Environmental Guidelines for

Pulp and Paper Mills

Industry Description and Practices

Pulp and paper are manufactured from raw materials containing cellulose fibers, generally from wood, recycled paper, and agricultural residues. In developing countries, about 60% of cellulose fibers originate from non-wood raw materials such as bagasse, cereal straws, 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: (a) raw material preparation (such as debarking of wood and chip making); (b) pulp manufacturing; (c) pulp bleaching, (d) paper manufacturing; and (e) fibers 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 (where wood is used as raw material), chipping, and other processes such as depithing (for example, where 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 uses mechanical (including thermo-mechanical), chemi-mechanical, and chemical methods. Mechanical pulping separates fibers by mechanical methods (such as disk abrasion or billeting). Chemi-mechanical processes involve mechanical abrasion, and the use of chemicals. Thermo-mechanical 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. Chemi-mechanical and chemi-thermo-mechanical pulping are similar, but use less mechanical energy while softening 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. Woods chips are cooked with caustic soda to produce brownstock. This 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 for printing papers, primarily newsprint, where low brightness is acceptable. However, for most printing, copying and some packaging grades, the pulp has to be bleached. For mechanical pulps, most of the original lignin in the raw pulp is retained, but 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, so called total chlorine free (TCF) bleaching. TCF processes allow the bleaching effluents to be fed to the recovery boiler for steam generation which is then also used to generate electricity, thereby reducing the amount of pollutants discharged. However, elemental chlorine free (ECF) processes (using chlorine dioxide) are required for bleaching certain grades of pulp. The use of elemental chlorine for bleaching is not recommended. Only elemental chlorine free (ECF) process are acceptable but total chlorine free (TCF) processes are preferable (from an environmental perspective). The soluble organic substances removed from the pulp in bleaching stages using chlorine or chlorine compounds, and also the substances removed in the subsequent alkaline stages, are chlorinated. Some of these chlorinated organic substances are toxic, and 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 (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 which also removes water from the pulp. The water remaining in the wet web is removed by pressing, and finally by drying, on a series of hollow-heated cylinders (for example, calendar rolls). Chemical additives are added to impart specific properties to paper, and pigments may be added to impart 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) 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 to over 30 kg/t.

Other pulping processes such as mechanical and thermo-mechanical generate significantly lower quantities of air emissions.

Steam and electricity generating units using coal or fuel oil generate fly ash, sulfur oxides, and nitrogen oxides emissions. 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 (m³/t) of ADP. They are high in biochemical oxygen demand (BOD₅), 10-40 kg/t of ADP; total suspended solids, 10-50 kg/t of ADP; chemical oxygen demand (COD), 20-200 kg/t of product; and chlorinated organic compounds (which may include dioxins, furans, and others, collectively referred to as adsorbable organic halides or AOX) at a rate of zero to 4 kg/t of ADP.

Waste water from chemical pulping contains 12-20 kg of BOD₅/t of ADP with values of up to 350 kg/t. The corresponding values for mechanical pulping wastewater are 15-25 kg BOD₅/t of ADP. For chemical pulping, BOD₅ discharges are three to ten times higher than those for mechanical pulping. Pollution loads of some processes such as those using non-wood 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

Major solid wastes of concern include wastewater treatment sludges (50-150 kg/t of ADP). Solid materials which 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 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 have taken place that demonstrate that total chlorine free (TCF) 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 the wastewater discharges and on minimizing air emissions. Process changes 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, TMP process and recycled fiber may be considered.
- Minimize the generation of effluents through process modifications and recycle (aim for total recycle) of wastewaters. Use the following to reduce effluent volume and treatment guidelines:
  - Use dry instead of wet debarking.
  - Recover pulping chemicals by concentrating black liquor, burning the concentrate in a recovery furnace, and recover cooking chemicals by recausticizing the smelt from the recovery furnace.
- Use high-efficiency washing and bleaching equipment.
  - Unplanned or non-routine discharges of wastewater and black liquor due to equipment failures, human error, and maintenance procedures should be minimized by operator training, establishing good operating practices, and the provision of 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:
    - Reduce the lignin content in the pulp (Kappa number of 10) for hardwood prior to bleaching by extended cooking and with oxygen delignification under elevated pressure.
    - Optimize pulp washing prior to bleaching.
    - Use total chlorine free (TCF) or at a minimum, elemental chlorine free (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.
  - Energy efficient processes for black liquor chemical recovery should be used preferably with high solid content (say 70 percent).

Target Pollution Loads

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

For air emissions, 1.5 kg NO\textsubscript{x}/t for both kraft and sulfite processes. For mechanical and chemi-mechanical processes used in newsprint manufacture, 260 nanograms per Joule (ng/J) of NO\textsubscript{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\textsuperscript{3}/t of ADP and levels of 20 m\textsuperscript{3}/t of ADP (or product) should be targeted. For paper mills, effluent discharges should be less than 5 m\textsuperscript{3}/t of ADP. Wherever feasible, use a total wastewater recycling system along with a total chlorine-free pulp bleaching system and incinerate bleaching effluents in the recovery boiler. As a minimum, use chlorine dioxide as a substitute for elemental chlorine for pulp bleaching system.

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 non-condensable are incinerated in a lime kiln or a dedicated combustion unit. Approximately, 0.5 kg sulfur/t of pulp for kraft process and 1.5 kg sulfur/t for sulfite process are considered acceptable emission levels. Electrostatic precipitators are used to control the release of particulate matter to the atmosphere.

Wastewater treatment typically includes neutralization, screening, sedimentation, and floatation/hydrocycloning to remove suspended solids, and biological/secondary treatment to reduce the organic content in wastewater and destroy toxic organics. Chemical precipitation is also used to remove certain cations. Recover and recycle fibers collected in primary treatment. A mechanical clarifier or a setting 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\textsubscript{5} 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 a 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 of 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.

Emission Guidelines

Emission levels for the design and operation of each project must be established through the Environmental Assessment (EA) process, based on country legislation and the Pollution Prevention and Abatement Handbook as applied to local conditions. The emission levels selected must be justified in the EA and acceptable to MIGA.

The following guidelines present emission levels normally acceptable to the World Bank Group in making decisions regarding provision of World Bank Group assistance, including MIGA guarantees; any deviations from these levels must be described in the project documentation.

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 following:

**Air Emissions from Pulp and Paper Manufacturing**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/Nm$^3$</td>
</tr>
<tr>
<td>Particulate matter*</td>
<td>100 for recovery furnace</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>15 (for lime kilns)</td>
</tr>
<tr>
<td>Total sulfur emitted</td>
<td></td>
</tr>
<tr>
<td>• Sulfite mills</td>
<td>1.5 kg/t ADP</td>
</tr>
<tr>
<td>• Kraft and other</td>
<td>1.0 kg/t ADP</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>2 kg/t ADP</td>
</tr>
</tbody>
</table>

*Where achieving 100 mg/Nm$^3$ is not cost-effective, an emission level up to 150 mg/Nm$^3$ is acceptable. N refers to normal condition. Air emission requirements are for dry gas, at 0°C and 1 atmosphere.

**Liquid Effluents**

Liquid effluents from pulp and paper manufacturing should achieve the following levels:

**Liquid Effluents from New Pulp and Paper Manufacturing***

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/L</td>
</tr>
<tr>
<td>pH</td>
<td>6-9</td>
</tr>
<tr>
<td>COD</td>
<td>300 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; and 250 mg/L (for paper mills)</td>
</tr>
<tr>
<td>AOX</td>
<td>40 mg/L and 2 kg/t (aim for 8 mg/L and 0.4 kg/t for retrofits and 4 mg/L, and 0.2 kg/t for new mills) for paper mills)</td>
</tr>
<tr>
<td>Total P</td>
<td>0.05 kg/t</td>
</tr>
<tr>
<td>Total N</td>
<td>0.4 kg/t</td>
</tr>
</tbody>
</table>

1 The effluent should not result in a temperature increase of more than 3 degrees Celsius 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.

*Molecular chlorine should not be used in the process.

Note: Effluent requirements are for direct discharge to surface waters.

**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.

**Ambient Noise**

Noise abatement measures should achieve either the following levels or a maximum increase in background levels of 3 dB(A). Measurements are to be taken at noise receptors located outside the project property boundary.

<table>
<thead>
<tr>
<th>Receptor</th>
<th>Daytime 07:00 - 22:00</th>
<th>Nighttime 22:00 - 07:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential;</td>
<td>55</td>
<td>45</td>
</tr>
<tr>
<td>institutional;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>educational</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial;</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>commercial</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The emission requirements given here can be consistently achieved by well-designed, well-operated and well-maintained pollution control systems.
Note: Timber cut for pulp and paper manufacturing should be compensated for by planting trees so as to ensure sustainability of forests in the region.

**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 above should be as detailed below.

Monitoring of air emissions should be on a continuous basis for opacity (maximum level of 10%) and daily for hydrogen sulfide, and annually for others. Liquid effluents should be monitored for the above listed parameters at least daily except 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. These should be reported to the responsible authorities and relevant parties, as required, and provided to MIGA if requested.

**Key Issues**

The following box summarizes the key production and control practices that will lead to compliance with emission guidelines:

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

**Further Information**

The following are suggested as sources of additional information (these sources are provided for guidance and are not intended to be comprehensive):


