Pulp and Paper Mills

Industry Description and Practices

Pulp and paper are manufactured from raw materials containing cellulose fibers, generally wood, recycled paper, and agricultural residues. In developing countries, about 60% of cellulose fibers originate from nonwood raw materials such as bagasse (sugar cane fibers), cereal straw, bamboo, reeds, esparto grass, jute, flax, and sisal. This document addresses environmental issues in pulp and paper manufacturing with unit production capacities greater than 100 metric tons per day (tpd).

The main steps in pulp and paper manufacturing are raw material preparation, such as wood debarking and chip making; pulp manufacturing; pulp bleaching; paper manufacturing; and fiber recycling. Pulp mills and paper mills may exist separately or as integrated operations. Manufactured pulp is used as a source of cellulose for fiber manufacture and for conversion into paper or cardboard.

Pulp manufacturing starts with raw material preparation, which includes debarking (when wood is used as raw material), chipping, and other processes such as depithing (for example, when bagasse is used as the raw material). Cellulosic pulp is manufactured from the raw materials, using chemical and mechanical means.

The manufacture of pulp for paper and cardboard employs mechanical (including thermomechanical), chemimechanical, and chemical methods. Mechanical pulping separates fibers by such methods as disk abrasion and billeting. Chemimechanical processes involve mechanical abrasion and the use of chemicals. Thermomechanical pulps, which are used for making products such as newsprint, are manufactured from raw materials by the application of heat, in addition to mechanical operations. Chemimechanical pulping and chemithermomechanical pulping (CTMP) are similar but use less mechanical energy, softening the pulp with sodium sulfite, carbonate, or hydroxide.

Chemical pulps are made by cooking (digesting) the raw materials, using the kraft (sulfate) and sulfite processes. Kraft processes produce a variety of pulps used mainly for packaging and high-strength papers and board. Wood chips are cooked with caustic soda to produce brownstock, which is then washed with water to remove cooking (black) liquor for the recovery of chemicals and energy. Pulp is also manufactured from recycled paper.

Mechanical pulp can be used without bleaching to make printing papers for applications in which low brightness is acceptable—primarily, newsprint. However, for most printing, for copying, and for some packaging grades, the pulp has to be bleached. For mechanical pulps, most of the original lignin in the raw pulp is retained but is bleached with peroxides and hydrosulfites. In the case of chemical pulps (kraft and sulfite), the objective of bleaching is to remove the small fraction of the lignin remaining after cooking. Oxygen, hydrogen peroxide, ozone, peracetic acid, sodium hypochlorite, chlorine dioxide, chlorine, and other chemicals are used to transform lignin into an alkali-soluble form. An alkali, such as sodium hydroxide, is necessary in the bleaching process to extract the alkali-soluble form of lignin. Pulp is washed with water in the bleaching process.

In modern 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. TCF processes allow the bleaching effluents to be fed to the recovery boiler for steam generation; the steam is then used to generate electricity, thereby reducing the amount of pollutants discharged. Elemental chlorine-free (ECF) processes, which use chlorine dioxide, are required for bleaching certain grades of pulp.

The use of elemental chlorine for bleaching is not recommended. Only ECF processes are acceptable, and, from an environmental perspective, TCF processes are preferred.

The soluble organic substances removed from the pulp in bleaching stages that use chlorine or chlorine compounds, as well as the substances removed in the subsequent alkaline stages, are chlorinated. Some of these chlorinated organic substances are toxic; they include dioxins, chlorinated phenols, and many other chemicals. It is generally not practical to recover chlorinated organics in effluents, since the chloride content causes excessive corrosion.

The finished pulp may be dried for shipment (market pulp) or may be used to manufacture paper on site (in an "integrated" mill).

Paper and cardboard are made from pulp by deposition of fibers and fillers from a fluid suspension onto a moving forming device that also removes water from the pulp. The water remaining in the wet web is removed by pressing and then by drying, on a series of hollow-heated cylinders (for example, calender rolls). Chemical additives are added to impart specific properties to paper, and pigments may be added for color.

Waste Characteristics

The significant environmental impacts of the manufacture of pulp and paper result from the pulping and bleaching processes. In some processes, sulfur compounds and nitrogen oxides are emitted to the air, and chlorinated and organic compounds, nutrients, and metals are discharged to the wastewaters.

Air Emissions

In the kraft pulping process, highly malodorous emissions of reduced sulfur compounds, measured as total reduced sulfur (TRS) and including hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide, are emitted, typically at a rate of 0.3–3 kilograms per metric ton (kg/t) of air-dried pulp (ADP). (Air-dried pulp is defined as 90% bone-dry fiber and 10% water.) Other typical generation rates are: particulate matter, 75–150 kg/t; sulfur oxides, 0.5–30 kg/t; nitrogen oxides, 1–3 kg/t; and volatile organic compounds (VOCs), 15 kg/t from black liquor oxidation. In the sulfite pulping process, sulfur oxides are emitted at rates ranging from 15 kg/t to over 30 kg/t. Other pulping processes, such as the mechanical and thermomechanical methods, generate significantly lower quantities of air emissions.

Steam- and electricity-generating units using coal or fuel oil emit fly ash, sulfur oxides, and nitrogen oxides. Coal burning can emit fly ash at the rate of 100 kg/t of ADP.

Liquid Effluents

Wastewaters are discharged at a rate of 20–250 cubic meters per metric ton (m^3/t) of ADP. They are high in biochemical oxygen demand (BOD), at 10–40 kg/t of ADP; total suspended solids, 10–50 kg/t of ADP; chemical oxygen demand (COD), 20–200 kg/t of ADP; and chlorinated organic compounds, which may include dioxins, furans, and other adsorbable organic halides, AOX, at 0–4 kg/t of ADP.

Wastewater from chemical pulping contains 12–20 kg of BOD/t of ADP, with values of up to 350 kg/t. The corresponding values for mechanical pulping wastewater are 15–25 kg BOD/t of ADP. For chemimechanical pulping, BOD discharges are 3 to 10 times higher than those for mechanical pulping. Pollution loads for some processes, such as those using nonwood raw materials, could be significantly different.

Phosphorus and nitrogen are also released into wastewaters. The main source of nutrients, nitrogen, and phosphorus compounds is raw material such as wood. The use of peroxide, ozone, and other chemicals in bleaching makes it necessary to use a complexing agent for heavy metals such as manganese.

Solid Wastes

The principal solid wastes of concern include wastewater treatment sludges (50–150 kg/t of ADP). Solid materials that can be reused include waste paper, which can be recycled, and bark, which can be used as fuel. Lime sludge and ash may need to be disposed of in an appropriate landfill.

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:

- Use energy-efficient pulping processes wherever feasible. Acceptability of less bright products should be promoted. For less bright products such as newsprint, thermomechanical processes and recycled fiber may be considered.
- Minimize the generation of effluents through process modifications and recycle wastewaters, aiming for total recycling.
- Reduce effluent volume and treatment requirements by using dry instead of wet debarking; recovering pulping chemicals by concentrating black liquor and burning the concentrate in a recovery furnace; recovering cooking chemicals by recausticizing the smelt from the recovery furnace; and using high-efficiency washing and bleaching equipment.
- Minimize unplanned or nonroutine discharges of wastewater and black liquor, caused by equipment failures, human error, and faulty maintenance procedures, by training operators, establishing good operating practices, and providing sumps and other facilities to recover liquor losses from the process.
- 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 (Kappa number of 10) for hardwood by extended cooking and by oxygen delignification under elevated pressure; optimize pulp washing prior to bleaching; use TCF or at a minimum, ECF bleaching systems; use oxygen, ozone, peroxides (hydrogen peroxide), peracetic acid, or enzymes (cellulose-free xylanase) as substitutes for chlorine-based bleaching chemicals; recover and incinerate maximum material removed from pulp bleaching; where chlorine bleaching is used, reduce the chlorine charge on the lignin by controlling pH and by splitting the addition of chlorine.
- Minimize sulfur emissions to the atmosphere by using a low-odor design black liquor recovery furnace.
- Use energy-efficient processes for black liquor chemical recovery, preferably aiming for a high solid content (say, 70%).

Target Pollution Loads

Implementation of cleaner production processes and pollution prevention measures can yield both economic and environmental benefits. The following production-related targets can be achieved by measures such as those described above. The values relate to the production processes before the addition of pollution control measures.

For air emissions, the target is 1.5 kg NO_x per ton for both kraft and sulfite processes; for mechanical and chemimechanical processes used in newsprint manufacture, 260 nanograms per joule (ng/J) of NO_x for coal; 130 ng/J for oil; and 86 ng/J for gas used as fuel.

Wastewater generation rates should not exceed 50 m^3/t of ADP, and levels of 20 m^3/t of ADP (or product) should be targeted. For paper mills, effluent discharges should be less than 5 m^3/t of ADP. Wherever feasible, use a total wastewater recycling system, along with a TCF pulp-bleaching system, and incinerate bleaching effluents in the recovery boiler. As a minimum, use chlorine dioxide as a substitute for elemental chlorine in pulp bleaching.

Treatment Technologies

Sulfur oxide emissions are scrubbed with slightly alkaline solutions. The reduced sulfur-compounds gases are collected using headers, hoods, and venting equipment. Condensates from the digester relief condenser and evaporation of black liquor are stripped of reduced sulfur compounds. The stripper overhead and noncondensable are incinerated in a lime kiln or a dedicated combustion unit. Approximately, 0.5 kg sulfur per ton of pulp for the kraft process and 1.5 kg sulfur per ton for the sulfite process are considered acceptable emissions levels. Electrostatic precipitators are used to control the release of particulate matter into the atmosphere.

Wastewater treatment typically includes (a) neutralization, screening, sedimentation, and floatation / hydrocycloning to remove suspended solids and (b) biological / secondary treatment to reduce the organic content in wastewater and destroy toxic organics. Chemical precipitation is also used to remove certain cations. Fibers collected in primary treatment should be recovered and recycled. A mechanical clarifier or a settling pond is used in primary treatment. Flocculation to assist in the removal of suspended solids is also sometimes necessary. Biological treatment systems, such as activated sludge, aerated lagoons, and anaerobic fermentation, can reduce BOD by over 99% and achieve a COD reduction of 50% to 90%. Tertiary treatment may be performed to reduce toxicity, suspended solids, and color.

Solid waste treatment steps include dewatering of sludge and combustion in an incinerator, bark boiler, or fossil-fuel-fired boiler. Sludges from a clarifier are dewatered and may be incinerated; otherwise, they are landfilled.

The following levels can be achieved by adopting good industrial practices: COD, 35 kg / t (aim for 15 kg / t); AOX, 2 kg / t of ADP (aim for 0.2 kg / t); total phosphorus, 0.02 kg / t; total nitrogen, 0.15 kg / t; and solid waste generation, 150 kg / t of ADP.

Emissions Guidelines

Emissions levels for the design and operation of each project must be established through the environmental assessment (EA) process on the basis of country legislation and the *Pollution Prevention and Abatement Handbook*, as applied to local conditions. The emissions levels selected must be justified in the EA and acceptable to the World Bank Group.

The following guidelines present emissions levels normally acceptable to the World Bank Group in making decisions regarding provision of World Bank Group assistance. Any deviations from these levels must be described in the World Bank Group project documentation. The emissions levels given here can be consistently achieved by well-designed, well-operated, and well-maintained pollution control systems.

The guidelines are expressed as concentrations to facilitate monitoring. Dilution of air emissions or effluents to achieve these guidelines is unacceptable.

All of the maximum levels should be achieved for at least 95% of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours.

Air Emissions

Air emissions from pulp and paper manufacturing should achieve the levels presented in Table 1.

Liquid Effluents

Liquid effluents from pulp and paper manufacturing should achieve the levels presented in Table 2.

Solid Wastes

Solid wastes should be sent to combustion devices or disposed of in a manner that avoids odor generation and the release of toxic organics to the environment.

Table 1. Air Emissions from Pulp and Paper Manufacturing

(milligrams per normal cubic meter)

Parameter	*Maximum value*
PM[a]	100 for recovery furnace
Hydrogen sulfide	15 (for lime kilns)
Total sulfur emitted	
Sulfite mills	1.5 kg/t ADP
Kraft and other	1.0 kg/t ADP
Nitrogen oxides	2 kg/t ADP

a. Where achieving 100 mg/Nm^3 is not cost-effective, an emissions level up to 150 mg/Nm^3 is acceptable. Air emissions requirements are for dry gas, at 0°C and 1 atmosphere.

Table 2. Liquid Effluents from New Pulp and Paper Manufacturing

Parameter	*Maximum value*
pH	6–9
COD	300 mg/l and 15 kg/t for kraft and CTMP pulp mills; 700 mg/l and 40 kg/t for sulfite pulp mills; 10 mg/l and 5 kg/t for mechanical and recycled fiber pulp; 250 mg/l for paper mills
AOX	40 mg/l and 2 kg/t (aim for 8 mg/l and 0.4 kg/t for retrofits and for 4 mg/l and 0.2 kg/t for new mills) and 4 mg/l for paper mills
Total phosphorus	0.05 kg/t
Total nitrogen	0.4 kg/t
Temperature	< 3°C[a]

Note: Molecular chlorine should not be used in the process. Effluent requirements are for direct discharge to surface waters.

a. The effluent should not result in a temperature increase of more than 3° C at the edge of the zone where initial mixing and dilution take place. Where the zone is not defined, use 100 meters from the point of discharge.

Ambient Noise

Noise abatement measures should achieve either the levels given below or a maximum increase in background levels of 3 decibels (measured on the A scale) [dB(A)]. Measurements are to be taken at noise receptors located outside the project property boundary.

	Maximum allowable log equivalent (hourly measurements), in dB(A)	
Receptor	*Day (07:00–22:00)*	*Night (22:00–07:00)*
Residential, institutional, educational	55	45
Industrial, commercial	70	70

Monitoring and Reporting

Frequent sampling may be required during start-up and upset conditions. Once a record of consistent performance has been established, sampling for the parameters listed in this document should be as described below.

Monitoring of air emissions for opacity (maximum level of 10%) should be continuous; daily monitoring should be conducted for hydrogen sulfide and annual monitoring for other pollutants. Liquid effluents should be monitored for the listed parameters at least daily, or more often when there are significant process changes.

Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Records of monitoring results should be kept in an acceptable format. The results should be reported to the responsible authorities and relevant parties, as required.

Key Issues

The key production and control practices that will lead to compliance with emissions guidelines can be summarized as follows:

- Prefer dry debarking processes.
- Prevent and control spills of black liquor.
- Prefer total chlorine-free processes, but at a minimum, use elemental chlorine-free bleaching systems.
- Reduce the use of hazardous bleaching chemicals by extended cooking and oxygen delignification.
- Aim for zero-effluent discharge where feasible. Reduce wastewater discharges to the extent feasible. Incinerate liquid effluents from the pulping and bleaching processes.
- Reduce the odor from reduced sulfur emissions by collection and incineration and by using modern, low-odor recovery boilers fired at over 75% concentration of black liquor.
- Dewater and properly manage sludges.
- Where wood is used as a raw material to the process, encourage plantation of trees to ensure sustainability of forests.

Sources

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