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ENVIRONMENTAL IMPACT OF PULP AND PAPER MILLS

Dan Gavrilescu[1*], Adrian Catalin Puitel[1], Gheorghe Dutuc[2], Grigore Craciun[2]

[1] *"Gheorghe Asachi" Technical University of Iasi, Faculty of Chemical Engineering and Environmental Protection, Department of Pulp, Paper and Fibers, 73 D. Mangeron Street, 700050 Iasi, Romania,*
[2] *SOMES Pulp and Paper Mill, 63 Bistritei Str., Dej, Romania*

Abstract

The paper aims to present the environmental impact of pulp and paper manufacturing and the most important production and control practices to minimizing this impact. The environmental consequences of manufacturing pulp and paper from pulping and bleaching processes are discussed in qualitative and quantitative terms. In these processes, sulfur compounds and nitrogen oxides are emitted to the air, and chlorinated and organic compounds and nutrients are discharged to the wastewaters. Large quantities of solid wastes and sludges are also generated.

Key words: air emissions, environment, liquid discharges, paper, pulp, solid wastes

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1. Introduction

Pulp and paper are manufactured from raw materials containing virgin cellulosic fibers on wood basis and recovered paper (Bobu and Gavrilescu, 2010). Another important source of cellulosic fibers originates from nonwood raw materials such cereal straw, reeds, esparto grass, jute, flax, and sisal (Gavrilescu et al., 2009; González-García et al., 2010; Puitel et al., 2011; Rodríguez et al., 2010).

The main steps in pulp and paper manufacture are: raw material preparation, (wood debarking and chipping), wood pulping; pulp bleaching; paper manufacturing. Pulp mills and paper mills may exist separately or as integrated operations. Pulp manufacturing starts with raw material preparation, which includes wood debarking, logs chipping and chips screening. In the chemical pulping process the fibers are liberated from the wood matrix as the lignin is removed by dissolving in the cooking liquor at a high temperature.

In the kraft pulp process the active cooking chemicals are sodium hydroxide (NaOH) and sodium sulphide (Na_2S).

As a result of the large amount of sodium hydroxide used, the pH value at the start of a cook is between 13 and 14 (Sixta et al., 2006). After cooking, pulp is washed and screened, and then is bleached (Fig. 1) (Puitel et al., 2010). The objective of pulp bleaching is to remove residual lignin remaining after cooking in order to enhance pulp brightness. Oxygen, hydrogen peroxide, ozone, peracetic acid, sodium hypochlorite, chlorine dioxide, chlorine, and other chemicals are used to transform lignin into a soluble form. An alkali, such as sodium hydroxide is necessary in the bleaching process to extract the alkali-soluble form of lignin. In modern pulp mills, oxygen is normally used in the first stage of bleaching. The trend is to avoid the use of any kind of chlorine chemicals and employ "Total Chlorine-Free" (TCF) bleaching (Bouiri and Amrani, 2010; Gavrilescu, 2010; Iosip et al., 2010; McKague and Carlberg, 1996; Takagi and Nakagawa, 2009).

The use of elemental chlorine for bleaching is not recommended. Only "Elemental Chlorine Free" (ECF) processes are acceptable, and from an environmental perspective, TCF bleaching is preferred (Craciun et al., 2010; Gavrilescu, 2010).

* Author to whom all correspondence should be addressed: e-mail: gda@ch.tuiasi.ro

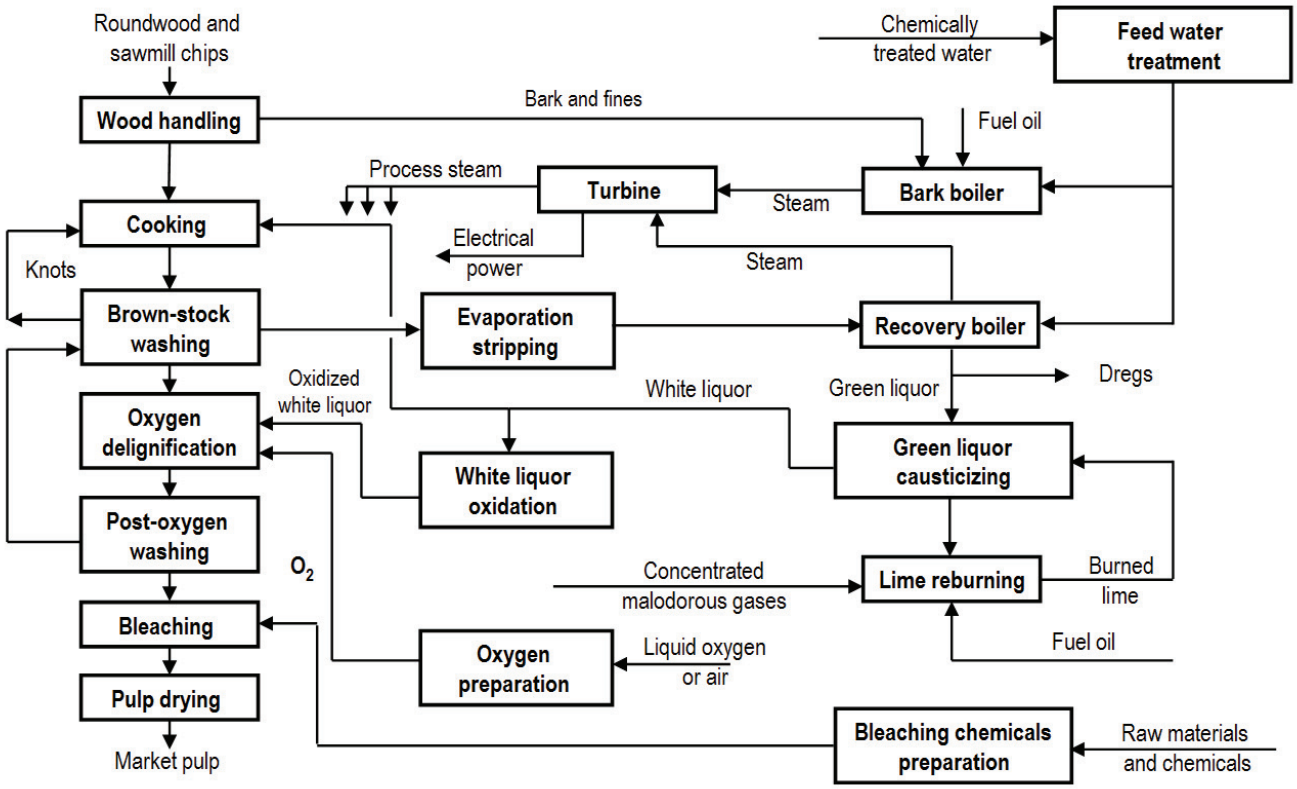

Fig. 1. Overview of the processes of a pulp mill

Paper is made from pulp by deposition of cellulosic fibers from a water suspension onto a moving forming fabric that also removes water from the pulp. The water remaining in the wet web is removed by pressing and then by drying. Chemical additives are added to impart specific properties to paper, and pigments may be added for color (Ek et al., 2009). Fig. 2 shows the papermaking process scheme.

In an integrated pulp and paper mill, there are various sources of pollution, as is presented in Table 1 (Hynninen, 1998). Table 1 shows that in each step of pulp and paper manufacture various pollutants are generated in air emissions, as liquid effluents and as solid wastes.

2. Pollutants quantities and characteristics

The environmental impact generated by the manufacture of pulp and paper results mainly from the wood pulping and pulp bleaching. In pulping processes, sulfur compounds and nitrogen oxides are emitted to the air, and during pulp bleaching chlorinated and organic compounds and nutrients are discharged to the wastewaters. The environmental impact of paper manufacture is lower, wastewater discharge being the most important source of pollution.

2.1. Air emissions

Chemical pulping is the main source for air emissions in the pulp and paper industry, mainly due the fact that chemical pulping is operating at higher temperatures.

Table 1. Pollution sources in producing pulp and paper (adapted from Hynninen, 1998)

Main imput	***Process step***	***Pollutants***
Raw material (wood)	Wood preparation	Solid wastes Wastewater
Chemicals Energy	Pulp manufacture	Air emissions Used water
Process water	Pulp washing and screening	Dissolved material Residual chemicals Wastewater
Chemicals Energy	Pulp bleaching	Air emissions Dissolved material Residual chemicals Wastewater
Energy	Pulp drying	Air emissions
Energy Water Chemicals	Paper manufacture	Solid wastes Dissolved material Residual chemicals Wastewater

Within chemical pulping, the origins for air emissions can be found from the chips storage, cooking, pulp washing, bleaching, bleaching chemicals preparation, chemicals recovery, evaporation plant, bark furnace, recovery and auxiliary boilers, white liquor preparation, the lime kiln, storage tanks and in case of market pulp, pulp drying process. Table 2 shows the process stages and the generated emissions.

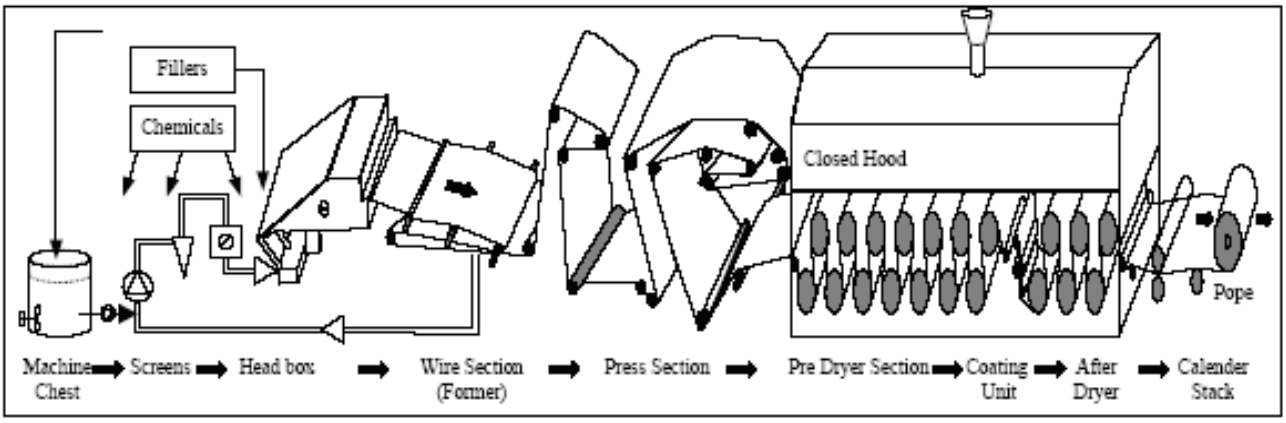

Fig. 2. Papermaking process

Major source of air emissions in a pulp mill is recovery boiler (Table 3). These emissions are mainly represented by sulfur dioxide but there are also particulate emissions, nitrogen oxides and malodorous compounds. NOx emissions depend on nitrogen content in the black liquor (dry solids content) and support fuel rate used in recovery boiler.

Table 2. Air emissions in a kraft pulp mill (Biermann, 1996)

Process	*Emissions*
Energy generation	Particulates, SO_2, NOx
Recovery boiler	Particulates, SO_2, TRS
Lime kiln	Particulates, TRS
Burning malodorous gases	SO_2, TRS
Pulp bleaching	ClO_2, VOC (methanol, chloroform)
Others	VOC

Steam and electricity generating units using coal or fuel oil emit fly ash, sulfur oxides, and nitrogen oxides (Table 3). Coal burning in a power boiler can emit fly ash at the rate of 100 kg/t of pulp (Meij, 2000).

2.2. Liquid effluents

Pulp and paper manufacture represents a large consumer of process water. Wastewater is discharged at a rate of 20–100 cubic meters per metric ton of product (Gavrilescu et al., 2008). Wastewater is high in biochemical oxygen demand (BOD), total suspended solids, chemical oxygen demand (COD), nitrogen and phosphorus (Table 4). In addition, chlorinated organic compounds are generated, which include dioxins, furans, and other absorbable organic halides (AOX), that represent 0–4 kg/t of pulp.

In producing chemical pulp, effluent rate represents 20-50 m^3/t of pulp, which contains up to 15 kg/t suspended solids. Wastewater from chemical pulping contains 5–20 kg of BOD/t of pulp and 20-40 kg of COD/t. The main source of nutrients, nitrogen, and phosphorus compounds is raw material used in pulp manufacture.

Table 3. Average emissions to the atmosphere from kraft pulp mill (Genco and Heiningen, 2001)

Source of emission	*Total gaseous S kg/t*	*NOx kg/t*	*Particulates kg/t*
Recovery boiler	0.01-2.0	0.8-1.8	0.2-1.8
Lime kiln	0.07-0.7	0.02-0.6	0.02-0.9
Bark boiler	0.02-0.06	0.03-0.2	0.03-0.3
Digesters	0.01-2	-	-
Total emissions from pulp mill	0.04-4.1	0.85-2.60	0.25-3.1

Paper manufacture generates 15-40 m^3 of wastewater per tone of paper depending on the paper grade. Wastewaters resulting from pulp and paper manufacture must be processed in a wastewater treatment plant.

2.3. Solid waste

Pulp manufacture generates large quantities of solid wastes. Solid waste includes wood waste (mainly bark), sodium salts from recovery boiler, pulp screening rejects and dregs and gritt from causticizing plant. In addition, ashes are generated during burning of wood wastes and sludges. An overall view of the solid waste rates in a pulp mill is presented in Table 5 (Gavrilescu, 2004).

Wood waste represents the most important residue of a pulp mill, and they are represented by bark, sawdust and other wood fragments. Wood wastes are incinerated in a boiler to produce energy for the mill. Pulp screening rejects (knots) are mixed with wood residue and are burned in the same boiler. Dregs and gritt generated in the causticizing plant (15-40 kg/t of pulp) are landfilled (Gavrilescu, 2005).

Table 4. Effluent loads from the manufacture of pulp and paper (European Commission, 2001)

Product	*Effluent m^3/t*	*Suspended solids kg/t*	*BOD kg/t*	*COD kg/t*	*N g/t*	*P g/t*
Pulp manufacture						
Unbleached	20-40	12-15	5-10	20-30	200-400	80
Bleached	30-50	10-15	14-18	25-40	400-600	100
Paper manufacture						
Packaging	15-30	5-10	2-4	4-8	100-200	15
Newsprint	10-25	5-10	1-3	2-4	10-20	5
Sanitary	20-40	5-10	1-3	3-6	50-80	8

Table 5. Waste generation in a sulfate pulp mill

Solid wastes	*Yield, kg/t pulp*
A. Wood wastes:	
1. Sawdust coming from the slasher deck	10-30
2. Bark falling from the debarking drum	100-300
3. Pins and fines from chip screening	50-100
4. Wood waste from woodyard	0-20
Total A:	160 – 450
B. Knots from pulp deknotting	25-70
C. Sodium salts from recovery boiler	5-15
D. Dregs and grit from causticizing:	
1. Dregs	5-10
2. Grit	10-30
Total D:	15-40
Total A, B, C, D:	**220-615**

The second residue as importance of the pulp and paper mill is the sludge generated during wastewater treatment. The volume of sludge varies greatly according to the paper grade being manufactured.

Pulp production generates 20-25 kg/t sludge and paper manufacture produces another 5-10 kg/t. If the paper is produced from recovered paper, sludge quantity rise up to roughly 150 kg/t of paper. After dewatering, sludge is burned (Gavrilescu, 2008).

3. Pollution prevention and control

The most significant environmental issues are the discharge of chlorine-based organic compounds from bleaching and of other toxic organics. The unchlorinated material is essentially black liquor that has escaped the mill recovery process.Some mills are approaching 100% recovery.

Industry developments demonstrate that total chlorine-free bleaching is feasible for many pulp and paper products but cannot produce certain grades of paper. The adoption of these modern process developments, wherever feasible, is encouraged.

Pollution prevention programs should focus on reducing wastewater discharges and on minimizing air emissions. Process recommendations may include the following (Gavrilescu et al., 2008; EIPPCB, 2001; World Bank, 1996):

a. Use energy-efficient pulping processes wherever feasible. Acceptability of less bright products should be promoted.

b. Minimize the generation of effluents through process modifications and recycle wastewaters, aiming for total recycling.

c. Reduce effluent volume and treatment requirements by using dry instead of wet debarking; recover pulping chemicals by black liquor evaporation and burning of black liquor in a recovery furnace; recover cooking chemicals by recausticizing of green liquor; use high-efficiency pulp washing and bleaching equipments.

d. Reduce bleaching requirements by process design and operation. Use the following measures to reduce emissions of chlorinated compounds to the environment: before bleaching, reduce the lignin content in the pulp by extended cooking and by oxygen delignification; optimize pulp washing prior to bleaching; use TCF or ECF bleaching systems; use oxygen, ozone, hydrogen peroxide, peracetic acid, or enzymes as substitutes for chlorine-based bleaching chemicals; recover and incinerate maximum material removed from pulp mill.

e. Minimize sulfur emissions to the atmosphere by using a modern low-odor black liquor recovery boiler.

f. Minimize unplanned discharges of wastewater and black liquor, caused by equipment failures, human error, and faulty maintenance procedures, by training operators, establishing good operating

practices; provide sumps and other facilities to recover liquor spills from the process.

4. Conclusions

1. The environmental impact of pulp and paper manufacture results mainly from wood pulping and pulp bleaching processes. The pollutants are represented by sulfur compounds and nitrogen oxides that are emitted to the air, and by bleaching chlorinated and organic compounds and nutrients that are discharged to the wastewaters.

2. Pulp and paper manufacture need a large volume of process water. Wastewaters are discharged at a rate of 20–100 cubic meters per ton of product, and these are high in biochemical oxygen demand (BOD), total suspended solids, chemical oxygen demand (COD), nitrogen and phosphorus.

3. Wood wastes and sludge represent the most important residues of a pulp and paper mill. These wastes are used to obtain energy by their burning in a suitable boiler.

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