We are IntechOpen, the world’s leading publisher of Open Access books
Built by scientists, for scientists

6,500 Open access books available
176,000 International authors and editors
190M Downloads

154 Countries delivered to
TOP 1% Our authors are among the most cited scientists
12.2% Contributors from top 500 universities

WEB OF SCIENCE™
Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com
Pollution Prevention in the Pulp and Paper Industries

Bahar K. Ince¹, Zeynep Cetecioglu² and Orhan Ince²

¹Bogazici 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 burns, 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 Gokcay, 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 sulfite 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 (C1), 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.

| Region       | Process Type          | Pulp Production (million tons) | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|--------------|-----------------------|--------------------------------|------|------|------|------|------|------|
| North America| Chemical wood pulp    | 59.6                           | 59.1 | 57.3 | 55.6 | 54.8 | 48.6 |      |
|              | Mechanical wood pulp  | 16.3                           | 16.2 | 15.3 | 14.4 | 13.6 | 11.7 |      |
|              | Total Production      | 75.9                           | 75.3 | 72.6 | 70.0 | 68.4 | 60.3 |      |
| Europe       | Chemical wood pulp    | 26.8                           | 25.9 | 27.5 | 27.3 | 32.4 | 29.5 |      |
|              | Mechanical wood pulp  | 11.5                           | 11.2 | 12.4 | 12.1 | 14.3 | 11.9 |      |
|              | Total Production      | 38.3                           | 37.1 | 39.9 | 39.4 | 46.7 | 41.4 |      |

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)
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; Erisction 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.

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

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.

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

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 (ESP's) 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; Baijai, 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 H$_2$S is less than high concentration of Ca$^{2+}$ and SO$_4^{2-}$. 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.,
1994; Sakurai et al., 2001). 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), $\text{Al}_2(\text{SO}_4)_3$, hexamethylene diamine epichlorohydvin 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.
| Treatment Process | Parameters | TSS (mg/L) | BOD (mg/L) | COD (mg/L) | AOX (mg/L) | Chlorinated Phenolics | Color | Methanol | References |
|-------------------|------------|------------|------------|------------|------------|----------------------|-------|----------|------------|
|                   | Influent   | Removal Efficiency (%) | Influent | Removal Efficiency (%) | Influent | Removal Efficiency (%) | Influent | Removal Efficiency (%) | Influent | Removal Efficiency (%) | Influent | Removal Efficiency (%) | |
| Activated sludge  | Paper mill | 145 | 90.6 | 512 | 94.2 | 1210 | 82.4 | - | - | - | - | - | - | Steinbrügge (1997) |
|                   | Pulp mill  | 738 | 76.4 | 336 | 93.8 | 1192 | 57.1 | 11.7 | 85 | - | - | - | - | Steinbrügge (1997) |
|                   | Kraft mill | 270 (>95) | 660 (F) | 60 | 22.5 | 60 | 22.5 | 40 | 0.255 | 83 | - | - | - | Scholl et al. (2000a) |
|                   | Pulp and paper mill | 270 (>98) | 660 (F) | 70 | 22.5 | 60 | 22.5 | 40 | 0.255 | 83 | - | - | - | Scholl et al. (2000a) |
|                   | Paper mill | 100 | 99 | 153 | 85 | - | - | - | - | - | - | - | - | Chavotta (2001) |
| Aerobic stabilization basin | Kraft mill | 270 (>95) | 660 (F) | 62 | 22.5 | 60 | 22.5 | 40 | 0.255 | 83 | - | - | - | Scholl et al. (2000a) |
|                   | Pulp mill  | 270 (>98) | 660 (F) | 73 | 22.5 | 60 | 22.5 | 40 | 0.255 | 83 | - | - | - | Scholl et al. (2000a) |
| Other Biological Reactor Types | EBC (TMB) Mill | - | - | 1150 | 98 | 330 | 79 | - | - | - | - | - | - | Magnus et al. (2003a) |
|                   | Total plant efficiency | - | - | 1400 | 89 | 900 | 86 | - | - | - | - | - | - | Magnus et al. (2003a) |
|                   | SBR (HRT 4.5 hrs) | - | - | 65-75 | - | 85-95 | - | - | - | - | - | - | - | Boorden et al. (1997) |
|                   | Anoxic reactor (GAC) | - | - | 1400 | 98 | - | - | - | - | - | - | - | - | Jackson-Miss et al. (1992) |
|                   | Kraft mill Windsor | - | - | 1429 | 69 | 2036 | 59 | - | - | - | - | - | - | Uskure et al. (2001) |

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 3800 mg/L; [3] Period 1: operating conditions for aerated stabilization basin-HRT 15 days, SRT 15 days, Temp. 30°C, VSS 60 mg/L; [4] Period 2: operating conditions for activated sludge-HRT 1 day, SRT 25 days, Temp. 30°C, VSS 2000 mg/L; [5] Period 2: operating conditions for aerated stabilization basin-HRT 15 days, SRT 15 days, Temp. 20°C, VSS 70 mg/L; [6] “a” means soluble COD, [7] “b” means unit in g/d and [8] “c” means BOD7).
Table 5. Selected anaerobic process performance at different pulp and paper industries (Bajpai, 2000)

| Reactor Type                  | Mill location                                      | Wastewater Source                      | Loading Rate (kg COD/m³/d) | BOD₅ (mg/L) | BOD₅ Removal % | COD (mg/L) | COD Removal % | TSS (mg/L) |
|------------------------------|----------------------------------------------------|----------------------------------------|-----------------------------|-------------|----------------|-------------|---------------|------------|
| Anaerobic contact reactor    | Hylte Bruk, AB, Sweden                             | TMP, groundwood, deink                 | 2.5                         | 1300        | 71             | 3500        | 67            | 520        |
|                              | SAICA, Zaragoza, Spain                             | Waste paper alkaline cooked straw      | 4.8                         | 10,000      | 94             | 30,000      | 66            |            |
|                              | Hannover paper, Alfred, Germany                    | Sulfite effluent condensate            | 4.2                         | 3000        | 97             | 6000        | 85            |            |
|                              | Niagara of Wisconsin, USA                          | CTMP                                   | 2.7                         | 2500        | 96             | 4800        | 77            | 3300       |
|                              | SCA Ostrand, Ostrand, Sweden                       | CTMP                                   | 6                           | 3700        | 50             | 7900        | 40            |            |
|                              | Alaska Pulp Corporation, Stika                     | Sulfite condensate, bleach caustic and pulp white water | 3                           | 3500        | 85             | 10,000      | 49            |            |
| Upflow anaerobic sludge blanket | Celtona, Holland                                  | Tissue                                 | 3                           | 600         | 75             | 1200        | 60            |            |
|                              | Southern paper converter, Australia                | Wastepaper                             | 10                          | 80          | 10,000         | > 80        |               |            |
|                              | Davidson, United Kingdom                           | Linerboard                             | 9                           | 1440        | 90             | 2880        | 75            |            |
|                              | Chimicadel, Frulii, Italy                          | Sulfite condensate                     | 12.5                        | 12,000      | 90             | 15,600      | 80            |            |
|                              | Quesnel River Pulp, Canada                        | TMP/CTMP                              | 18                          | 3000        | 60             | 7800        | 50            |            |
|                              | Lake Utopia Paper, Canada                          | NSSC                                  | 20                          | 6000        | 80             | 16,000      | 55            |            |
|                              | EnsoGutzeit, Finland                               | Bleached TMP/CTMP                     | 13.5                        | 1800        | 75             | 4000        | 60            |            |
|                              | McMillian Bloedel, Canada                         | NSCC/CTMP                             | 15                          | 7000        | 80             | 17,500      | 55            |            |
| Anaerobic filter             | Lanaken, Belgium                                   | CTMP                                  | 12.7                        | 4000        | 85             | 7900        | 70            |            |
| Anaerobic fluidized bed:     | France                                             | Paperboard                             | 35                          | 1500        | 83.3           | 3000        | 72.2          |            |
| Treatment Process | Parameters | Influent (mg/L) | Removal Efficiency (%) | References |
|-------------------|------------|----------------|------------------------|------------|
|                   | TSS        |                |                        |            |
| Polyelectrolyte   |            | 3620          | 100                    | Rebella et al. (2003) |
| Coagulation       | CDD        | 4112          | 55.65                  |              |
|                  | TOC        |                |                        |            |
|                  | AOX        |                |                        |            |
|                  | Color      |                |                        |            |
|                  | Lignite/Resin or Fatty acid | | | |
| Adsorption        | Influent (mg/L) | Removal Efficiency (%) | | | |
| Charcoal #1       |            | -              | -                      | - 3.9 mg/L | 98.13 | Grunewald et al. (1991) |
| Coal ash #2       |            | -              | -                      | - 3.9 mg/L | 98.5 | Grunewald et al. (1991) |
| Fuller earth #3   |            | -              | -                      | - 3.9 mg/L | 99.21 | Grunewald et al. (1991) |
| Activated coke #4 |            | -              | -                      | - 3.9 mg/L | 98.13 | Grunewald et al. (1991) |
| Oxidation         | Wet oxidation | -              | -                      | - 3.9 mg/L | 98.13 | Grunewald et al. (1991) |
|                   | Ozonation + UV | -              | -                      | - 3.9 mg/L | 98.13 | Grunewald et al. (1991) |
|                   | Ozone + UV | -              | -                      | - 3.9 mg/L | 98.13 | Grunewald et al. (1991) |
|                   | Photocat. ozone | -              | -                      | - 3.9 mg/L | 98.13 | Grunewald et al. (1991) |
| Membrane          | Ultrafiltration | -              | -                      | - 3.9 mg/L | 98.13 | Grunewald et al. (1991) |
|                   | Nanofiltration | -              | -                      | - 3.9 mg/L | 98.13 | Grunewald et al. (1991) |
|                   | Dissolved air  | -              | -                      | - 3.9 mg/L | 98.13 | Grunewald et al. (1991) |
|                   | Microfiltration | -              | -                      | - 3.9 mg/L | 98.13 | Grunewald et al. (1991) |

Table 6. Typical wastewater quality of pulp and paper industry and physico-chemical treatment efficiencies of these wastewater (†) Charcoal dose 0.4 g/L and pH 2.0; (‡) Coal ash dose 12 g/L and pH 2.0; (§) Fuller earth dose 4 g/L and pH 2.0; (¶) 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 Duraiswamy, 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
Afonso, M.D. & Pinho, M.N. (1991). Membrane separation processes in pulp and paper production. Filtr. Sep., Vol.2, No.1, pp.42- 4.
Aghamohammadi, B. & Durai-Swamy, K. (1995). A disposal alternative for sludge waste from recycled paper and cardboard. Environmental Issues and Technology in the Pulp and Paper Industry. A TAPPI Press Anthology of Published Papers, 1991–1994, pp. 445–449.
Albertson, D.M. (1999). Paper sludge - waste disposal problem or energy opportunity. Energy Products of Idaho.
Andreasan, K.; Agertved, J.; Petersen, J.O. & Skaarup, H. (1999) Improvement of sludge settleability in activated sludge plants treating effluent from pulp and paper industries. Water Sci. Technol., Vol. 40, No.11 –12, pp.215–21.
Bajpai, P. (2000). Treatment of pulp and paper mill effluents with anaerobic technology. Randalls Road, Leatherhead, UK: Pira International.
Bajpai, P. (2001). Microbial degradation of pollutants in pulp mill effluents. *Adv. Appl. Microbiol.*, Vol.48, pp. 79–134.

Balcioglu, A.I. & Ferhan, C. (1999). Treatability of kraft pulp bleaching wastewater by biochemical and photocatalytic oxidation. *Water Sci. Technol.*, Vol. 40, No.1, pp.281–8.

Billings, R.M. & DeHaas, G.G. (1971). Pollution control in the pulp and paper industry. In: *Industrial Pollution Control Handbook*, Lund, H.F. (Ed.), McGraw-Hill, New York, pp. 18–28.

Borch-Du, A.; Anderson, R. & Opheim, B. (1997). Treatment of integrated newsprint mill wastewater in moving bed biofilm reactors. *Water Sci. Technol.*, Vol.35, No.2-3, pp.173–180.

Busbin, S.J. (1995). Fuel specifications – sludge. *Environmental Issues and Technology in the Pulp and Paper Industry. A TAPPI Press Anthology of Published Papers*, 1991–1994, pp. 349–353.

Cabral, F.; Vasconcelos, E.; Goss, M. & Cordovil, C. (1998). The value, use, and environmental impacts of pulp-mill sludge addition to forest and agricultural lands in Europe. *Environmental Reviews*, Vol.6, p. 55–64.

CANMET Energy Technology Centre. (2005). Pulp and paper sludge to energy – preliminary assessment of technologies. Canada

Carr, J.M. & Gay, C.L. (1997). Demonstrating the environmental benefit of land application of kraft mill biosolids. In: *Environmental Conference and Exhibit. TAPPI Proceedings, Book 2*, Minneapolis Convention Center, pp. 849–852.

Cecen, F.; Urban, W. & Haberl, R. (1992). Biological and advanced treatment of sulfate pulp bleaching *Water Sci. Technol.*, Vol.26, pp.435-444.

Chandra, R. (2001). Microbial decolourisation of pulp mill effluent in presence of nitrogen and phosphorous by activated sludge process. *J Environ Biol.*, Vol.22, No.1, pp.23–27.

Chernysh, A.; Liss, N.S. & Allen, G.D. (1992). A batch study of the aerobic and anaerobic removal of chlorinated organic compounds in an aerated lagoon. *Water Pollut. Res. J. Can.*, Vol.27, No.3, pp.621–38.

Cheremisinoff, N.P. & Rosenfeld, P.E. (1998). The best practices in the wood and paper industries, ISBN 978-0-08-096446-1, Elsevier, Burlington, USA.

Choudhury, S.; Sahoo, N.; Manthan, M. & Rohela R.S. (1998). Fungal treatment of pulp and paper mill effluents for pollution control. *J. Ind. Pollut. Control*, Vol. 14, No.1, pp.1–13.

Christmas, P. (2002). Building materials from deinking plant residues – a sustainable solution. In: *COST Workshop Managing Pulp and Paper Residues*, Barcelona, Spain.

Cingolani, L.; Ciccarelli, E.; Cossignani, M.; Tornari, Q. & Scarlata, V. (1994). Management of paper mill wastes: the role of filamentous microorganisms as indicators. *Water Sci. Technol.*, Vol. 29, pp. 185-188.

Daneault, C.; Leduc, C. & Valade, J.L. (1994). The use of xylanases in Kraft pulp bleaching: a review. *Tappi J.*, Vol. 77, pp. 125–131.

Davis, D.A.; Gounder, P.K. & Shelor, F.M. (1995). Combined cycle fluidized bed combustion sludges and other pulp and paper mill wastes to useful energy. *Environmental
Issues and Technology in the Pulp and Paper Industry. A TAPPI Press Anthology of Published Papers, 1991–1994, pp. 379–381.

De Pinho, M.N.; Minhalma, M.; Rosa, M.J. & Taborda, F. (2000). Integration of flotation/ultrafiltration for treatment of bleached pulp effluent. *Pulp Pap Can.*, Vol. 104, No. 4, pp. 50–54.

Demirbas, A. (2007). Progress and recent trends in biofuels. *Prog. Energ. Combust. Sci.*, Vol. 33, No. 1, pp. 1–18.

Demirbas, G.; Gökçay, C.F. & Dilek, F.B. (1999). Treatment of organic chlorine in pulping effluents by activated sludge. *Water Sci Technol.*, Vol. 40, No. 1, pp. 275–9.

Dilek, F.B. & Gökçay, C.F. (1994). Treatment of effluents from hemp-based pulp and paper industry: waste characterization and physicochemical treatability. *Water Sci. Technol.*, Vol. 29, No. 9, pp. 161–3.

Dube, M.; McLean, R., MacLatchy, D. & Savage, P. (2000). Reverse osmosis treatment: effects on effluent quality. *Pulp Pap Can.*, Vol. 101, No. 8, pp. 42–5.

Dufresne, R.; Liard, A. & Blum, S.M. (2001). Anaerobic treatment of condensates: at a kraft pulp and paper mill. *Water Environ Res.*, Vol. 73, No. 1, pp. 103–9.

Duraiswamy, K.; Warren, D.W. & Mansour, M.N. (1991). Indirect steam gasification of paper mill sludge waste. *TAPPI J.*, 137–143.

Duran, N.; Esposito, E.; Innincenich-Mei, L.H. & Canhos, P.V. (1994). A new alternative process for kraft E1 effluent treatment. *Biodegradation*, Vol. 5, pp. 13–9.

Eaton, D.; Chang, H.-M. & Kirk, T.K. (1980). Fungal decolorization of Kraft bleach effluents. *Tappi J.*, Vol. 63, pp. 103–106

EPA Office of Compliance Sector Notebook Project. Profile of the Pulp and Paper Industry. 2nd ed. Washington, November 2002.

Erisction, G. & Larsson, A. (2000). DNA A dots in perch (Perca fluviatillis) in coastal water pollution with bleached in pulp mill effluents. *Ecotoxicol Environ Saf.*, Vol. 46, pp. 167–73.

Eweiss, J.B.; Ergas, S.J.; Chang, D.P.Y. & Schroeder, E.D. (Eds.), (1998). *Bioremediation Principles*, ISBN 9780070577329, McGraw-Hill, Singapore

Falth, F. (2000). Ultrafiltration of E1 stage effluent for partial closure of the bleach plant. Proc. 86th PAPTAC annual meeting, Montreal, Quebec. Canada: Pulp and Paper Technical Association of Canada, p. B85.

FAOSTAT. - Forestry, Food and Agriculture Organization of the United Nations, February 2011. <http://faostat.fao.org/site/630/default.aspx>.

Fitzpatrick, J. & Seiler, G.S. (1995). Fluid bed incineration of paper mill sludge. Environmental Issues and Technology in the Pulp and Paper Industry. A TAPPI Press Anthology of Published Papers, 1991–1994, pp. 369–376.

Fio Rito, W.A. (1995). Destructive distillation. Paper mill sludge management alternative. Environmental Issues and Technology in the Pulp and Paper Industry. A TAPPI Press Anthology of Published Papers, 1991–1994, pp. 425–427.

Forster, C.F., 1996. Aspects of the Behaviour of Filamentous Microbes in Activated Sludge. *J. Inst. Water & Environ. Mange.*, Vol. 12, pp. 290-294.
Franta, J.R. & Wilderer, P.A. (1997). Biological treatment of paper mill wastewater by sequencing batch reactor technology to reduce residual organics. *Water Sci. Technol.*, Vol. 35, No.1, pp. 129–136.

Frederik, W.M.J.; Isa, K.; Lundy, J.R.; O’Connor, W.K.; Reis, K.; Scott, A.T.; Sinquefield, S.A.; Srircharoenchaikul, V. & Van Vooren, C.A. (1996). Energy and materials recovery from recycled paper sludge. *TAPPI J.*, Vol. 79, No. 6, pp. 123–131.

Freire, R.S.; Kunz, A. & Duran, N. (2000). Some chemical and toxicological aspects about paper mill effluent treatment with ozone. *Environ Technol.*, Vol. 21, pp. 717–721.

Fytili, D. & Zabaniotou, A. (2008). Utilization of sewage sludge in EU application of old and new methods – a review. *Renew. Sustain. Energy Rev.*, Vol. 12, No. 1, pp. 116–140.

Ganjidoust, H.; Tatsumi, K.; Yamagishi, T. & Gholian, R.N. (1997). Effect of synthetic and natural coagulant on lignin removal from pulp and paper wastewater. *Water Sci Technol.*, Vol. 35, No.2–3, pp. 291–296.

Gea, T.; Artola, A. & Sanchez, A. (2005). Composting of deinking sludge from the recycled paper manufacturing industry. *Bioresource Technol.*, Vol. 96, pp. 1161–1167.

Gokcay, F.C. & Dilek, F.B. (1994). Treatment of effluents from hemp-based pulp and paper industry biological treatability of pulping effluents. *Water Sci Technol.*, Vol. 29, No.9, pp. 165–168.

Gullichsen, J. (1991). Process internal measures to reduce pulp mill pollution load. *Water Sci. Technol.*, Vol. 24, No. 3-4, pp. 45–53.

Hackett, G.A.R.; Easton, C.A. & Duff, S.J.B. (1999). Composting of pulp and paper mill fly ash with wastewater treatment sludge. *Bioresource Technol.*, Vol. 70, No. 3, pp. 217–224.

Hamm, U.; Bobek, B. & Goyysching, L. (1991). Anaerobic treatment of wastewater from wastepaper converting paper-mills. *Papier*, Vol. 45, pp. 55-63.

Hansen, E.; Zadura, L; Frankowski, S. & Wachowicz, M. (1999). Upgrading of an activated sludge plant with floating biofilm carriers at Frantschach Swiecie S.A. to meet the new demands of year 2000. *Water Science and Technology*, Vol. 40, No. 11–12, pp. 207–214.

Hassan, M.M. & Hawkward, C.J. (2002). Decolourisation of aqueous dyes by sequential oxidation treatment with ozone and Fenton’s reagent. *Journal of Chemical Technology and Biotechnology*, Vol. 77, pp. 834-841.

Hickey, C.W. & Martin, M.L. (1995). Relative sensitivity of five benthic invertebrate species to reference toxicants and resin acid contaminated sediments. *Environ. Toxicol. Chem.*, Vol. 14, pp. 1401–1409.

Holland, R.M. (1997). A unique approach to solid waste reduction. In: *Environmental Conference and Exhibit. TAPPI Proceedings, Book 1*. Minneapolis Convention Center, pp. 489–490.

Holmberg, J. & Gustavsson, L. (2007). Chemical mechanical Biomass use in chemical and mechanical pulping with biomass-based energy supply. *Resources, Conservation and Recycling*, Vol. 52, pp. 331–350.

Hostachy, J.C.; Lenon, G.; Pisicchio, J.L.; Coste, C. & Legay, C. (1997). Reduction of pulp and paper mill pollution by ozone treatment. *Water Sci. Technol.*, Vol. 35, pp. 261-268.
Ince, O.; Kolukirik, M.; Cetecioglu, Z.; Eyice, O.; Tamerler, C. & Ince, B. (2007). Methanogenic and sulfate reducing bacterial population levels in a full-scale anaerobic reactor treating pulp and paper industry wastewater using fluorescence in situ hybridization. *Water Science and Technology*, Vol. 55, No. 10, pp. 183–191.

Jackson-Moss, C.A.; Maree, J.P. & Wotton, S.C. (1992). Treatment of bleach plant effluent with the biological granulated activated carbon process. *Water Sci. Technol.*, Vol. 26, No. 1–2, pp. 427–434.

Johnsen, K.; Tana, J.; Lehtinen, K.J.; Stuthridge, T.; Mattsson, K.; Hemming, J. & Carlberg, G.E. (1998). Experimental field exposure of brown trout to river receiving effluent from an integrated newsprint mill. *Ecotoxicology and Environmental Safety*, Vol. 40, pp. 184–193.

Jokela, J.; Rintala, J.; Oikari, A.; Reinkainen, O.; Mutka, K. & NyroÃNNen, T. (1997). Aerobic composting and anaerobic digestion of pulp and paper mill sludges. *Water Sci. Technol.*, Vol. 36, No. 11, pp. 181–188.

Kay, M. (2002). Development of waste management options for paper sludge. In: *4th Annual Dutch International Paper and Board Technology Event*. Pira International.

Kay, M. (2003). What to do with sludge? It’s best to determine local needs before choosing an option. *Pulp Pap. Int.*, Vol. 45, No. 8, pp. 19–21.

Kirk, T.K. & Jeffries, T.W. (1996). Roles for microbial enzymes in pulp and paper processing. In *Enzymes for Pulp and Paper Processing*; Jeffries, T.W., Viikari, L., Eds.; American Chemical Society Symposium, Series 655, 2–14.

Kirkpatrick, N.; Reid, I.D.; Ziomek, F. & Paice, M.G. (1990). Biological bleaching of hardwood Kraft pulp using Trametes (Coriolus) versicolor immobilized in polyurethane foam. *Appl. Microbiol. Biotechnol.*, Vol. 33, pp. 105–108.

Knudsen, L.; Pedersen, J.A. & Munck, J. (1994). Advanced treatment of paper mill effluents by a two-stage activated sludge process. *Water Sci Technol.*, Vol. 30, No. 3, pp. 173–181.

Kovacs, T.G. Martel, P.H. & Voss, R.H. (2002). Assessing the biological status of fish in a river receiving pulp and paper mill effluents. *Environ Pollut.*, Vol. 118, pp. 123–140.

Larson, E.; Consonni, S. & Kreutz, T. (2000). Preliminary economics of black liquor gasifier/gas turbine cogeneration at pulp and paper mills. *Journal of Engineering for Gas Turbines and Power*, Vol. 122, No. 3, pp. 255–261.

Leppanen, H. & Oikari, A. (1999). Occurrence of retene and resin acids in sediments and fish bile from lake receiving pulp and a paper mill effluents. *Environ. Toxicol. Chem.*, Vol. 18, No. 7, pp. 1498–505.

Lettinga, G.; Field, J.A.; Alvarez, R.S.; Vanlier, J.B. & Rintala, J.B. (1991). Future perspectives for the anaerobic treatment of forest industry wastewaters. *Water Sci. Technol.* Vol. 24, pp. 91-102.

Lindstrom-Seppa, P.; Hunskonen, S.; Kotelevtsev, S.; Mikkelson, P.; Rannen, T. & Stepanova, L. (1998). Toxicity and mutagenity of wastewaters from Baikalpsk pulp and paper mill: evaluation of pollutant contamination in lake Baikal. *Mar Environ Res.*, Vol. 46, No. 1–5, pp. 273–277.
Liss, S.N.; Bicho, P.A.; McFarlane, P.N. & Saddler, J.N. (1997). Microbiology and degradation of resin acids in pulp mill effluents: a mini review. *Can. J. Microbiol.*, Vol. 75, pp. 599–611.

Livernoche, D.; Jurasek L.; Desrochers, M.; Dorica J. & Veliky, I.A. (1983). Removal of color from Kraft mill wastewaters with the cultures of white-rot fungi and with immobilized mycelium of *Coriolus versicolor*. *Biotechnol. Bioeng.*, Vol. 25, pp. 2055–2065.

Magnus, E.; Carlberg, G.E. & Norske, H.H. (2001). TMP wastewater treatment including a biological high-efficiency compact reactor. *Nord. Pulp. Pap. Res. J.*, Vol. 15, No. 1, pp. 29–36.

Marten, W.L. & Daigger, G.T. (1997). Full-scale evaluation of factors affecting the performance of anoxic selectors. *Water Environ. Res.*, Vol. 69, pp. 1272-1281.

Mata-Alvarez, J.; MaceÁL, S. & LlabreÁLs, P. (2000). Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource Technol.*, Vol. 74, No. 1, pp. 3–16.

McDonough, T. (1992). Bleaching agents (pulp and paper). In: *Kirk-Othmer Encyclopedia of Chemical Technology*, Grayson, M., Ed., 4th ed.; John Wiley and Sons: New York, 301–311.

Mehta, V. & Gupta, J.K. (1992). Biobleaching eucalyptus Kraft pulp with *Phanerochaete chrysosporium* and its effect on paper properties. *Tappi J.*, Vol. 75, pp. 151–152.

Merrill, D.T.; Maltby, C.V.; Kahmark, K.; Gerhardt, M. & Melecer, H. (2001). Evaluating treatment process to reduce metals concentrations in pulp and paper mill wastewaters to extremely low values. *Tappi J.*, Vol. 84, No. 4, pp. 52.

Mohamed, M.; Matayun, M. & Lim, T.S. (1989). Chlorinated organics in tropical hardwood kraft pulp and paper mill effluents and their elimination in an activated sludge treatment system. *Pertanika*, Vol. 2, No. 3, pp. 387–394.

Monte, M.C.; Fuente, E.; Blanco, A. & Negro, C. (2009). Waste management from pulp and paper production in the European Union. *Waste Manag.*, Vol. 29, pp. 293-308.

Murthy, B.S.A.; Sihorwala, T.A.; Tilwankar, H.V. & Killedar, D.J. (1991). Removal of colour from pulp and paper mill effluents by sorption technique—a case study. *Indian J Environ Prot.*, Vol. 11, No. 5, p.360.

Nurmesniemi, H.; Poykio, R. & Keiski, R.L. (2007). A case study of waste management at the Northern Finnish pulp and paper mill complex of Stora Enso Veitsiluoto Mills. *Waste Management*, Vol. 27, pp. 1939-1948, ISSN 0956-053X

Oeller, H.J.; Daniel, I. & Weinberger, G. (1997). Reduction in residual COD in biologically treated paper mill effluents by means of combined Ozone and Ozone/UV reactor stages. *Water Sci. Technol.*, Vol. 35, No. 2–3, pp. 269–276.

Ooral, J.; Sikula, J.; Puchyr, R.; Hajny, Z.; Stehlík, P. & Bebar, L. (2005). Processing of waste from pulp and paper plant. *J. Cleaner Production.*, Vol. 13, pp. 509–515.

Owens, J.W.; Swanson, S.M. & Birkholz, D.A. (1994). Environmental monitoring of bleached kraft pulp mill chlorophenolic compounds in a Northern Canadian River system. *Chemosphere*, Vol. 29, No. 1, pp. 89–109.
Perez, M.; Torrades, F.; Domenech, X. & Peral, J. (2002). Treatment of bleaching Kraft mill effluents and polychlorinated phenolic compounds with ozonation. *J Chem Technol Biotechnol.*, Vol. 77, pp.891–897.

Poggi-Varaldo, H.M.; Estrada-Vazquez, C.; Fernandez-Villagomez, G. & Esparza-Garcia, F. (1996). Pretreatment of black liquor spills effluent. *Proceedings of the Industrial Waste Conference*, West Lafayette, USA, Vol. 51, pp. 651–61.

Pokhrel, D & Viraraghavan, T. (2004). Treatment of pulp and paper mill wastewater – a review. *Sci. Tot. Environ.*, Vol. 333, pp. 37-58.

Porteous, A. (2005). Why energy from waste incineration is an essential component of environmentally responsible waste management. *Waste Manag.*, Vol. 25, pp. 451–459.

Prendl, L. & Kroiss, H. (1998). Bulking sludge prevention by an aerobic selector. *Water Sci. Technol.*, Vol. 38, pp. 19-27.

Rajvaidya, N. & Markandey, D.K. (1998). *Advances in environmental science and technology: treatment of pulp and paper industrial effluent*. Ansari Road, New Delhi, India: A.P.H. Publishing.

Rohella, R.S.; Choudhury, S.; Manthan, M. & Murthy, J.S. (2001). Removal of colour and turbidity in pulp and paper mill effluents using polyelectrolytes. *Indian J Environ Health*, Vol. 43, No. 4, pp. 159-63.

Rouleau, G. & Sasseville, M. (1996). Waste reduction: a sound business decision. *Pulp Paper Canada*, Vol. 97, No. 12, pp. 114–116.

Sakurai, A.; Yamamoto, T.; Makabe, A.; Kinoshita, S. & Sakakibara, M. (2001). Removal of lignin in a liquid system by an isolated fungus. *J Chem Technol Biotechnol.*, Vol. 77, pp. 9–14.

Saunamaki, R. (1997). Activated sludge plants in Finland. *Water Sci. Technol.*, Vol. 35, No. 2–3, pp. 235–243.

Schnell, A.; Sabourin, M.J.; Skog, S. & Garvie, M. (1997). Chemical characterization and biotreatability of effluents from an integrated alkalineperoxide mechanical pulping/machine finish coated paper mill. *Water Sci Technol.*, Vol. 35, No. 2–3, pp. 7–14.

Schnell, A.; Steel, P.; Melcer, H.; Hodson, P.V. & Carey, J.H. (2000a). Enhanced biological treatment of bleached kraft mill effluents: I. Removal of chlorinated organic compounds and toxicity. *Water Res.*, Vol. 34, No. 2, pp. 493–500.

Schnell, A.; Steel, P.; Melcer, H.; Hodson, P.V. & Carey, J.H. (2000b). Enhanced biological treatment of bleached kraft mill effluents: II. Reduction of mixed function oxygenase (MFO) induction in fish. *Water Res.*, Vol. 34, No. 2, pp. 501–9.

Shawwa, A.R.; Smith, D.W. & Sego, D.C. (2001). Color and chlorinated organics removal from pulp wastewater using activated petroleum coke. *Water Res.*, Vol. 35, No. 3, pp. 745–749.

Slade, A.H.; Nicol, C.M. & Grigsby, J. (1999). Nutrients within integrated bleached Kraft mills: sources and behaviour in aerated stabilization basins. *Water Sci. Technol.*, Vol. 40, No. 11–12, pp.77-84.

Smook, G.A. (1992). *Handbook for Pulp & Paper Technologists*. Second edition. Vancouver: Angus Wilde Publications.
Pollution Prevention in the Pulp and Paper Industries

Stigsson, L. (1998). Chemrec Black Liquor Gasification. Proceedings, International Chemical Recovery Conference, Tampa, Florida, pp. 663–674.

Stuthridge, T.R. & Mcfarlane, P.N. (1994). Adsorbable organic halide removal mechanisms in a pulp and paper mill aerated lagoon treatment system. Water Sci Technol., Vol. 29, No. 5–6, pp. 195–208.

Sumathi, S. & Hung, Y.T. (2006). Treatment of pulp and paper mill wastes, In: Waste treatment in the process industries. Eds: Wang, L.K, Hung, Y.T., Lo, H.H., Yapijakis, C. pp. 453–497. Taylor&Francis. ISBN 0-8493-7233-X, USA.

Taseli, B. & Gokcay, C.F. (1999). Biological treatment of paper pulping effluents by using a fungal reactor. Water Sci Technol., Vol. 40, No. 11–12, pp. 93–09.

Thompson, G.; Swain, J.; Kay, M. & Forster, C. (2001). The treatment of pulp and paper mill effluent: a review. Bioresource Technology, Vol. 77, pp. 275–286.

Tong, Z.; Wada, S.; Takao, Y.; Yamagishi, T.; Hiroyasu, I. & Tamatsu, K. (1999). Treatment of bleaching wastewater from pulp-paper plants in China using enzymes and coagulants. J. Environ. Sci. Vol. 11, No. 4, pp. 480–484.

Torrades, F.; Peral, J.; Perez, M.; Domenech, X.; Hortal, J.A.G. & Riva, M.C. (2001). Removal of organic contaminants in bleached kraft effluents using heterogeneous photocatalysis and ozone. Tappi J. Vol. 84, No. 6, pp. 63.

US EPA. EPA office of compliance sector notebook project: profile of pulp and paper industry. Washington, DC 20460, USA: EPA/310-R-95-015; 1995.

Vass, K.K.; Mukopadhyay, M.K.; Mistra, K. & Joshi, H.C. (1996). Respiratory stresses in fishes exposed to paper and pulp wastewater. Environ Ecol., Vol. 14, No. 4, pp. 895–897.

Verenich, S.; Laari, A. & Kallas, J. (2000). Wet oxidation of concentrated wastewater of paper mills for water cycle closing. Waste Manage (N.Y.), Vol. 20, No. 4, pp. 287–293.

Verstraete, W. & Vandevivere, P. (1999). New and broader applications of anaerobic digestion. Crit. Rev. Environ. Sci. Technol. Vol. 29, No. 2, pp. 151–173.

Van Horn, J.T. (1997). Land Application of Solid Waste Stone Container Corporation. Environmental Conference and Exhibit. TAPPI Proceedings. Minneapolis Convention Center, pp. 845–848.

Wang, S.H.; Ferguson, J.F. & McCarthy, J.L. (1992). The decolorization and dechlorination of Kraft bleach plant effluent solutes by use of three fungi: Ganderma lacidum, Coriolus versicolor and Hericium erinaceum. Holzforschung, Vol. 46, pp. 219–233.

Welander, T.; Lofqvist, A. & Selmer, A. (1997). Upgrading aerated lagoons at pulp and paper mills. Water Sci Technol., Vol. 35, No. 2–3, pp. 117–122.

Yamamoto, S. (2001). Ozone treatment of bleached kraft pulp and waste paper. Japan Tappi J., Vol. 55, No. 4, pp. 90–97.

Yen, N.T.; Oanh, N.T.K.; Reutergard, L.B.; Wise, D.L. & Lan, L.T.T. (1996). An integrated waste survey and environmental effects of COGIDO, a bleached pulp and paper mill in Vietnam on the receiving water body. Global Environ Biotechnol., Vol. 66, pp. 349–364.

Zaidi, A.; Buisson, H.; Sourirajan, S. & Wood, H. (1992). Ultra-and nano-filtration in advanced effluent treatment schemes for pollution control in the pulp and paper industry. Water Sci Technol., Vol. 25, No. 10, pp. 263–276.
Zhou, H. & Smith, D.W. (1997). Process parameter development for ozonation of kraft pulp mill effluents. *Water Sci. Technol.*, Vol. 35, No. 2–3, pp. 251–259.
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.

How to reference
In order to correctly reference this scholarly work, feel free to copy and paste the following:

Bahar K. Ince, Zeynep Cetecioglu and Orhan Ince (2011). Pollution Prevention in the Pulp and Paper Industries, Environmental Management in Practice, Dr. Elzbieta Broniewicz (Ed.), ISBN: 978-953-307-358-3, InTech, Available from: http://www.intechopen.com/books/environmental-management-in-practice/pollution-prevention-in-the-pulp-and-paper-industries
