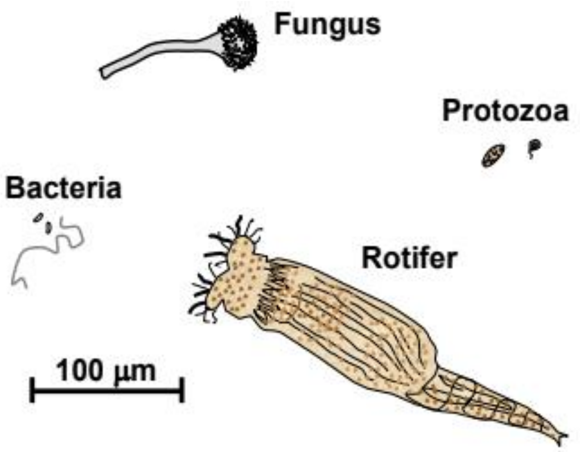


Figure 17: Relative sizes of typical kinds of organisms involved in the biodegradation of pulp and paper mill effluents (Hubbe et al. 2016).

4.5.3. Tertiary treatment (Advanced technologies)

Nitrogen and phosphorus are usually considered as hard-to-remove particles during either primary, or secondary treatment, thus the last stage of tertiary advanced water treatment might be utilized to improve quality of water discharged back to the environment (Younas et al. 2018). In tertiary treatment have been presented technologies like membrane filtrations, particularly microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Ozonation has been promoted as one of the treatment solutions as well.

4.5.3.1. Membrane filtration

Membrane filtration is widely used at several different stages during wastewater treatment process, frequently employed to separate any final entities like chemical elements, molecules, toxins, contaminants, etc., remaining in water. There are various kinds of membranes applied according to pore sizes in membrane grid, generally smaller than about 100 μm. In Table 3 below are demonstrated the most common types of membrane filtration depending on pore sizes like MF, UF, NF and RO with an ability to exclude undesirable residues (Hubbe et al. 2016; Younas et al. 2018).

Table 3: Classification of Membrane Filtrations Systems (Hubbe et al. 2016).

Membrane filtration type	Typical pore sizes
Microfiltration	0.1 to 2 μm
Ultrafiltration	2 to 100 nm
Nanofiltration, dialysis	1 to 5 nm
Reverse osmosis	< 1 nm

As shown in Table 3, MF on the very top of the table is indicated, as the one with coarsest membrane, employed more likely in pre-filtration and separation of solids in wastewater treatment (Hubbe et al. 2016). Sierka et al. (1997) and Ordóñez et al. (2011) demonstrated that MF and UF methods are very effective as pre-treatments membrane technologies before reverse osmosis approach.

UF is considered as more suitable in P&P wastewater treatment processes. During several studies from Tavares et al. (2002); Simonič and Vnučec (2012); Singh et al. (2012) and Quezada et al. (2014) have been shown that UF's membrane has a capability to exclude viruses, and biological cells, as well as metals like iron, calcium compounds or magnesium.

NF has been indicated as very good methods in terms of removing large molecules from the permeate. According to several researchers, for instance Gönder et al. 2011 and Khosravi et al. 2011 and Sheldon et al. 2012, can be NF applied as very efficient technology for exclusion of colour and hard-to-degrade organic compounds from P&P industry wastewaters. In addition, Lastra et al. (2004) demonstrated in his study a successful removal of metal complexes from wastewater as a result of NF.

RO is widely used technology in household's wastewater treatment management, same as in industrial wastewater treatment, including P&P industry. RO is considered as the most effective membrane in terms of particles separation, because of its feature to allow going through only water while it separates molecules and salt ions. The membrane has the tightest size between pores from all membranes previously mentioned. While in case of MF, UF and NF, the size of particles for those technologies is gradually larger compare to RO, as showed Table 3 above. The principle of RO operation is based on natural process called osmosis, which is the process of diffusion of water through a membrane from areas of higher concentration to areas of lower concentration until both sides are equal in concentration. It is based on highly pressured water flow through a semi-permeable membrane. Jahan (2019) reported that up to 99% of impurities and contaminants is possible to eliminate duo to RO. This technology is the most suitable for removing organic compounds, biomolecules, microorganisms and bacteria from water. As presented in Table 3, this method can remove pollutants from wastewater that is less than 1 nm in diameter. However, RO utilization in P&P industry must be taken to consideration, thus semi membrane is vulnerable to oxidizing agents, which can be used during bleaching process of pulp in form of chlorine. If so, elimination of oxidizing agents must be done during primary or secondary treatment. In terms of pH level is RO's membrane considered as stable.

Summarization of different types of membrane filtrations, substances that can be held back and required trans-membrane pressures are displayed in Figure 18 below.

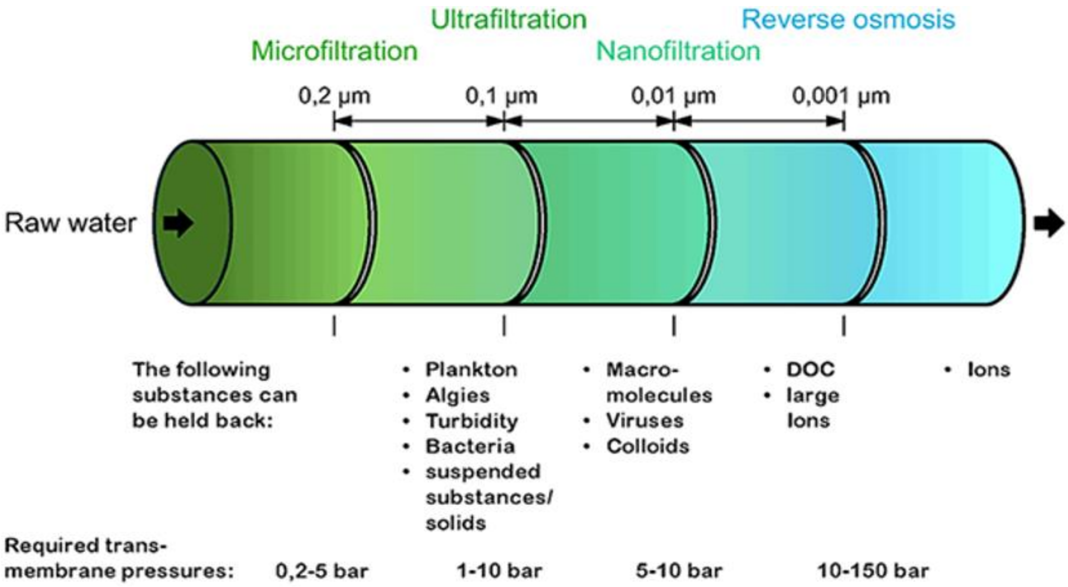


Figure 18: Membrane processes (HydroGroup 2020).

4.5.3.2. Ozonation

Ozonation is a very effective method applied in combination with biological treatment, which can be implemented before or after biological processes (Bijan & Mohseni 2005; Balcioğlu et al. 2006). Ozonation is described as a highly energetic form of oxygen, particles of O^2 are transformed to O^3 after entering an ozone generator (see Figure 19) (Toshiba 2019), which is applied for breaking down hard-to-biodegrade organic compounds generated from operational process during pulping and bleaching (Hubbe et al. 2016). During ozonation of wastewater, foam is developed, which has an ability to catch phosphates and nitrates (Younas et al. 2018). Implementing of ozonation technology has been shown as very effective in wastewater treatment resulting in several positive effects, for instance decolouration and deodorization, which remove unpleasant colour and odour from water. Next favourable effect of ozone in water is its ability of disinfection, when bacteria and DNA/RNA of viruses are directly killed, due to a breaking down of their cell membrane. Finally, residual organic matter in the water is eliminated by powerful oxidation effect (Toshiba 2018). Also, an application of pre-ozonation before activated sludge stage ensure successful reducing of COD and BOD loads in wastewater during treatment (Tuhkanen et al. 1997; Thompson et al. 2001). According to Catalkaya and Kargi 2007 and Meza et al. 2011 is possible to improve the purity and colour of water by 80%-90%. Ozonation is recommended methods for wastewater treatment because of a low impact on the environment, however it is rather employed in industry producing drinkable water, also for its reason of costly implementation (Zhou and Smith 1997; Freire et al. 2001).

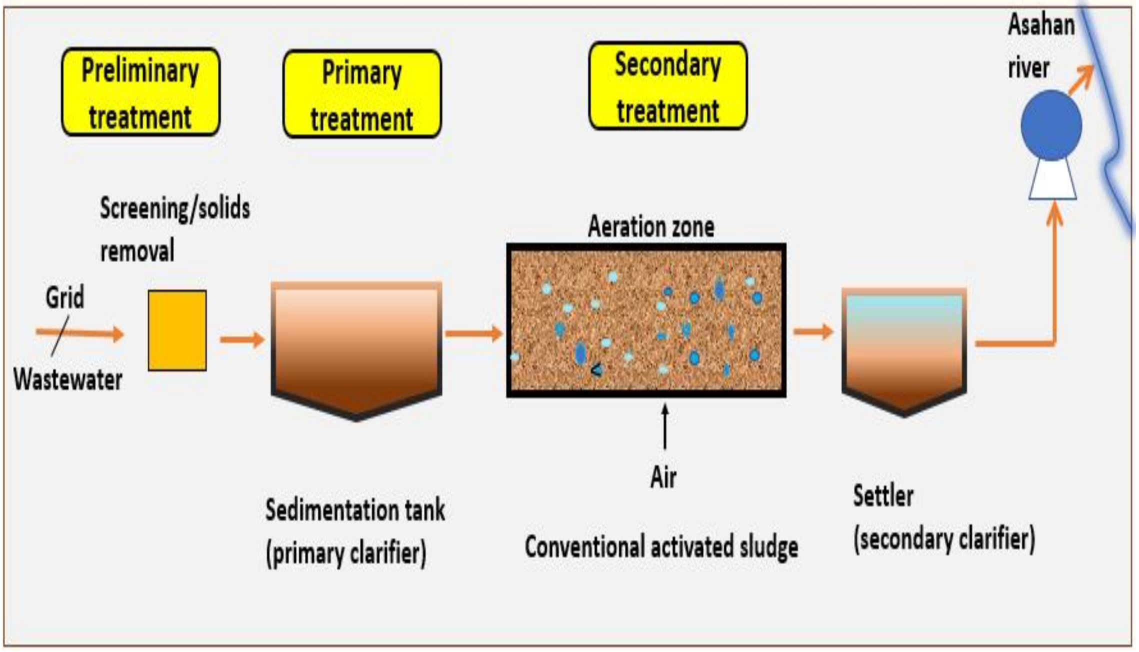
Figure 19: Industrial generator for wastewater treatment (Alibaba 2020).

4.6. Proposal of water treatment plant for TPL's pulp mill

In this chapter all technologies described in previous paragraphs are summarised and inserted into the recommended final water purification plant schema for TPL's pulp mill (see Scheme 2). The aim of this thesis was to propose an effective water treatment plant, which is illustrated in Scheme 2, where particular technologies have been added, and existing technologies based on Scheme 1 have been improved.

Scheme 1 below indicates a simple wastewater treatment plant that starts with solids removal in preliminary treatment. Next, sedimentation technology is applied during primary treatment, followed by an activated sludge tank in secondary treatment. As a final step a settler is implemented, once again, commonly based on the sedimentation process. Ultimately, purified effluent from the TPL pulp mill is discharged into the Asahan river.

Scheme 1: Existing conventional wastewater treatment plant in TPL pulp mill (Author 2020).

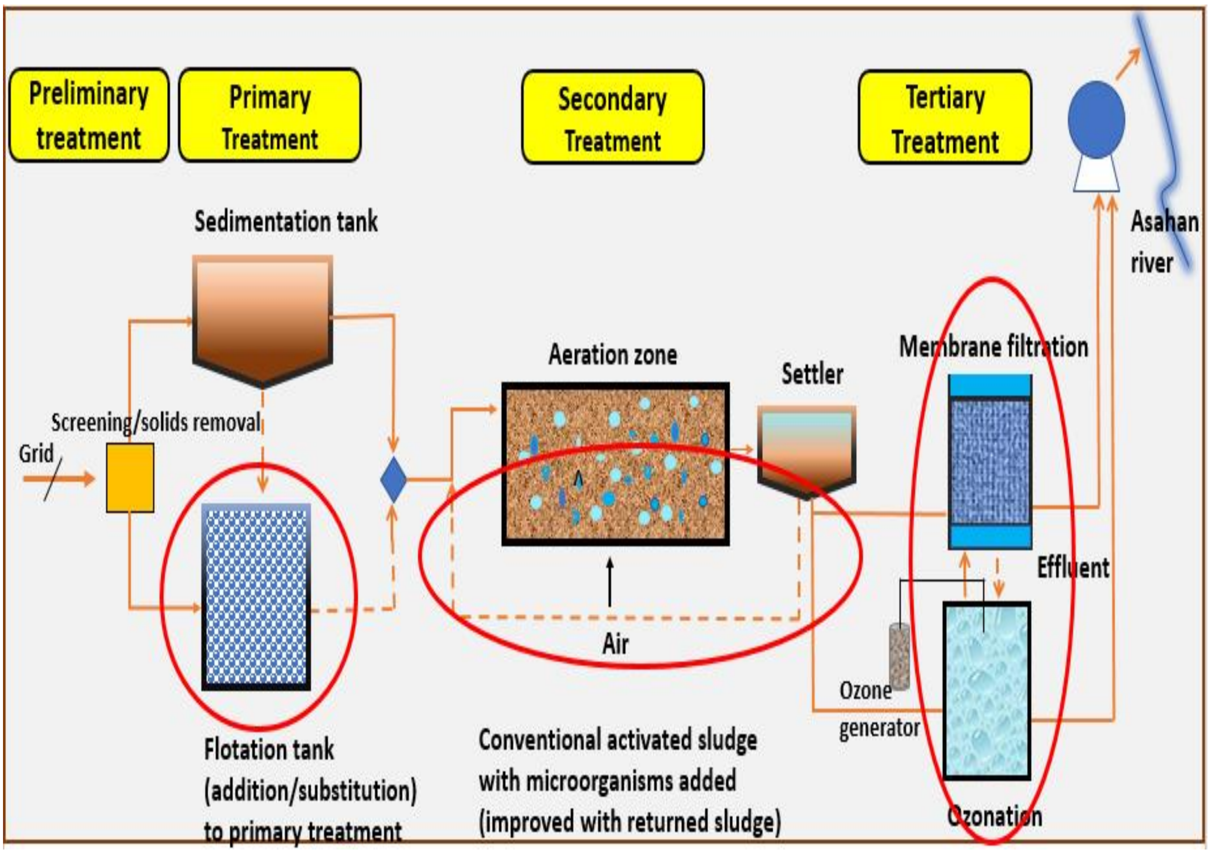


A similar design described in more detail, as shown in Scheme 1, can be seen in chapter 4.5 "Water treatment process". The reason to show the illustration again is to provide a simple and easy to see comparison between the conventional wastewater treatment plant, which is implemented in TBL (see Scheme 1), and the improved water treatment plant (see Scheme 2).

Due to the widespread pollution produced by P&P factories, which is indicated predominantly by the COD, BOD, and TSS parameters, the operation process of the wastewater treatment plant has been enhanced. Consequently, the proposal for an improved water treatment plant contains the following improvements highlighted in red circles in Scheme 2:

1. Substitution or addition of **flotation** into the primary treatment.
2. Implementation of **returned sludge** into activated sludge and addition of a certain volume of **protozoa, rotifer, bacteria**, etc. into the secondary treatment.
3. Addition of **membrane filtration** and/or **ozonation** technology into the tertiary treatment.

Scheme 2: Proposal of improved water treatment plant (Author 2020).



In the primary process a conventional method of sedimentation has been designed, which could be substituted, or simply added by flotation, as a more effective method using air bubbles instead of gravity, in order to separate particles.

Secondary treatment uses an activated sludge, which is one of the most common and efficient methods used in the P&P industry. I took the liberty to propose as the first variant a recycling process based on the aerobic treatment reactor after primary clarifying. Aerobic treatment systems are based on biological processes operated and controlled under aerobic conditions (with aeration) that effectively stabilize the level of COD, BOD, TSS, including carbon dioxide and newly presenting biomass in the water. The enrichment in this stage proposed adding certain volume of microorganisms, such as protozoa, bacteria, rotifers and fungus into tanks with activated sludge, hence enhancing water quality based on biological treatment.

In tertiary treatment, also advanced treatment, were described membrane filtrations like MC, UF, NF and RO, where RO has the most effective membrane in form of particles removal. In addition, the ozonation might be employed as an alternative variant in tertiary wastewater treatment. After utilization these technologies has been water considered as perfectly cleaned and it is ready to be discharged into the Asahan river. The obstacle in application such technologies in tertiary treatment is a matter of finance, especially for developing country like Indonesia could be considered very costly.

The information for designing such a solution (see Scheme 2) was collected predominantly from scientific sources. In addition, a visitation of Jihočeské papírny Větřní, likewise observing the area concerned in Sumatra, have contributed to my decision, which technologies to implement in improved final water treatment plant.

5. Discussion

Over the last century, the living conditions and well-being of people radically raised. Growing population, urbanization and changing diets result in higher demand for energy and fresh water itself. Ecolab (2018) estimates, that by 2030, demand for freshwater is expected to exceed supply by 40 %. Therefore, in the interest of each P&P, emphasis should be placed on so important maintaining the sustainability and strictly controlling of generated effluents into the environment. In order to meet an environmental regulation law, Indonesia as developing country should strength its governmental institutions, set up some standards and requirements for each P&P mill to fulfil, which would be controlled by eligible policy maker. This could be limited by weak monitoring system and law enforcement, which are one of the main reasons, that TPL could have been running for more than 30 years, without considering an environmental burden caused by inadequate operational process within the TPL and its wastewater management.

Several hazards presenting a risk, might be formed by advanced development of industry and expanding technologies established in rural areas lacking adequately skilled staff. Another danger can be associated with purchasing an expensive machinery and equipment, on which is the factory fully dependent. Moreover, keeping the industry in operational at the highest possible capacity is requiring, again, experienced head chief and employees.

Furthermore, a future unpredictable danger can occur for Southern producers including Indonesia, due to changes in norms, regulations and recycling laws governed by Worlds institutions concerned in wastewater treatment. That would mean decrease in yields of eucalyptus, or market competition stemmed from new manufacturers in the Brazil or anywhere else in the world (Lohmann 1996).

However, I visited the TBL factory in July 2018 and collected as much data as was possible about wastewater treatment techniques and plant, I have found very difficult to rely on materials and information propagated by factory and provided by its employees. Essentially, the model of wastewater treatment plant presented by TBL on illustration has presented a perfect conventional technology utilized in P&P industry worldwide. So, where all the environmental problems come from? This company makes a very controversial impression since its establishing. It almost seems like due to its remoteness in the middle of the Sumatra island, the TPL has been overlooked in terms of controlling of water and air pollution.

On the other hand, the TBL is putting considerable effort into technological improvements in wastewater treatment plant during last few years, as its annual reports reported (TBL 2019). More detailed information of water samples and getting permission to have appointment inside the factory is under future research.

6. Conclusion

As discussed, the P&P industry is one of the most water demanding industrial sectors in the world. Various issues resulting from the mill operation process may be caused if it is not operated according to required norms, which are typically set by the government or other environmental institutions. The company Toba Pulp Lestari (TBL), previously renamed from Inti Indorayon Utama (IIU), has been operating since the end of the 1990s. Since this time TBL has been labelled with a poor reputation because of its insufficient pollutant treatment management that allowed the discharge of improperly treated wastewater and gas emissions from the pulp mill back into the environment, either in liquid or gas form. TBL's operations has created a huge environmental burden for highly valued forest ecosystems that have been devastated by deforestation of extensive areas resulting in a loss of biodiversity. Moreover, in a developing country like Indonesia, the operational process of TBL has been done in unsustainable ways, causing social conflicts within local communities and human rights violations.

Therefore, this bachelor's thesis has placed an emphasis on wastewater treatment technologies utilized in the P&P industry within the primary, secondary, and tertiary treatment stages, particularly focused on TPL's pulp mill in Sumatra. As a result, an adequate wastewater treatment plant was designed, which has been summarized and illustrated (see Scheme 2) in chapter 4.6. Conventional wastewater treatment technologies have been transformed into more sophisticated and sustainable ones. These would be recommended to every pulp mill to implement, including TPL, to meet environmental restrictions discharging standards and to provide harmless living conditions for the local population without polluting the environment. Responsible operation of Toba Pulp Lestari (TBL) in terms of efficient plantation development for the conservation of forest and a method for cleaner and more effective development of wastewater management would generate many benefits for the population living nearby Lake Toba, as well as for the economy of Indonesia as a whole. Moreover, the evolution of TPL's pulp mill should go hand in hand with development of the local area without harming the environment and providing a more sustainable way of resource usage.

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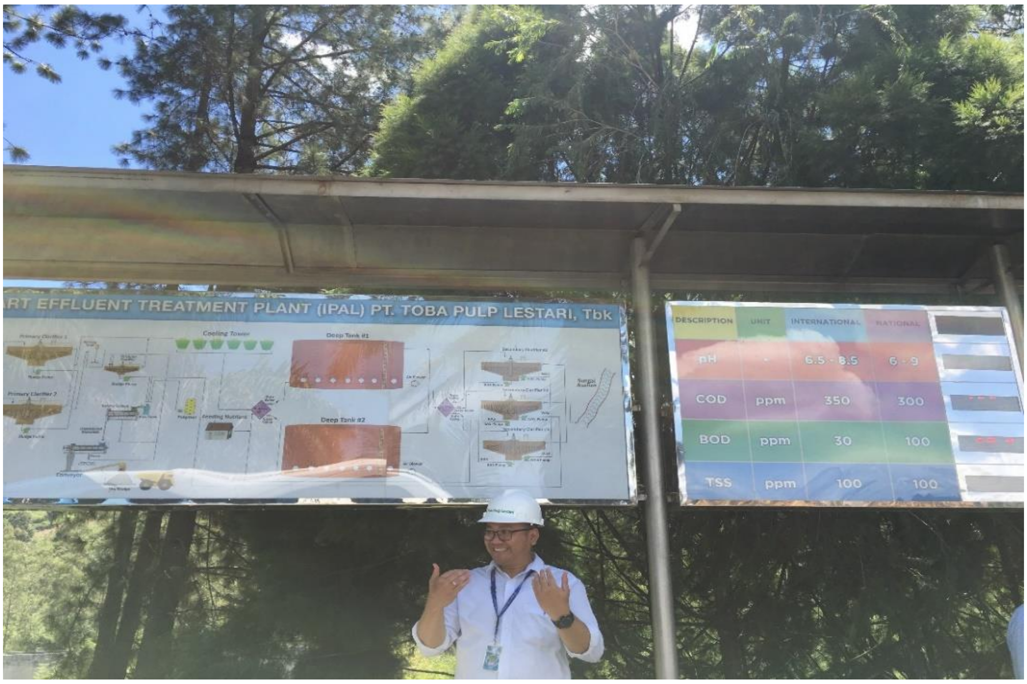
Appendices

List of the Appendices:

Appendix 1: Flow chart effluent treatment plant & table of effluent parameters in Toba Pulp Lestari (Author 2018).



Appendix 2: TBL's garden, where is tested a purity of effluent from the factory (Author 2018).

Appendix 3: TPL's wastewater treatment tank (Author 2018).

Appendix 4: Compressor (on the left) and an automatic flocculant device (on the right) utilized for adding the correct volume of flocculant into a flotation tank (see Figure 14) in the paper mill JIP Větřní (Author 2020).