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Pollution Prevention in the Pulp and Paper Industries
Bahar K. Ince1, Zeynep Cetecioglu2 and Orhan Ince2
1Boğaziçi University, Institute of Environmental Science, Istanbul, Turkey
2Istanbul Technical University, Environmental Engineering Department, Istanbul, Turkey

1. Introduction

Pulp and paper industry is considered as one of the most polluter industry in the world (Thompson et al., 2001; Sumathi & Hung, 2006). The production process consists two main steps: pulping and bleaching. Pulping is the initial stage and the source of the most pollutant of this industry. In this process, wood chips as raw material are treated to remove lignin and improve fibers for papermaking. Bleaching is the last step of the process, which aims to whiten and brighten the pulp. Whole processes of this industry are very energy and water intensive in terms of the fresh water utilization (Pokhrel & Viraraghavan, 2004). Water consumption changes depending on the production process and it can get as high as 60 m3/ton paper produced in spite of the most modern and best available technologies (Thompson et al., 2001).

The wastewaters generated from production processes of this industry include high concentration of chemicals such as sodium hydroxide, sodium carbonate, sodium sulfide, bisulfites, elemental chlorine or chlorine dioxide, calcium oxide, hydrochloric acid, etc (Sumathi & Hung, 2006). The major problems of the wastewaters are high organic content (20-110 kg COD/air dried ton paper), dark brown coloration, adsorbable organic halide (AOX), toxic pollutants, etc.

The environmental problems of pulp and paper industry are not limited by the high water consumption. Wastewater generation, solid wastes including sludge generating from wastewater treatment plants and air emissions are other problems and effective disposal and treatment approaches are essential. The significant solid wastes such as lime mud, lime slaker grits, green liquor dregs, boiler and furnace ash, scrubber sludges, wood processing residuals and wastewater treatment sludges are generated from different mills. Disposal of these solid wastes cause environmental problems because of high organic content, partitioning of chlorinated organics, pathogens, ash and trace amount of heavy metal content (Monte et al., 2009).

The major air emissions of the industry come from sulfite mills as recovery furnaces and burners, sulfur oxides (SOx), from Kraft operation as reduced sulfur gases and odor problems, from wood-chips digestion, spent liquor evaporation and bleaching as volatile organic carbons (VOCs), and from combustion process as nitrogen oxides (NOx) and SOx. VOCs also include ketone, alcohol and solvents such as carbon disulfide methanol, acetone and chlorofom (Smook, 1992).
Many kinds of the wastes as summarized above are generated from different processes. The amount, type and characteristics of these wastes are important to provide the best treatment technology. Physicochemical and biological treatment technologies are used extensively for the pulp and paper mills. The lab-scale and full-scale studies about sedimentation/floatation, coagulation and precipitation, adsorption, chemical oxidation and membrane filtration were carried out in the literature to examine physico-chemical approach (Pokhrel & Viraraghavan, 2004). Biological treatment both aerobic and anaerobic technologies are preferred for treatment of pulp and paper mills because of wastewater composition consisting of high organic compounds and economical aspects. Additionally, some fungi species are used to remove color and AOX from the effluents (Taseli and Gökçay, 1999). In some countries, tertiary treatment is applied to obtain discharge limits of regulations (Thompson et al., 2001). Finally, the wide application in the full-scale plants for treatment pulp and paper mills is hybrid systems, which is combined physico-chemical and biological treatment alternatives (Pokhrel & Viraraghavan, 2004).

Disposal strategy of solid wastes generated from pulp and paper industry is varied depends on the country and the regulations obeyed. After sorting and handling, dewatering, thermal application such as combustion and anaerobic digestion to obtain energy and deposit in landfills are general applications. However, the solid wastes should be monitored after landfill deposition because of toxic characteristics of the compounds (Monte et al., 2009). Also gaseous pollutants are other environmental problems generated from pulp and paper industry. To minimize these pollutants, physico-chemical methods such as adsorption to activated coal filters absorption, thermal oxidation, catalytic oxidation and condensation have been widely used (Eweis et al., 1998). In the last decade, low cost and effective trends have been developed to prevent the limitation of physico-chemical applications such as energy cost and generating secondary pollutants (Sumathi & Hung, 2006).

Waste minimization, recycle, reuse, and innovative approaches developed in last 10 years become more than an issue. In this chapter, waste characterization of this industry in terms of type and source with management approaches was discussed. Exemplary applications were presented. Finally ‘state of the art’ approaches for the environmental problems of this industry were argued.

2. Waste characterization and source

Pulp and paper industry is one of the most water and energy consuming industry in the world. This industry uses the fifth largest energy consumer processes; approximately 4% of total energy is used worldwide. Also during pulp and paper process, the important amount of waste is produced. It has been estimated that 500 million tons of paper and etc. per year will be produced in 2020. Three different raw materials are used in the pulp and paper industry as nonwood fibers and wood materials; soft and hard woods. Waste and wastewaters are generated from both of pulp and bleaching processes. Additionally, 100 million kg of toxic pollutants are released every year from this industry (Cheremisinoff & Rosenfeld, 2010).

2.1 Manufacturing technologies and process description

Pulping process is the first step of the production. The main steps of this part are debarking, wood chipping, chip washing, chip digestion, pulp screening, thickening, and washing. Mechanical and chemical operation processes in pulping are used in the worldwide. While
mechanical processes involve mechanical pressure, disc refiners, heating, and light chemical processes to increase pulping yield; wood chips are cooked in pulping liquors at high temperature and under pressure in the chemical pulping processes. (Sumathi & Hung, 2006). Additionally, mechanical and chemical processes can be combined in some applications. The yield of mechanical processes is higher (90-95%) compared to chemical processes (40-50%). However quality of the pulp obtained from mechanical processes is lower and also the pulp is highly coloured and includes short fibers (Pokhrel & Viraraghavan, 2004). Therefore, chemical pulping carrying out in alkaline or acidic media is mostly preferred. In alkaline media generally referred as Kraft Process, the woodchips are cooked in liquor including sodium hydroxide (NaOH) and sodium sulfide (NaS$_2$). Mixture of sulphurous acid (H$_2$SO$_3$) and bisulfide ions (HSO$_3^-$) is used in acidic media named as sulfide process.

During the pulp processing, approximately 5-10% of the lignin comes from the raw materials cannot be removed and these are responsible from the dark colour of the end product. The production of white paper (pulp bleaching) includes five or optional six treatment steps with sequentially elemental chlorine (Cl1), alkali (E1), optional hypochlorite (H) stage, chlorine dioxide (D1), alkali (E2), and chlorine dioxide (D2). The general process steps are given in Figure 1.

2.2 Wastewater

Different pulping processes utilize different amount of water and all of these processes are water intensive. The quality of wastewater generated from pulping and bleaching is significantly distinctive because of the process and chemical types (Billings and Dehaas, 1971). Approximately 200 m$^3$ water are used for per ton of produced pulp and most of them are highly polluted, especially wastewater generated from chemical pulping process (Cecen et al., 1992). Wood preparation, pulping, pulp washing, screening, washing, bleaching, paper machine and coating operations are the most important pollution sources among various process stages. Wastewaters generated from pulping stage include mostly wood debris, soluble wood materials, and also some chemicals from chemical pulping process. Bleaching process wastewater has a different quality. These wastewaters are not higher strength than pulping process wastewater, however they include toxic components. Process steps and the generated wastewaters from these steps are given in Figure 2.

The wastewater characteristics and their strengths changed depending upon the pulping processing. Kraft process is widely used worldwide approximately 60% within all pulp production includes both mechanical and chemical pulping (Holmberg & Gustavsson, 2007). The regional or geographical distribution of the pulping processes is given in Table 1.

<table>
<thead>
<tr>
<th>Region</th>
<th>Process Type</th>
<th>Pulp Production (million tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2004</td>
</tr>
<tr>
<td>North America</td>
<td>Chemical wood pulp</td>
<td>59.6</td>
</tr>
<tr>
<td></td>
<td>Mechanical wood pulp</td>
<td>16.3</td>
</tr>
<tr>
<td></td>
<td>Total Production</td>
<td>75.9</td>
</tr>
<tr>
<td>Europe</td>
<td>Chemical wood pulp</td>
<td>26.8</td>
</tr>
<tr>
<td></td>
<td>Mechanical wood pulp</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td>Total Production</td>
<td>38.3</td>
</tr>
</tbody>
</table>

Table 1. Pulp production in North America and Europe (Food and Agriculture Organization (FAO) Database, 2011)
Fig. 1. Process scheme of a conventional pulp and paper industry (Sumathi & Hung, 2006)
Pollution Prevention in the Pulp and Paper Industries

The wastewaters generated from pulping process consist various wooden compounds such as lignin, carbohydrate and extractives and the treatment of these wastewaters by biologically is difficult. Addition of them, some toxic compounds such as resin acids, unsaturated fatty acids, diterpene alcohols, juvaniones, chlorinated resin acids, and others can exist in the wastewaters subjecting to the process (Pokhrel & Viraraghavan, 2004). The most important reaction in the bleaching step is oxidation of chlorine and the main problem about the wastewater content is chlorinated organic compounds or AOX (Sumathi & Hung, 2006). The toxic effects of these by-products in the wastewaters on environment have been studied. Various studies reported that fish living in pulp and paper industry wastewaters have toxic/lethal effects on the daphnia, fish, planktons and other bioata in the receiving water bodies (Owens et al., 1994; Hickey and Martin, 1995; Yen et al., 1996; Vass et al., 1996; Liss et al., 1997; Lindstrom-Seppa et al., 1998; Leppanen and Oikari, 1999; Johnsen et al., 1998; Eriştean and Larsson, 2000; Schnell et al., 2000b; Kovacs et al., 2002).

2.3 Solid and hazardous wastes
Wastewater and consequently solid wastes are the main environmental problem of the pulp and paper mills because this industry has a very water intensive production processes
Solid wastes from pulp and paper industries are mainly treatment sludges, lime mud, lime slaker grits, green liquor dregs, boiler and furnace ash, scrubber sludges, and wood processing residuals. Wastewater treatment sludges have a significant concern for the environment because of including chlorinated compounds (EPA, 2002). The characteristics of all solid waste generated from the pulp and paper mills are organic exception of boiler and furnace ash. The chemicals of the solid wastes are varied depends on the process type. Solid wastes, sources and qualities are given in Table 2.

<table>
<thead>
<tr>
<th>Source</th>
<th>Waste Type</th>
<th>Waste Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater Treatment Plant</td>
<td>Sludge</td>
<td>Organic fraction consists wood fibers and biosludge. Inorganic fraction consists clay, calcium carbonate, and other materials 20-60% solid content pH≈7</td>
</tr>
<tr>
<td>Caustic Process</td>
<td>Dregs, muds</td>
<td>Green liquor dregs consisting of non-reactive metals and insoluble materials; lime mud</td>
</tr>
<tr>
<td>Power Boiler</td>
<td>Ash</td>
<td>Inorganic compounds</td>
</tr>
<tr>
<td>Paper Mill</td>
<td>Sludge</td>
<td>Colour waste and fibre clay including slowly biodegradable organics such as cellulose, wood fibres and lignin</td>
</tr>
</tbody>
</table>

Table 2. Solid waste types and sources from pulp and paper mills (EPA, 2002; Nurmesniemi et al., 2007)

2.4 Gas emissions
Air pollutants and gas emissions are the other concern about the pulp and paper industry. The most important gas emission is water vapours. Additionally, particulates, nitrogen oxides, volatile organic compounds (VOCs), sulfur oxides and total reduced sulfur compounds (TRS). The gas emissions sources and types are given Table 3.

3. Waste management
During the pulp and paper production, high usage of water and energy results in large amount of waste generation like wastewater, solid waste and air emissions. Different types
of waste are produced from different production steps and all these wastes pose important environmental problem. To solve this problem:
- Waste minimization can be done by using new and best available technologies.
- End-of-pipe treatment technologies should be used before the discharge and/or disposal.

<table>
<thead>
<tr>
<th>Source</th>
<th>Major Pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Pulping Process</td>
<td>VOCs (terpenes, alcohols, phenols, methanol, acetone, chloroform, methyl ethyl ketone (MEK))</td>
</tr>
<tr>
<td></td>
<td>Reduced sulfur compounds (TRS)</td>
</tr>
<tr>
<td></td>
<td>Organo-chlorine compounds</td>
</tr>
<tr>
<td>Bleaching</td>
<td>VOCs (acetone, methylene chloride, chloroform, MEK, chloromethane, trichloroethane)</td>
</tr>
<tr>
<td>Wastewater Treatment Plant</td>
<td>VOCs (terpenes, alcohols, phenols, methanol, acetone, chloroform, MEK)</td>
</tr>
<tr>
<td>Power Boiler</td>
<td>SO2, Nox, fly ash, coarse particulates</td>
</tr>
<tr>
<td>Evaporator</td>
<td>Evaporator noncondensibles (TRS, volatile organic compounds: alcohols, terpenes, phenols)</td>
</tr>
<tr>
<td>Recovery Furnace</td>
<td>Fine particulates, TRS, SO2, Nox</td>
</tr>
<tr>
<td>Calcining (Lime Kiln)</td>
<td>Fine and coarse particulates</td>
</tr>
</tbody>
</table>

Table 3. Air pollutants types and sources from pulp and paper mills (EPA, 2002)

3.1 Waste minimization

Modern waste minimization approach is by two means. This first way is chemical recovery and recycling. This system especially in chemical pulping process significantly reduces pollutants and additionally economical return is another important aspect. Chemical recovery is necessary because of the basic economic viability of the kraft process. According to EPA, all kraft pulp mills worldwide use chemical recovery systems. However, there is still no recovery system in some sulfite mills. Additionally, scrubber system particulate "baghouses" or electrostatic precipitators (ESPs) are often mill air pollution control components (EPA, 2002).

The second way to minimize waste production from pulp and paper mills is the application of best available techniques (BAT) according to the Integrated Pollution, Prevention and Control (IPPC) Regulation. An effective waste minimization method reduces cost, liability, regulatory burdens of hazardous waste management (Rouleau & Sasseville, 1996; Holland, 1997). Furthermore, hazardous waste generation can be reduced by waste management methods including:
- production, planning and sequencing
- process adjustment and/or modification
- raw material replacement
- housekeeping waste segregation and separation
- recycling
The industries have developed and applied new technologies instead of conventional pulping and bleaching processes. Some examples of these new technologies are given below:

Organic Solvent Pulping: This process is more economical for small and medium scale plants for significant recovery and reuse of chemicals. In this process, organic solvent like ethanol, methanol, etc. are preferred. However, this process is more energy consumer than conventional ones (Sumathi & Hung, 2006).

Acid Pulping: Acetic acid under the high pressure is used for treating of wood chips. The disadvantage of this process is to loss of acid, however recovery is possible (Sumathi & Hung, 2006).

Biopulping: Microorganism or microbial enzymes such as xylanases, pectinases, cellulases, hemicellulases, ligninases, and their combination are used in the pulping process to improve the properties of pulp (Kirk et al., 1996). Biopulping is preferred because:

- To reduce the chemical and energy utilization
- To reduce the pollutants
- To increase the yield and strength properties of pulp.

Elemental Chlorine Free (ECF) and Total Chlorine Free (TCF) Bleaching: Elemental chlorine has been used instead of chlorine dioxide and hypochlorite and oxygen, ozone, caustic soda, and hydrogen peroxide have been applied for TCF bleaching of Kraft pulps to reduce the chlorinated organic wastes (Sumathi & Hung, 2006).

Biobleaching: Fungal cells and or their enzymes are used for pretreatment of pulp. A number of studies showed that application of white rod fungi reduces the chemical dosage of bleaching and enhances the brightness of paper (Kirkpatrick et al., 1990; Reid et al., 1990; Daneult et al., 1994).

Extended Delignification: Enhanced removal of lignin before bleaching step is the main concern of this method (Gullichsen, 1991; McDonough, 1992). It may be achieved by extended cooking, oxygenation, ozonation, and addition of chemical catalysts. Extended delignification positively affect on the bleach effluent quality parameters such as COS, BOD, color and AOX.

### 3.2 Treatment strategies

Although the best approach is to minimize the waste generation from the pulp and paper mills and to recycle, the treatment applications are still necessary. In this section, up-to-date treatment technologies are given.

#### 3.2.1 Wastewater treatment

End of the pipe pollution treatment strategies are necessary to provide the discharge limits. The general flow-chart of a typical wastewater treatment plant is given Figure 3.

The main treatment application for wastewater generated from pulp and paper process is primary and secondary treatment. However, tertiary treatment can be an obligation in future due to possible new legislations. The physicochemical step is rare at present.

**Primary Treatment**

In this step, the aim is to remove suspended solid such as bark particles, fiber, fiber debris, filler and coating materials and consequently organic materials. Primary clarification can also be achieved without sedimentation and flotation. However Thompson et al. (2001) mentioned that sedimentation is generally preferred application for the pulp and paper mills in UK and approximately 80% of suspended solid was removed successfully. Also
Rajvaid and Markandey (1998) reported 70-80% of removal in the sedimentation. Dissolved air flotation and filtration are the other option as primary treatment for pulp and paper mills.

Fig. 3. Flow scheme of general wastewater treatment plant of pulp and paper industry

**Secondary Treatment**

Aerobic lagoons, activated sludge systems, anaerobic treatment and sequential biological treatment (aerobic-anaerobic or anaerobic-aerobic) are the most common biological treatment application for pulp and paper mills. In this section, the details of these processes are given and they are discussed. Performances of various biological treatment processes are summarized in Tables 4.

Activated Sludge Systems:

This conventional treatment system is used in treatment of several industrial wastewater types in order to remove COD, BOD, SS, and AOX. There are a lot of studies in the literature to show the treatability of pulp and paper mills by activated sludge system. Some of them focused on the BOD, COD, AOX and other specific compound removal under different operation conditions. Schnell et al. (1997) showed that 74% of filtered COD, nearly %100 BOD5, resin and fatty acid removal were achieved in the full-scale plant. Saunamaki (1997) reported that 82% and 60% COD removal efficiency at paper mills and pulp mills, respectively in full-scale activated sludge systems of Finland. Knudsen et al. (1994) claimed high COD and BOD removal efficiency by two stage activated sludge process. Also Hansen et al. (1999) and Chandra (2001) showed similar results.

The other part of these studies focused on the removal of AOX and other specific compounds such as chlorinated phenols, guaiacols, catechols, vanillins, 1,1-dichlorodimethyl sulfone (DSS), and chlorinated acetic acid (Mohamed et al., 1989; Demirbas et al., 1999; Bajpai, 2001; Chandra, 2001). The main operational problems of the pulp and paper mills are macro nutrient (N and P) limitation in the systems and growth of the filamentous microorganisms and bulking problems. The nutrient limitation problem is overcome by addition of nutrient. However, the dosage is important point on this step because the external addition causes adverse environmental effects such as eutrophication.
Cingolani et al. (1994) highlighted that the main causes of bulking in the pulp and paper mills treatment are poor oxygenation, low organic loading rates and also nutrient limitations. This problem can also be controlled by installation of a selector or addition of chemicals such as chlorine, ferrous salts, lime or talk powder. Selectors are mostly preferred application for bulking (Forster, 1996; Marten and Daigger, 1997; Prendle and Kroiss, 1998; Andreasen et al., 1999).

Aerated Lagoons (Stabilization Basins):
Aerated lagoons are the simple and economical biological systems and they have been studies very well as lab-scale and full-scale at the pulp and paper mills. These systems have been used for removal of BOD, low-molecular weight AOX and fatty acids at full-scale applications (Bajpai, 2001). Stuthridge and Macfarlane (1994) showed that 70% of AOX could be removed efficiently in a short residence time. Welander et al. (1997) reported that COD removal was achieved as 30-40% in a full-scale lagoon and 60-70% in a pilot-scale plant. Lab-scale treatability studies were conducted by Chernysh et al. (1992) to monitor the AOX and TOC removal of bleached kraft effluent. Slade et al. (1999) also reported three aerated stabilization basins, which treated elemental chlorine free (ECF) integrated bleached Kraft mill effluents.

Anaerobic Treatment Processes:
Anaerobic treatment processes are more suitable for treatment of high strength wastewater such as pulp and paper mills. In the literature, there are a variety of studies on the anaerobic treatability and microbial community of this type of effluents (Poggi-Varaldo et al., 1996; Bajpai, 2000; Ince et al., 2007). Also, anaerobic microorganisms are more efficient than aerobics in order to degrade chlorinated organic compounds. However, the sulphur content in the wastewaters is the main disadvantages for application of anaerobic systems, because one of the end products is hydrogen sulphide in the anaerobic biodegradation in the presence of sulphate (Lettinga et al., 1991). Although Hamm et al. (1991) reported that the toxic effect of H2S is less than high concentration of Ca2+ and SO42-. The other important issues for the application of anaerobic treatment in pulp and paper mills are toxicity of wastewater, anaerobic biodegradability characteristic of specific waste types such as lignin derivates, resin and fatty acids, loading capacity, response to loading fluctuation, and recovery of energy and chemicals (Sumathi and Hung, 2006). Several hundred tons of inorganic chemicals per day for delignification are used in a conventional pulp and paper mill. So, the recovery and reuse of these chemicals are one of the most economical and environmental concern. Addition of it, the black liquor is rich in lignin and a conventional pulp and paper mill produces 1.7-1.8 tons dry solid of black liquor per ton produced pulp and the potential energy of this liquor from anaerobic digestion is 250-500 MW (Stigsson, 1998; Larson et al., 2000). Anaerobic contact reactor, up-flow anaerobic sludge blanket (UASB) reactor, anaerobic filter, and fluidized bed reactor are mostly employed reactor types in pulp and paper mills. The anaerobic treatment efficiency of different plants from pulp and paper industry is given in Table 5.

Fungal Treatment:
Fungal species have been used to remove colour and COD from pulp and paper mills (Eaton et al., 1980; Livernoche et al., 1983; Wang et al., 1992; Gokcay and Dilek, 1994; Duran et al.,
Pencillium sp., *P. chrysosporium* and white rod fungi are the most widely used species. Choudhury *et al.* (1998) reported that *Pleurotus ostreatus* was removed 77% of lignin, 76.8% of BOD, 60% of COD, and 80% of colour.

**Tertiary Treatment**

**Coagulation/Precipitation:**

Addition of metal salts to generate larger flocs from small particles for removing the pollutants easily is the main principle of this method. There are some studies to find the most effective chemicals such as horseradish peroxide (chitosan), Al$_2$(SO$_4$)$_3$, hexamethylenediamine epichlorohydrin polycondensate (HE), polyethyleneimine (PEI) to remove AOX, total organic carbon and colour (Tong *et al.*, 1999; Ganjidoust *et al.*, 1997). The authors reported that chitosan is more effective to remove these pollutants from others. Dilek and Gokcay (1994) stated that alum salts as coagulant were removed 96% of COD from the paper machine, 50% of COD from pulping, and 20% COD from bleaching effluents. The other study showed that polyelectrolytes were more effective than the conventional coagulant on the removal of turbidity, COD, and colour (Rohella *et al.*, 2001).

**Adsorption:**

This method relies on the addition of an adsorbant such as activated coke, fuller’s earth, coal ash, activated carbon, and activated charcoal to the wastewater to remove the pollutants. High removal of colour by activated charcoal, fuller’s earth, and coal ash was reported (Murthy *et al.*, 1991). Also Shawwa *et al.* (2001) showed that high removal of colour, COD, DOC, and AOX from bleaching wastewater by activated coke.

**Chemical Oxidation:**

Advanced oxidation methods such as photocatalysis, photo-oxidation, Fenton type reactions, wet oxidation, ozonation are used to achieve the destruction of chromophoric and nonchromophoric pollutants in pulp and paper mills. The achievement of photocatalytic reaction in the removal of COD is depended on the concentration of COD and chloride, which are below a certain level (Balcioglu and Ferhan, 1999). Fenton and photo-fenton reactions are highly effective for the treatment of bleaching kraft mill effluent (Perez *et al.*, 2002). Verenich *et al.* (2000) showed that wet-oxidation are increased the biodegradability of the pulp and paper mill effluent from 30% to 70%. Also ozonation is one of the most effective methods. Several author showed that the effectiveness of this method (Hostachy *et al.*, 1997; Zhou and Smith, 1997; Yamamoto, 2001; Freire *et al.*, 2000).

**Membrane Filtration:**

Membrane filtration is a potential method to remove colour, COD, AOX, salts, heavy metals, and total dissolved solids from pulp and paper mills (Zaidi *et al.*, 1992; Afonso and Pinho, 1991; Falth, 2000; Merrill *et al.*, 2001). The effluent of membrane filtration can be used again in production process or discharge directly to the receiving water bodies. Dube *et al.* (2000) showed that 88% and 89% removal of BOD and COD, respectively was achieved by reverse osmosis (RO).

The performance of physico-chemical process at the pulp and paper industry is summarized in Table 6.
<table>
<thead>
<tr>
<th>Treatment Process</th>
<th>TSS</th>
<th>BOD</th>
<th>COD</th>
<th>AOX</th>
<th>Chlorinated Phenolics</th>
<th>Color</th>
<th>Methanol</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Influent (mg/L)</td>
<td>Removal Efficiency (%)</td>
<td>Influent (mg/L)</td>
<td>Removal Efficiency (%)</td>
<td>Influent (mg/L)</td>
<td>Removal Efficiency (%)</td>
<td>Influent (mg/L)</td>
<td>Removal Efficiency (%)</td>
</tr>
<tr>
<td>Activated sludge</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper mill</td>
<td>1435</td>
<td>90.6</td>
<td>512</td>
<td>94.2</td>
<td>1210</td>
<td>82.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pulp mill</td>
<td>738</td>
<td>76.4</td>
<td>336</td>
<td>93.9*</td>
<td>1192</td>
<td>57.1</td>
<td>11.7</td>
<td>85</td>
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<tr>
<td>Kraft mill</td>
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<td></td>
<td>I</td>
<td>-</td>
<td>270</td>
<td>&gt;95*</td>
<td>660 (F)</td>
<td>60</td>
<td>22.5</td>
<td>36</td>
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<tr>
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<td>II</td>
<td>-</td>
<td>270</td>
<td>&gt;98</td>
<td>660 (F)</td>
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<td></td>
<td>-</td>
<td>-</td>
<td>1000</td>
<td>-99</td>
<td>1533</td>
<td>85</td>
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<td>Aerobic stabilization basin</td>
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<td>Kraft mill</td>
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<td>I</td>
<td>-</td>
<td>270</td>
<td>&gt;95*</td>
<td>660 (F)</td>
<td>62</td>
<td>22.5</td>
<td>33</td>
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<tr>
<td></td>
<td>II</td>
<td>-</td>
<td>270</td>
<td>&gt;98</td>
<td>660 (F)</td>
<td>73</td>
<td>22.5</td>
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<tr>
<td>Kraft mill</td>
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</tr>
<tr>
<td></td>
<td>-</td>
<td>-</td>
<td>20-45</td>
<td>-</td>
<td>17-20</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>IRB (TMP Mill)</td>
<td>-</td>
<td>-</td>
<td>1150</td>
<td>98</td>
<td>3340</td>
<td>79</td>
<td>-</td>
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<tr>
<td>Total plant efficiency</td>
<td>-</td>
<td>-</td>
<td>1400</td>
<td>99</td>
<td>5000</td>
<td>86</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SBR (4,5 hr)</td>
<td>-</td>
<td>-</td>
<td>65-75</td>
<td>-</td>
<td>85-95</td>
<td>-</td>
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<tr>
<td>Anoxic (CAS)</td>
<td>-</td>
<td>-</td>
<td>98</td>
<td>-</td>
<td>85-93</td>
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<tr>
<td>SBR</td>
<td>-</td>
<td>-</td>
<td>1400</td>
<td>98</td>
<td>50</td>
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<tr>
<td>Kraft mill Windser</td>
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<td>-</td>
<td>1428</td>
<td>69</td>
<td>2036</td>
<td>59</td>
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</tbody>
</table>

Table 4. Typical wastewater quality of pulp and paper industry and biological treatment efficiencies of these wastewaters (1) "P" means fraction of COD or soluble COD; (2) Period 1: operating conditions for activated sludge- HRT 2 days, SRT 25 days, Temp. 30°C, VSS 3600 mg/l; (3) Period 2: operating conditions for activated sludge-HRT 1 day, SRT 25 days, Temp. 30°C, VSS 2800 mg/l; (4) Period 2: operating conditions for aerated stabilization basin-HRT 15 days, SRT 15 days, Temp. 20°C, VSS 700 mg/l; (5) "a" means soluble COD; (6) "b" means unit in g/d; and (7) "m" means BOD5.
<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>Mill Location</th>
<th>Wastewater Source</th>
<th>Loading Rate (kg COD/m³/d)</th>
<th>BODS (mg/L)</th>
<th>BODS Removal %</th>
<th>COD (mg/L)</th>
<th>COD Removal %</th>
<th>TSS (mg/L)</th>
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</thead>
<tbody>
<tr>
<td>Anoerobic contact reactor</td>
<td>Hylte Bruk, AB, Sweden</td>
<td>TMP, groundwood</td>
<td>2.5</td>
<td>1300</td>
<td>71</td>
<td>3500</td>
<td>67</td>
<td>520</td>
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<tr>
<td></td>
<td>SAICA, Zaragoza, Spain</td>
<td>Waste paper alkaline cooked straw</td>
<td>4.8</td>
<td>10,000</td>
<td>94</td>
<td>30,000</td>
<td>66</td>
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<tr>
<td></td>
<td>Hannover paper, Alfred, Germany</td>
<td>Sulfite effluent condensate</td>
<td>4.2</td>
<td>3000</td>
<td>97</td>
<td>6000</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Niagara of Wisconsin, USA</td>
<td>CTMP</td>
<td>2.7</td>
<td>2500</td>
<td>96</td>
<td>4800</td>
<td>77</td>
<td>3300</td>
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<tr>
<td></td>
<td>SCA Ostrand, Ostrand, Sweden</td>
<td>CTMP</td>
<td>6</td>
<td>3700</td>
<td>50</td>
<td>7900</td>
<td>40</td>
<td></td>
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<td></td>
<td>Alaska Pulp Corporation, Sitka</td>
<td>Sulfite condensate, bleach caustic and pulp whitewater</td>
<td>3</td>
<td>3500</td>
<td>85</td>
<td>10,000</td>
<td>49</td>
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<td>Upflow anaerobic sludge blanket</td>
<td>Celtona, Holland</td>
<td>Tissue</td>
<td>3</td>
<td>600</td>
<td>75</td>
<td>1200</td>
<td>60</td>
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<tr>
<td></td>
<td>Southern paper converter, Australia</td>
<td>Wastepaper</td>
<td>10</td>
<td>80</td>
<td>10,000</td>
<td>&gt; 80</td>
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<td></td>
<td>Davidson, United Kingdom</td>
<td>Linerboard</td>
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<td>1440</td>
<td>90</td>
<td>2800</td>
<td>75</td>
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<td>Chemicad, Friluli, Italy</td>
<td>Sulfite condensate</td>
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<td>12,000</td>
<td>90</td>
<td>15,600</td>
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<td>Quesnel River Pulp, Canada</td>
<td>TMP/CTMP</td>
<td>18</td>
<td>3000</td>
<td>60</td>
<td>7800</td>
<td>50</td>
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<tr>
<td></td>
<td>Lake Utopia Paper, Canada</td>
<td>NSSC</td>
<td>20</td>
<td>6000</td>
<td>80</td>
<td>16,000</td>
<td>55</td>
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<tr>
<td></td>
<td>ErsoGutzeit, Finland</td>
<td>Bleached, TMP/CTMP</td>
<td>13.5</td>
<td>1800</td>
<td>75</td>
<td>4000</td>
<td>60</td>
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<td></td>
<td>McMillan Bloedel, Canada</td>
<td>NSSC/CTMP</td>
<td>15</td>
<td>7000</td>
<td>80</td>
<td>17,500</td>
<td>55</td>
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<tr>
<td>Anaerobic filter</td>
<td>Lanaken, Belgium</td>
<td>CTMP</td>
<td>12.7</td>
<td>4000</td>
<td>85</td>
<td>7900</td>
<td>70</td>
<td></td>
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<tr>
<td>Anaerobic fluidized bed</td>
<td>France</td>
<td>Paperboard</td>
<td>35</td>
<td>1500</td>
<td>83.3</td>
<td>3000</td>
<td>72.2</td>
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Table 5. Selected anaerobic process performance at different pulp and paper industries (Bajpai, 2000)
<table>
<thead>
<tr>
<th>Treatment Process</th>
<th>Parameters</th>
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</thead>
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<tr>
<td></td>
<td>TSS</td>
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<tr>
<td></td>
<td>Influent (mg/L)</td>
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<tr>
<td>Coagulation</td>
<td>Polyelectrolyte</td>
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<tr>
<td></td>
<td>Chitosan</td>
</tr>
<tr>
<td></td>
<td>PFU PEI</td>
</tr>
<tr>
<td></td>
<td>Alum</td>
</tr>
<tr>
<td>Adsorption</td>
<td>Charcoal #1</td>
</tr>
<tr>
<td></td>
<td>Charcoal #2</td>
</tr>
<tr>
<td></td>
<td>Fuller earth #3</td>
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<tr>
<td></td>
<td>Activated coke #4</td>
</tr>
<tr>
<td>Oxidation</td>
<td>Wet oxidation</td>
</tr>
<tr>
<td></td>
<td>Ozonation</td>
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<tr>
<td></td>
<td>Ozone + UV</td>
</tr>
<tr>
<td></td>
<td>Photocatalysis</td>
</tr>
<tr>
<td></td>
<td>Photocatalysis + UV</td>
</tr>
<tr>
<td>Membrane</td>
<td>Ultrafiltration</td>
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<td></td>
<td>Nanofiltration</td>
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<tr>
<td></td>
<td>Dissolved air + UF</td>
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<tr>
<td></td>
<td>Microfiltration</td>
</tr>
</tbody>
</table>

Table 6. Typical wastewater quality of pulp and paper industry and physico-chemical treatment efficiencies of these wastewater (#1) Charcoal dose 0.4 g/l and pH 2.0; (#2) Coal ash dose 12 g/l and pH 2.0; (#3) Fuller earth dose 4 g/l and pH 1.0; (#4) activated coke dose 15,000 mg/L.
3.2.2 Management and disposal of solid wastes

Integrated solid waste management of pulp and paper mills are through anaerobic digestion, composting, land applications, thermal processes such as incineration/combustion, pyrolysis, steam reforming, and wet oxidation.

Anaerobic Digestion: This process type is a cost effective way due to the high-energy recovery (Verstraete and Vandevivere, 1999; Mata-Alvarez et al., 2000). Industrial wastes, which have high organic content and digestable, are suitable for anaerobic digestion like paper sludge and wastewater treatment plant sludge (Kay, 2003; CANMET, 2005).

Composting: This method is suitable for the wastes and sludge, especially paper fibres and organic materials. The wastes are stabilized via microorganisms with minimal carbon loss. The end product of this process, humus-like material, can be used for houseplants, greenhouse and agriculture (Jokela et al., 1997; Hackett et al., 1999; Christmas, 2002; Gea et al., 2005).

Land Application: This method has been preferred disposal method, especially for the acidic soil due to CaCO$_3$ content of sludge. This application is widely used in the United Kingdom and Northern Europe. Before the application, dewatering and/or incineration treatment are done to the waste/sludge in order to reduce volume (Carr and Gay, 1997; Van Horn, 1997).

Incineration (Combustion): Combination of incineration with power and steam generation is one of the most applied methods in Europe, especially for wastewater treatment plant sludge. However, water and ash content of most sludges cause the energy deficiency. Fluidized bed boiler technology is becoming the one of the best solution for the final disposal of paper mill wastes in order to provide successful thermal oxidation of high ash, high moisture wastes (Busbin, 1995; Fitzpatrick and Seiler, 1995; Davis et al., 1995; Albertson, 1999; Porteous, 2005; Oral et al., 2005).

Pyrolysis: In this process, organic wastes are converted to gaseous and liquid phase under high temperature and in the absence of oxygen. This is an alternative technology to incineration and landfill. This method is suitable for organic content high wastes such as wood, petroleum, plastic waste. However this technology is not sufficient for pulp and paper mill waste. Some investigations have been continue to adapt this technology to pulp and paper mills (Fio Rito, 1995; Frederik et al., 1996; Kay, 2002; Fytili and Zabaniotou, 2008).

Steam Reforming: This technology is used for sludge treatment, however it is still considered as an emerging technology for paper sludges. Steam reforming is a novel combustion technology, which carries out in a steam reforming reaction system (Duraiswamy et al., 1991; Aghamohammadi and Durai-Swamy, 1995; Demirbas, 2007).

Wet Oxidation: The principle of wet oxidation is that organic compound as solid or liquid form is firstly transferred to water where it contacts with an oxidant under high temperature and pressure. During wet oxidation, waste pulped with water is carbonized and its fuel value increases to the equivalent of medium-grade coal. The waste does not cause any air emission in order to combust without flame or smoke (Kay, 2002). This technology is also considered as an emerging technology like steam reforming.

3.2.3 Treatment of gas emissions

Air pollution control at pulp and paper mills has been important concern in the recent years. Especially VOCs produced form pulp and bleaching steps and steam are conventionally treated by physico-chemical methods such as adsorption to activated coal filters, absorption, thermal oxidation, catalytic oxidation, and condensation (Eweis et al., 1998). I spite of these
pollutants are removed from gaseous phase, they transferred another phase and they are also different pollutants for environment. More innovative approach to solve this problem is biofilters and bioscrubbers that have three steps to remove pollutants from gaseous phase;

- The transfer of pollutants from air to liquid phase,
- The transfer of pollutants from liquid phase to biofilm phase where microorganisms are located, and
- Mineralization of pollutants by microorganisms.

4. Conclusion

The paper demand increases every day as a result of developed population and industrialisation. Water and energy utilization and in particularly waste generation are becoming more important concern ever worldwide. A major goal is to decrease damage to environment by waste minimization, reuse and recycle. To use best available techniques and innovative methods is becoming more an issue. However, end-of-pipe treatment is still the major approach to minimize the risk. To evaluate pollutants and to develop treatment technologies need a holistic approach.

The major pollution load constitutes wastewaters from pulp and paper mills. A variety of wastewater is generated from diverse processes. Different technologies and their combinations have been used for their treatment. The most common applied systems are biological treatment, sequential anaerobic and aerobic systems, followed after primary treatment. Solid waste management and disposal are also another concern. During the final disposal step, the aim should be chemical compound and energy recovery because of environmental and economical aspects. However, the waste minimization has still the first and important approach. Biofilters and bioscrubbers are mostly used for removal of air pollutants and other applications are limited.

The best available treatment technology for all three waste phases depends on the production processes, raw materials and the regulations, which the industries have to obey.

5. References


In recent years the topic of environmental management has become very common. In sustainable development conditions, central and local governments much more often notice the need of acting in ways that diminish negative impact on environment. Environmental management may take place on many different levels - starting from global level, e.g. climate changes, through national and regional level (environmental policy) and ending on micro level. This publication shows many examples of environmental management. The diversity of presented aspects within environmental management and approaching the subject from the perspective of various countries contributes greatly to the development of environmental management field of research.

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