

Category		Title
NFR:	<b>2.H.1</b>	<b>Pulp and paper industry</b>
SNAP:	<b>040601 040602 040603 040604</b>	<b>Chipboard Paper pulp (Kraft process) Paper pulp (acid sulphite process) Paper pulp (neutral sulphite semi-chemical process)</b>
ISIC:		
Version	<b>Guidebook 2013</b>	

**Coordinator**

Jeroen Kuenen

**Contributing authors (including to earlier versions of this chapter)**

Marc Deslauriers, Carlo Trozzi and Mike Woodfield

## Contents

1	Overview .....	3
2	Description of sources.....	3
2.1	Process description .....	3
2.2	Techniques .....	4
2.3	Emissions .....	9
2.4	Controls .....	11
3	Methods.....	13
3.1	Choice of method .....	13
3.2	Tier 1 default approach.....	14
3.3	Tier 2 technology-specific approach .....	15
3.4	Tier 3 emission modelling and use of facility data.....	18
4	Data quality .....	20
4.1	Completeness .....	20
4.2	Avoiding double counting with other sectors.....	20
4.3	Verification.....	20
4.4	Developing a consistent time series and recalculation .....	20
4.5	Uncertainty assessment .....	20
4.6	Inventory quality assurance/quality control (QA/QC) .....	20
4.7	Gridding .....	21
4.8	Reporting and documentation .....	21
5	References.....	21
6	Point of enquiry.....	22

# 1 Overview

The present chapter covers emissions from pulp and paper production. Pulp and paper production consists of three major processing steps: pulping, bleaching and paper production. The type of pulping and the amount of bleaching used depends on the nature of the feedstock and the desired qualities of the end product. This chapter discusses three different chemical pulping processes:

- Kraft (sulphate) pulping is the most widely used pulping process and is typically used to produce strong paper products. The Kraft pulping process includes wood (or other cellulose-bearing materials) digestion in a water solution of sodium sulphite and sodium hydroxide, pulp washing, bleaching, chemical recovery and by-product recovery.
- Sulphite pulping (acid sulphite process) involves chemically pulping the wood using sulphur dioxide (SO<sub>2</sub>) adsorbed in a base solution. Sulphite pulping produces a weaker paper than some other types of pulping, but the pulp is less coloured making it more suitable for printing, often with little bleaching.
- Neutral sulphite semi-chemical pulping (NSSC) is one of the chemical pulping processes that can be used. It involves partial delignification of wood feedstock using a buffered sodium sulphite solution, with completion of the pulping process by mechanical means. NSSC pulps are used in corrugating media and in certain writing and printing papers.

Emissions from paper and pulp production include non-methane volatile organic compounds (NMVOC), sulphur oxides (SO<sub>x</sub>), particulates, nitrogen oxides (NO<sub>x</sub>) and carbon monoxide (CO). Not all emissions from pulping or one of the related processes are reported in source category 2.H.1. It is good practice to report emissions from combustion in boilers/furnaces in the pulp and paper industry in source category 1.A.2.d, from lime kilns in source category 1.A.2.f, from the paper-mill industry in source category 1.A.2.d and emissions from waste water treatment in source category 5.B. For more information it is recommended to refer to the specific chapter.

## 2 Description of sources

### 2.1 Process description

Paper is essentially a sheet of cellulose fibres with a number of added constituents to affect the quality of the sheet and its fitness for intended end use. The pulp for papermaking may be produced from virgin fibre by chemical or mechanical means or by the re-pulping of recovered paper (RCF). In the pulping process, the raw cellulose-bearing material is broken down into its individual fibres. Wood is the main raw material but straw, hemp, grass, cotton and other cellulose-bearing materials can be used as well. The precise composition of the wood will vary according to the type and species but the most important constituents are cellulose, hemicelluloses and lignin.

Most pulp is produced for the purpose of subsequent manufacture of paper or paperboard, while some is destined for other uses such as thick fibreboard or products manufactured from dissolved cellulose.

The process of pulp and papermaking consists of several stages. Besides the fibrous material, various chemicals and a great deal of water, power is required in the process. The wide range of processes involved in the manufacture of pulp and paper can be broken down into a number of unit operations. A sequence of operations can be described from raw materials to product but

individual processes will not involve all the operations and some are mutually exclusive alternatives.

While the European paper industry could be conceptualised in different ways, the description below was chosen because it is reasonable and manageable. To clarify the variety of processes involved, the most important pulp, paper and board manufacturing processes are described in the next section.

Figure 2.1 shows a general process scheme for the pulp and paper production industry.

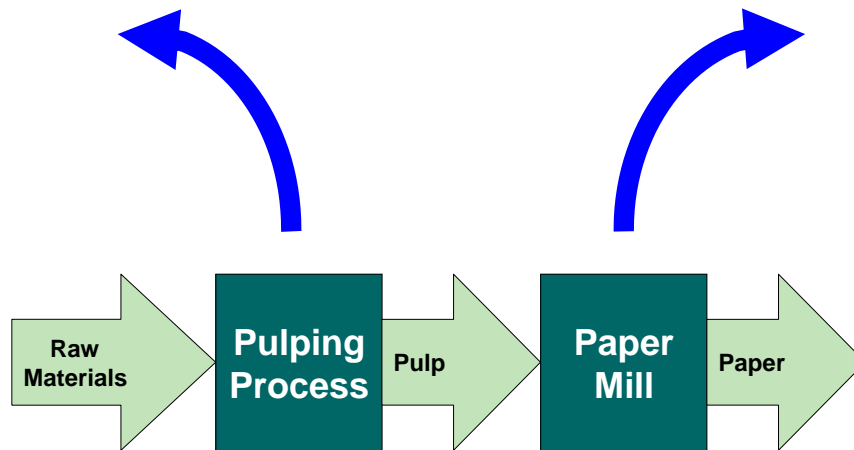


Figure 2.1 Process scheme for source category 2.H.1 Pulp and paper industry

## 2.2 Techniques

This sub-section describes the different chemical pulping processes that can be used in the paper and pulp production.

### 2.2.1 Kraft pulping

In Kraft pulping, white liquor, a water solution of sodium sulphide and sodium hydroxide, is used under high temperature and pressure to chemically dissolve the lignin that binds the cellulose fibres of the wood together. After the wood chips are subjected to this digestion, the wood pulp is washed, screened and dried to unbleached pulp or further delignified in an oxygen stage and bleached in a bleach plant. The inclusion of a bleaching step depends upon the intended use of the product. The remainder of the Kraft processes are designed to recover chemicals and heat. The spent cooking liquor, containing process chemicals and water and spent chemicals from the wood, is combined with pulp wash water to form what is called black liquor. This black liquor is concentrated through evaporation and then combusted in a recovery furnace, where heat from the combustion of organics is recovered for process use and for the generation of electrical power; inorganic chemicals are recovered as molten smelt. Water and quicklime are used to convert this smelt back to white liquor in a causticising tank. The lime mud that precipitates from the tank is calcined in a lime kiln to regenerate quicklime. Kraft recovery systems may also receive spent liquor from neutral sulphite semi-chemical pulping mills.

The main process steps involved in Kraft pulping are briefly described below.

#### **2.2.1.1 Debarking, wood chipping and screening**

Wet or dry debarking techniques may be used when wood is debarked.

#### **2.2.1.2 Digestion**

Wood chips are cooked in a digester with white liquor, a mixture of sodium hydroxide (NaOH) and sodium sulphide (Na<sub>2</sub>S). There are two types of digester systems: batch and continuous. Once cooking is complete in either a batch or continuous process, the chemical mixture (black liquor) and pulp are discharged into a blow tank - a low pressure vessel. Vapours from the blow tank may be vented to an accumulator or a vapour sphere for collection. The vapours may be incinerated, stripped, or recovered for resale as turpentine or tall oil.

#### **2.2.1.3 Washing**

The pulp from the blow tank is washed to remove the black liquor from the pulp. There are several types of washers, including counter-current vacuum, diffusion, rotary pressure, horizontal belt filters, chemiwashers, wash press, and dilution/extraction. The black liquor extracted from this process is diluted with wash water, and so is called weak black liquor.

#### **2.2.1.4 Delignification**

In many mills, delignification is done in the digester. However, additional reductions in lignin may be achieved through oxygen delignification and/or ozone bleaching.

#### **2.2.1.5 Bleaching**

The pulp is produced as slurry after removal of spent cooking chemicals and dissolved wood organics. Bleaching is then used to remove further lignin to make the pulp whiter. Bleaching is usually done in different steps using a combination of chlorine dioxide and oxygen-based chemicals. The vast majority of the pulp is bleached.

#### **2.2.1.6 Turpentine production**

The vapours discharged from the digester contain up to about 6 kg turpentine per tonne of pulp, depending upon wood species and cooking conditions. These vapours are normally condensed as part of the odour control system. Turpentine has a different specific gravity than water, and so can be decanted or recovered by other processes based on the density differences. The recovered turpentine is usually purchased by refining companies, or is used as fuel in the mill, most commonly in the lime kiln (see chapter 2.A.2) (Environment Canada, 1983).

#### **2.2.1.7 Tall oil recovery**

Tall oil precursors can be recovered from black liquor cooling and evaporation. The black liquor can have soap and other tall oil precursors skimmed from the surface of weak, intermediate or strong black liquor storage tanks and from the black liquor oxidation process. The soap can then be sold or processed into tall oil by acidification (US EPA, 1991).

### **2.2.1.8 Chemical recovery**

The primary functions of the Kraft recovery system are: converting sulphur compounds in the black liquor to  $\text{Na}_2\text{S}$ ; regenerating  $\text{NaOH}$ ; generating large quantities of steam from combustion of organic by-products; and reducing or eliminating a potential pollution source by destroying the organic substances (mostly lignin) dissolved during the cooking. The key steps in the black liquor recovery are: evaporation or concentration; black liquor oxidation (optional); combustion/oxidation in a recovery furnace; recausticizing; and calcining in a lime kiln (the latter is described in chapter 2.A.2) (US EPA, 1991).

### **2.2.1.9 Evaporation**

The majority of water removal from the weak black liquor, to about 55 % solids, is usually carried out in multiple effect evaporators. These are series of evaporators operated at different pressures so that the vapour from one evaporator body becomes the steam supply to the next evaporator.

### **2.2.1.10 Black liquor oxidation**

Generation of  $\text{H}_2\text{S}$  results in the direct contact evaporator when sodium sulphide in black liquor comes in contact with carbon dioxide in the recovery furnace gases. This can largely be eliminated by oxidising the sodium sulphide with air, or oxygen, to sodium thiosulphite. Black liquor oxidation is not required if indirect evaporator concentrators are used (US EPA, 1991).

### **2.2.1.11 Recovery furnace**

The black liquor recovery furnace further concentrates the liquor solids. The heavy black liquor from the evaporators is heated and sprayed into the furnace. Water is evaporated from the liquor solids and the organics are burned to reduce oxidised sulphur components to sulphide. The inorganic black liquor chemicals form a molten smelt.

### **2.2.1.12 Recausticizing**

In recausticizing, sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) in the smelt is converted into  $\text{NaOH}$ , an active cooking chemical. The smelt from the recovery furnace is dissolved in a tank with weak wash to form green liquor. After clarification, the green liquor is mixed with reburned lime to form slurry and agitated at high temperatures to form lime mud. White liquor is clarified from the lime mud by decantation. The lime mud then goes to the lime kiln for calcination (chapter 2.A.2).

## **2.2.2 Acid sulphite pulping**

Currently, research in new pulping processes based on organic solvents is directed to reduce the environmental effects and to reduce operating and investment costs. These organosolve processes result in lower gaseous emissions of sulphur dioxide and odorous compounds. However, these processes are generally characterised by high reaction temperatures and pressures, complicated pulp washing and recovery systems, and inferior pulp strength.

In the acid sulphite process, a caustic solution (cooking liquor) is used under high temperature and pressure to chemically dissolve the lignin that binds the cellulose fibres of the wood together. The caustic solution is  $\text{SO}_2$  adsorbed in a base solution. The bases commonly used are calcium, magnesium, ammonia or sodium. After digestion, the wood pulp is washed and dried for sale as market pulp, or further treated by refining, cleaning and addition of other pulps and chemicals, and made into paper on-site. Depending on the intended use of the product, the pulp may or may not

be bleached. Heat and/or chemical recovery may also be done, depending on the cooking liquor used. An acid plant will normally be necessary to supply the mill sulphite requirement.

The main process steps involved in acid sulphite pulping are briefly described below. It is good practice to note that some of the main sources for acid sulphite pulping are inventoried under other source categories (Environment Canada, 1983; US EPA, 1985; US EPA, 1991).

### **2.2.2.1 Digestion**

Digestion is carried out under high pressure and high temperature, in either batch mode or continuous digesters, in the presence of a sulphurous acid/bisulphite cooking liquid (see acid plant below). The delignification is accomplished by sulphonation and hydrolysis reactions which form soluble ligno-sulphates. When this is completed, the contents of the digester are either discharged at high pressure into a blow pit or pumped into a dump tank at lower pressure. A blow pit is a tank with a finely perforated bottom to allow liquids to drain out while retaining the pulp. A blow tank is commonly an atmospheric cyclone. The spent sulphite liquor (sometimes called red liquor) is drained, and discharged or treated and incinerated or sent to a plant for recovery of heat and/or chemicals.

### **2.2.2.2 Washing**

The pulp is then washed with fresh water to further remove dissolved chemicals. This water is usually routed to recovery operations.

### **2.2.2.3 Bleaching**

The pulp is produced as slurry after removal of spent cooking chemicals and dissolved wood organics. Bleaching chemical pulps is generally complex. Strictly speaking, bleaching is part of the paper making process, as opposed to pulping, but has been included under this source category for complete coverage of the pulp and paper industry as a whole.

### **2.2.2.4 Chemical recovery**

More than a dozen types of recovery systems, using widely different processes, are in operation around the world. The variety of systems for heat and/ or chemical recovery is largely due to the variety of cooking bases used.

The sulphite cooking process is based on the use of aqueous sulphur dioxide (SO<sub>2</sub>) and a base of calcium, sodium, magnesium or ammonium. The specific base used will impact upon the options available within the process in respect of chemical and energy recovery system and water use. Today, the use of the relatively cheap calcium base is outdated because the cooking chemicals cannot be recovered. In Europe (European Commission, 2001) there was still one mill (in France) using ammonium as a base. The dominant sulphite pulping process in Europe is magnesium sulphite pulping with some mills using sodium as base. Both magnesium and sodium bases allow chemical recovery. The lignosulphonates generated in the cooking liquor can be used as a raw material for producing different chemical products.

In calcium base systems, chemical recovery is not practical, and the spent liquor is usually discharged or incinerated. In ammonium base operations, heat can be recovered by combusting the spent liquor but the ammonium base and sulphur are lost. In sodium or magnesium base operations, the heat, sulphur and base may all be recovered.

The first step in all recovery systems is the concentration of red liquors in a multiple effect evaporator and possibly a direct contact evaporator, to anywhere from 35 to 60 % solids, depending upon the type of combustion unit to be used. The 'strong' liquor is then sprayed into a furnace and burned, producing steam to operate the processes or other power requirements.

When only heat recovery is practiced, the recovery process can be considered conventional combustion and inventoried under source category 1.A Combustion.

When magnesium base liquor is burned, the combustion products are a carbon-free MgO ash and SO<sub>2</sub>. The gases pass through a series of multiple cyclones where the ash is collected and flushed with water to a retention tank. The MgO slurry is then converted to Mg(OH)<sub>2</sub> in the slaking system and used for absorption of the SO<sub>2</sub> in a series of venturi scrubbers. The overall chemical recovery of sulphur and Mg(OH)<sub>2</sub> is around 80 %.

When sodium base liquor is burned, the inorganic compounds are recovered as a molten smelt containing sodium sulphide and sodium carbonate. This smelt may be further processed and used to adsorb SO<sub>2</sub> from the flue gas and sulphur, or sold to a Kraft mill as raw material for producing green liquor. It is not suitable for reuse in sulphite cooking.

#### **2.2.2.5 Acid plant**

In an acid plant, sulphur is normally burned in a rotary or spray burner. The gas produced is then cooled by heat exchangers and a water spray and then absorbed in a variety of different scrubbers containing either limestone or a solution of the base chemical. In the past, limestone was used exclusively in the gas absorption tower, serving both as a packing and a chemical source of calcium. More recently, soluble bases such as magnesium, sodium and ammonium are used for environmental reasons as well as improved pulp strength. Before the raw acid is used in pulping it is fortified with relief SO<sub>2</sub> from the digester. The fortification takes place in the low and high pressure accumulators, which are pressurised to increase the solubility of SO<sub>2</sub> in the liquor.

#### **2.2.3 Neutral sulphite pulping**

In the NSSC process, a cooking liquor is used under high temperature and pressure to chemically dissolve the lignin that binds the cellulose fibres of the wood together. The main cooking agent is sodium sulphite, buffered with sodium bicarbonate to maintain a neutral solution. This prevents alkalinity and acidity from degrading the hemicelluloses in the pulp but also retards delignification. Thus after blowing from the digester, the pulping is completed using mechanical disc refiners. The pulp is then cleaned and thickened and dried for sale as market pulp or further processed into paper products on-site. Spent liquor handling methods vary widely. Options include disposal, recovery of heat and/or chemicals or transfer of the spent liquor to conventional Kraft recovery mills for cross recovery.

The Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques (BREF) (European Commission, 2001) describe the process but do not indicate specific emission factors. The IPPC BREF document declare that the dominating sulphite pulping process in Europe is the magnesium sulphite pulping with some mills using sodium as a base.

The main process steps involved in neutral sulphite semi-chemical pulping are briefly described below.



### 2.2.3.1 Digestion

Digestion is carried out under high pressure and high temperature, in either batch mode or continuous digesters, in the presence of a buffered sodium sulphite cooking solution (liquor). Delignification occurs by lignin sulphonation and hydrolysis. Buffering, usually by the addition of sodium carbonate to the cooking liquor, retards the delignification process. When about half the lignin is dissolved, delignification tends to slow down considerably. The pulp is blown to a blow pit at this point and dewatered. Pulping is completed using mechanical disc refiners. This method achieves yields as high as 60–80 %, much higher than the 50–55 % yields for other chemical processes.

The pulp may then be dried for sale as market pulp or further refined, cleaned and made into paper on site. Most of the pulp used for the manufacture of printing products is bleached.

### 2.2.3.2 Bleaching

Bleaching chemical pulps is generally complex and uses several chlorine-based chemicals. Strictly speaking, bleaching is part of the paper making process, as opposed to pulping, but it has been included in this source category for complete coverage of the pulp and paper industry as a whole.

### 2.2.3.3 Chemical recovery

In some NSSC processes, chemical recovery is not practiced. In other cases, NSSC spent liquor is delivered directly to a conventional Kraft recovery system, a technique known as cross recovery. This is only feasible when a Kraft mill is close by and where chemical losses in the Kraft mill warrant cross recovery.

In some cases, however, chemical recovery is practiced on site. Fluidised bed reactors are used to combust the spent liquors after preconcentration in multiple effect evaporators to 30–35 % solids. The inorganic chemicals and sodium organic salts are chiefly oxidised to sodium sulphate and sodium carbonate pellets. This matter is removed from the reactor and can be sold to a Kraft mill for use as its chemical make up, if a suitable market exists.

### 2.2.3.4 Acid preparation plant

In an acid plant, sulphur is normally burned in a rotary or spray burner. The gas produced is then cooled by heat exchangers and a water spray and passed to an absorber tower.

## 2.3 Emissions

### 2.3.1 Kraft pulping

Emission sources at Kraft pulp and paper mills are summarised in Table 2.1 (NCASI, 1993; US EPA, 1985).

The term ‘non-condensable gases’ is applied to the gases emitted from the pulping and black liquor evaporation processes, including digester relief gases, digester blow gases, evaporator gases and condensate stripper gases. These gases, which are stored in a tank, consist of a mixture of terpenes, total reduced sulphur (TRS) compounds and methanol along with a variety of less significant organics. Strictly speaking, these gases are all condensable but the term is used to distinguish them from the vapours that condense in the relief vent, blow heat recovery vent and

evaporator non-condensable extraction system under normal conditions of operation.  
(Environment Canada, 1983)

In some cases these non-condensable gases are not collected, and so are considered as emission sources at the point of creation (i.e. digester, evaporator). However, they are, in North America and Scandinavia, typically collected and incinerated in the lime kiln or a dedicated boiler. In certain circumstances (about 2 % of the time), however, these gases may be vented to the atmosphere, although in Scandinavia there is usually a second or back-up system for collection and destruction of non-condensable gases, which means that these gases are directly vented to the atmosphere less than 0.5 % of the time. The non-condensable gases, collected but not incinerated, must be considered a potential source of volatile organic compounds (VOCs) (NCASI, 1993). Thus in Table 2.1 the digestion and evaporators will not be sources of VOCs if non-condensable gases are collected.

**Table 2.1 Emission sources in paper pulping — Kraft process.**

Source							
	TPM	PM 10	PM 2.5	SO <sub>2</sub>	NO <sub>x</sub>	VOC <sub>s</sub>	CO
Debarking, wood handling						x	
Washing							
Bleaching							
<b>Non-condensable gases:</b>							
— Collected, not incinerated				X <sup>(a)</sup>			
— Incinerated				X <sup>(a)</sup>	x		
Turpentine production							
Tall oil recovery							
<b>Chemical recovery</b>							
— Black liquor oxidation							
— Recovery furnace		X		X	X		x
— Lime kiln <sup>(b)</sup>		X		x	X		x
Pulp drying <sup>(b)</sup> (this will have to be confirmed based on source category 1.A.2.d)							
Boilers (fuel-dependent) <sup>(b)</sup>		x		X	X		

Major sources are marked with an 'X'; minor sources are marked with an 'x'.

<sup>(a)</sup> Depending on if the emissions are treated in a scrubber or if the incineration takes place in the lime kiln.

<sup>(b)</sup> Recorded under source category 1.A.2.d.

Although these contaminants are emitted in varying quantities, the major problem for this industry is odour due to TRS emissions.

### ***2.3.2 Acid sulphite pulping***

SO<sub>2</sub> is usually considered the major pollutant from acid sulphite processes. The digester and blow pit (or blow tank) system is a major source of SO<sub>2</sub>. It is present in the intermittent digester relief gases, as well as in the gases released when the digester is discharged into the blow pit or blow tank. SO<sub>2</sub> is also released from the recovery system, the various pulp washing, screening and cleaning operations, as well as from evaporators and acid fortification towers (Environment Canada, 1983; US EPA, 1985).

Particulate may be released from the absorption system handling the recovery furnace exhaust. Ammonium base systems generate less particulate than do magnesium or sodium base systems (US EPA, 1985).

The recovery furnace is a source of VOCs (Stockton and Stelling, 1991) Bleaching operations may also be minor sources of VOCs (NCASI, 1993).

In a magnesium sulphite mill (European Commission, 2001) the main source for sulphur oxide emissions is the recovery boiler. After the recovery boiler, magnesium oxide ash is collected from the flue gas in electrostatic precipitators and washed with water forming magnesium hydroxide. This liquid is used in venturi scrubbers to absorb SO<sub>2</sub> and SO<sub>3</sub> from the recovery boiler (and in a few mills also from the digesters, washers and evaporators). The absorption system is made up with a number of scrubbers, normally three, four or five.

### ***2.3.3 Neutral sulphite pulping***

Particulate emissions are only a potential problem when a fluidised bed reactor is used for chemical recovery.

Absorbing towers, digester/blow tank systems and the recovery furnace are the main sources of SO<sub>2</sub>.

The fluid bed reactor has been reported as a minor source of NO<sub>x</sub> and VOCs. Bleaching plants may also be minor sources of VOCs.

## **2.4 Controls**

### ***2.4.1 Kraft pulping***

Emissions control at these mills is a major consideration in the design of a Kraft pulping mill and will, to a large extent, depend on the methods used to control odours. Control may include process modifications and improved operating conditions, as well as add-on emissions control.

For example, particulate control on recovery furnaces is achieved in a number of ways. In mills with either a cyclonic scrubber or cascade evaporator as a direct contact evaporator, particulate control efficiencies of 20–50 % are achieved for the recovery furnace if gases from the recovery furnace are routed to these processes. An electrostatic precipitator or venturi scrubber and possibly auxiliary scrubbers may then be added to achieve the desired reduction of 85–99 % (US EPA, 1985).

Since the particulate material that is released is largely sodium sulphate and sodium carbonate, the recovery through the use of ESPs or scrubbers is normally practised for economic reasons on all recovery furnaces (Environment Canada, 1983).

Sulphur dioxide is emitted mainly from oxidation of reduced sulphur compounds in the recovery furnace. US EPA (1985) reports that the direct contact evaporator absorbs about 75 % of these emissions and that further scrubbing can provide additional control. Other methods may also be used to decrease the SO<sub>2</sub> emissions from the recovery boiler (SEPA, 1992):

- modification of changed combustion conditions;
- increased dry solids content of the strong black liquor;
- decreased sulphur-to-sodium ratio in the furnace;
- improved process control.

The major cause of carbon monoxide emissions from the recovery furnace is furnace operation well above rated capacity, which results in failing to maintain oxidising conditions.

Non-condensable gases are usually incinerated. In older installations, the non-condensable gases are incinerated in a dedicated incinerator, which is effective but usually requires auxiliary fuel to maintain combustion. Nowadays, most installations incinerate the gases in the lime kiln, the power boiler or the recovery furnace. Incineration of these gases does result in emissions of SO<sub>2</sub>. Scrubbers may be used to recover sulphur for the pulping process prior to incineration (Environment Canada, 1983).

Please refer to European Commission (2001), Environment Canada (1983), and SEPA (1992) for more details.

#### **2.4.2 Acid sulphite pulping**

Many mills have separate blow tanks, or pits, and emission stacks for each digester. Water showers may be installed in the blow tank vents to control the blowing SO<sub>2</sub> emissions or a scrubber may be used. The latter may achieve an efficiency of as high as 99 % (Environment Canada, 1983).

Magnesium, sodium and ammonium base recovery systems all use absorption systems to recover SO<sub>2</sub> from sources such as the recovery furnaces, acid fortification towers and multiple effect evaporators. Generally these recover more than 95 % of the sulphur for reuse, by scrubbing with the base chemical slurry or solution. (Environment Canada, 1983; US EPA, 1985)

Depending on local conditions the following devices and systems can be found in sulphite pulp mills for collecting and purifying emissions to the atmosphere (European Commission, 2001):

- a cyclone for chip blowing;
- gases from the continuous pressure control relief of the digesters are led to combustion in the recovery boiler;
- a collecting system for aerating gases from digesters, blow tanks, knot screens, washing filters, all weak and thick liquor tanks and fibre filters; these gases are led to combustion in the recovery boiler;
- scrubbers for the absorption of sulphur dioxide in aerating gases from the bleach plant;
- non-condensable gases from the evaporation are led to combustion in the recovery boiler;
- absorption of SO<sub>2</sub> in the flue gases leaving the recovery boilers in the acid preparation plant (venturi-scrubber system);
- a collection system for ventilation gases from the boiler house's liquor and condensate tanks, weak liquor filter and mix tank; the gases are led to combustion in the recovery boiler;

- dust separation from flue gases from the auxiliary-boiler (burning bark, oil or other fuels) with electrofilter (ESP) and wet scrubber;
- NO<sub>x</sub>-reduction in the bark boiler by injection of urea.

### **2.4.3 Neutral sulphite pulping**

Particulate controls are usually installed to improve chemical recovery rates, since the particulate is mainly sodium sulphate and sodium carbonate.

The sources of SO<sub>2</sub> are normally controlled with scrubbers.

## **3 Methods**

### **3.1 Choice of method**

Figure 3.1 presents the procedure to select the methods for estimating process emissions from the pulp and paper industry. The basic procedure is as follows:

- If detailed information is available: use it.
- If the source category is a key category, a Tier 2 or better method must be applied and detailed input data must be collected. The decision tree directs the user in such cases to the Tier 2 method, since it is expected that it is more easy to obtain the necessary input data for this approach than to collect facility-level data needed for a Tier 3 estimate.
- The alternative of applying a Tier 3 method, using detailed process modelling is not explicitly included in this decision tree. However, detailed modelling will always be done at the facility level and the results of such modelling could be seen as 'facility data' in the decision tree.

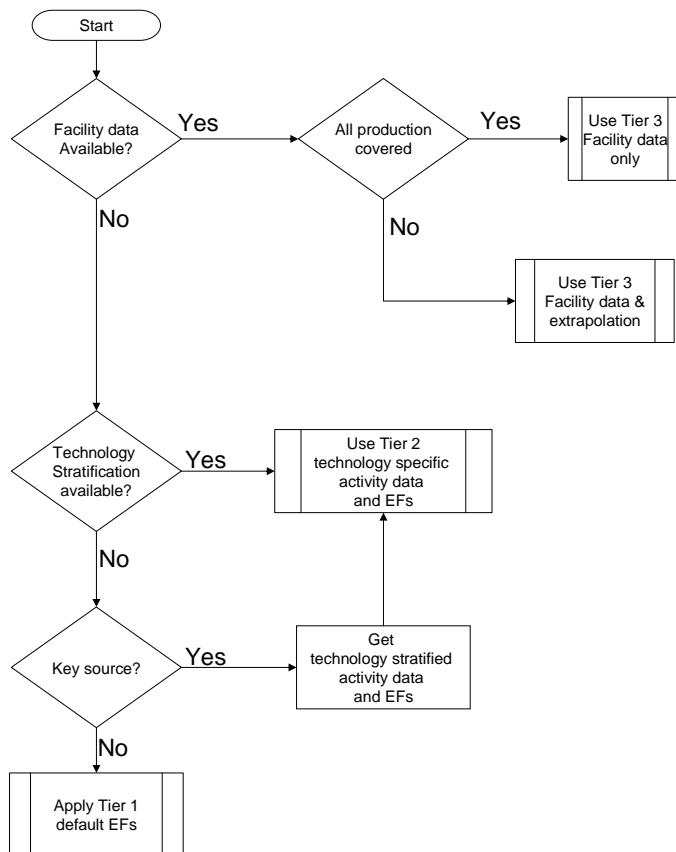


Figure 3.1 Decision tree for source category 2.H.1 Pulp and Paper

## 3.2 Tier 1 default approach

### 3.2.1 Algorithm

The Tier 1 approach for process emissions from pulp and paper uses the general equation:

$$E_{pollutant} = AR_{production} \times EF_{pollutant} \quad (1)$$

This equation is applied at the national level, using annual national total pulp and paper production. Information on the production of pulp and paper, suitable for estimating emissions using the simpler estimation methodology (Tier 1 and 2), is widely available from United Nations statistical yearbooks or national statistics.

The Tier 1 emission factors assume an averaged or typical technology and abatement implementation in the country and integrate all sub-processes in the pulp and paper industry.

In cases where specific abatement options are to be taken into account a Tier 1 method is not applicable and a Tier 2 or Tier 3 approach must be used.

### 3.2.2 Default emission factors

The proposed Tier 1 default emission factors are those for Kraft pulping, since this is by far the most important process in the manufacturing of pulp and paper. Values are taken from the BREF document for pulp and paper industries (European Commission, 2001); the emission factor for CO is from US EPA (1985) and the emission factor for BC is obtained from US EPA, SPECIATE database version 4.3 (US EPA, 2011).

**Table 3.1 Tier 1 emission factors for source category 2.H.1 Pulp and paper industry**

Tier 1 default emission factors					
	Code	Name			
NFR source category	2.H.1	Pulp and paper industry			
Fuel	NA				
Not applicable	Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCB, PCDD/F				
Not estimated	NH <sub>3</sub> , Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3--cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NO <sub>x</sub>	1	kg/Mg air dried pulp	0.85	2.6	European Commission (2001)
CO	5.5	kg/Mg air dried pulp	0.55	55	US EPA (1985)
NMVOG	2	kg/Mg air dried pulp	1	4	European Commission (2001)
SO <sub>2</sub>	2	kg/Mg air dried pulp	0.04	4	European Commission (2001)
TSP	1	kg/Mg air dried pulp	0.25	3	European Commission (2001)
PM <sub>10</sub>	0.8	kg/Mg air dried pulp	0.2	2.4	US EPA (1985) applied on TSP
PM <sub>2.5</sub>	0.6	kg/Mg air dried pulp	0.15	1.8	US EPA (1985) applied on TSP
BC	2.6	% of PM <sub>2.5</sub>	1.3	5.2	US EPA (2011, file no.: 900152.5)

### 3.2.3 Activity data

The Tier 1 emission factors are based on the production of air dried tonnes of pulp. Production of tall oil and/or turpentine in tonnes and tonnes of black liquor solids recausticized may also be relevant statistics.

## 3.3 Tier 2 technology-specific approach

### 3.3.1 Algorithm

The Tier 2 approach is similar to the Tier 1 approach. To apply the Tier 2 approach, both the activity data and the emission factors need to be stratified according to the different techniques that may occur in the country.

The Tier 2 approach is as follows:

Stratify the pulp and paper production in the country to model the different product and process types occurring in the national pulp and paper industry into the inventory by:

- defining the production using each of the separate product and/or process types (together called 'technologies' in the formulae below) separately;
- applying technology specific emission factors for each process type:

$$E_{\text{pollutant}} = \sum_{\text{technologies}} AR_{\text{productiontechnology}} \times EF_{\text{technologypollutant}} \quad (2)$$

where:

$AR_{\text{production,technology}}$  = the production rate within the source category, using this specific technology

$EF_{\text{technology,pollutant}}$  = the emission factor for this technology and this pollutant

A country where only one technology is implemented will result in a penetration factor of 100 % and the algorithm reduces to:

$$E_{\text{pollutant}} = AR_{\text{production}} \times EF_{\text{technology,pollutant}} \quad (3)$$

where:

$E_{\text{pollutant}}$  = the emission of the specified pollutant

$AR_{\text{production}}$  = the activity rate for the pulp and paper production

$EF_{\text{pollutant}}$  = the emission factor for this pollutant

The emission factors in this approach will still include all sub-processes within the industry from inputting raw materials until the produced pulp and paper is shipped to the customers.

### 3.3.2 *Technology-specific emission factors*

Applying a Tier 2 approach for the process emissions from paper and pulp production, technology-specific emission factors are needed. The emission factors are provided in the present sub-section. Emission factors for BC are available for the Kraft process and for pulp and paper mills in general. The BC EF for the Kraft process is proposed to be applied for the sulphite process as well. The BC EF for pulp and paper mills is obtained from US EPA (US EPA, 2011). A BREF document for this industry is available at <http://eippcb.jrc.es/pages/FActivities.htm>.

The present sub-section provides a series of technology-specific process emission factors for the pulp and paper production. The most used technique is the Kraft process.

#### 3.3.2.1 **Kraft process**

The Kraft pulping process is the most used in the pulp and paper industry. The default emission factors when using this technique are presented in Table 3.2 below.



**Table 3.2 Tier 2 emission factors for source category 2.H.1 Pulp and paper industry, Kraft process**

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.H.1	Pulp and paper industry			
Fuel	NA				
SNAP (if applicable)	040602 Paper pulp (Kraft process)				
Technologies/Practices					
Region or regional conditions					
Abatement technologies	Scrubber and electrostatic precipitator				
Not applicable	Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCB, PCDD/F				
Not estimated	NH <sub>3</sub> , Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3--cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NO <sub>x</sub>	1	kg/Mg air dried pulp	0.85	2.6	European Commission (2001)
CO	5.5	kg/Mg air dried pulp	0.55	55	US EPA (1985)
NMVOG	2	kg/Mg air dried pulp	1	4	European Commission (2001)
SO <sub>2</sub>	2	kg/Mg air dried pulp	0.04	4	European Commission (2001)
TSP	1	kg/Mg air dried pulp	0.25	3	European Commission (2001)
PM <sub>10</sub>	0.8	kg/Mg air dried pulp	0.2	2.4	US EPA (1985) applied on TSP
PM <sub>2.5</sub>	0.6	kg/Mg air dried pulp	0.15	1.8	US EPA (1985) applied on TSP
BC	2.6	% of PM <sub>2.5</sub>	1.3	5.2	US EPA (2011, file no.: 900152.5)

**3.3.2.2 Acid sulphite process**

This process is much smaller than the production of Kraft pulps (European Commission, 2001) and is used for special purposes in papermaking rather than as an alternative to Kraft pulping.

The emission factors in Table 3.3 are based on magnesium sulphite pulping. The mills running in Europe are unimportant in terms of both capacity and numbers. Emission factors are taken from the BREF document (European Commission, 2001). PM<sub>10</sub> and PM<sub>2.5</sub> emissions are calculated from the TSP emissions using the profile in US EPA (1985) and the emission factor for BC is obtained from US EPA, SPECIATE database version 4.3 (US EPA, 2011).

**Table 3.3 Tier 2 emission factors for source category 2.H.1 Pulp and paper industry, acid sulphite process**

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.H.1	Pulp and paper industry			
Fuel	NA				
SNAP (if applicable)	040603 Paper pulp (Acid sulfite process)				
Technologies/Practices					
Region or regional conditions					
Abatement technologies	Scrubber and electrostatic precipitator				
Not applicable	Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCB, PCDD/F				
Not estimated	CO, NH <sub>3</sub> , Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3--cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NO <sub>x</sub>	2	kg/Mg air dried pulp	1	4	European Commission (2001)
NMVOG	0.2	kg/Mg air dried pulp	0.1	0.4	European Commission (2001)
SO <sub>2</sub>	4	kg/Mg air dried pulp	2	8	European Commission (2001)
TSP	1	kg/Mg air dried pulp	0.25	3	European Commission (2001)
PM <sub>10</sub>	0.8	kg/Mg air dried pulp	0.2	2.4	US EPA (1985) applied on TSP
PM <sub>2.5</sub>	0.6	kg/Mg air dried pulp	0.15	1.8	US EPA (1985) applied on TSP
BC	2.6	% of PM <sub>2.5</sub>	1.3	5.2	US EPA (2011, file no.: 900152.5)

### 3.3.2.3 Neutral sulphite semi-chemical process

For this process, very limited data are available on emission factors. Only NMVOC emission factors are reported here, all other emissions are not estimated. The value is given on a carbon basis, the type of pulp is not specified and it is applicable for a bleach plant. The factor is adapted from NCASI (1993).

The IPPC BREF document (European Commission, 2001) describes the process, but does not suggest emission factors. The document states that this process is hardly ever used in Europe, the dominant process in sulphite pulping is the magnesium sulphite pulping with some mills using sodium as base (see sub-section 3.3.2.2 above on the acid sulphite process).

**Table 3.4 Tier 2 emission factors for source category 2.H.1 Pulp and paper industry, neutral sulphite semi-chemical process (NSCC)**

Tier 2 emission factors					
NFR Source Category	2.D.1	Pulp and paper			
Fuel	NA				
SNAP (if applicable)	040603	Paper pulp (acid sulfite process)			
Technologies/Practices					
Region or regional conditions					
Abatement technologies	unknown				
Not applicable	Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB, PCDD/F, Benzo(a)pyrene, PCP, SCCP				
Not estimated	NOx, CO, SOx, NH3, TSP, PM10, PM2.5, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, Total 4 PAHs, HCB				
Pollutant	Value	Unit	95% confidence interval		Reference
			Lower	Upper	
NMVOC	0.05	kg/Mg air dried pulp	0.004	0.14	NCASI (1993)

### 3.3.3 Abatement

Not available for this source category.

### 3.3.4 Activity data

Most emission factors are based on the production of air dried pulp. Production of tall oil and/or turpentine in tonnes and tonnes of black liquor solids recausticized may also be relevant statistics.

## 3.4 Tier 3 emission modelling and use of facility data

### 3.4.1 Algorithm

There are two different methods to apply emission estimation methods that go beyond the technology-specific approach described above:

- detailed modelling of the pulp and paper production process;
- facility-level emission reports.

#### 3.4.1.1 Detailed process modelling

A Tier 3 emission estimate, using process details will make separate estimates for the consecutive steps in the pulp and paper production process.

### 3.4.1.2 Facility-level data

Where facility-level emission data of sufficient quality (see the chapter on investment management in Part A of the Guidebook) are available, it is good practice to use these data. There are two possibilities:

- the facility reports cover all pulp/paper production in the country;
- facility-level emission reports are not available for all facilities in the country.

If facility-level data cover all production in the country, it is good practice to compare the implied emission factors (reported emissions divided by national production) with the default emission factor values or technology-specific emission factors. If the implied emission factors are outside the 95 % confidence intervals for the values given below, it is good practice to explain the reasons for this in the inventory report

If the total annual pulp and paper production in the country is not included in the total of the facility reports, it is good practice to estimate the missing part of the national total emissions from the source category, using extrapolation by applying:

$$E_{Total,pollutant} = \sum_{Facilities} E_{Facility,pollutant} + \left( National\ Production - \sum_{Facilities} Production_{Facility} \right) \times EF \quad (4)$$

Depending on the specific national circumstances and the coverage of the facility level reports as compared to the total national production, it is good practice to choose the emission factor (*EF*) in this equation from the following possibilities, in decreasing order of preference:

- technology specific emission factors, based on knowledge of the types of technologies implemented at the facilities where facility level emission reports are not available;
- the implied emission factor derived from the available emission reports:

$$EF = \frac{\sum_{Facilities} E_{Facility,pollutant}}{\sum_{Facilities} Production_{Facility}} \quad (5)$$

- the default Tier 1 emission factor. This option should only be chosen if the facility level emission reports cover more than 90 % of the total national production

### 3.4.2 Tier 3: emission modelling and use of facility data

Pulp and paper production facilities are major industrial facilities and emission data for individual plants might be available through a pollutant release and transfer registry (PRTR) or another emission reporting scheme. When the quality of such data is assured by a well developed quality assurance/quality control (QA/QC) system and the emission reports have been verified by an independent auditing scheme, it is good practice to use such data. If extrapolation is needed to cover all production in the country either the implied emission factors for the facilities that did report, or the emission factors as provided above could be used.

US EPA (1999) contains emission factors for different processes in the Kraft mills. These emission rates are given for different control devices, so care must be taken when using these emission factors. US EPA (1997) gives control efficiencies on particulates for PM<sub>10</sub>, PM<sub>6</sub> and PM<sub>2.5</sub>. These may be used in cases where additional abatement equipment is installed.

### **3.4.3 Activity data**

Since PRTRs generally do not report activity data, such data in relation to the reported facility-level emissions are sometimes difficult to find. A possible source of facility-level activity might be the registries of emission trading systems.

## **4 Data quality**

### **4.1 Completeness**

No specific issues.

### **4.2 Avoiding double counting with other sectors**

No specific issues.

### **4.3 Verification**

Information regarding the Best Available Techniques (BAT) for the pulp and paper industry is given in the BREF document for the pulp and paper industry (European Commission, 2001). No emission factors associated with the use of BAT could be extracted from this document.

### **4.4 Developing a consistent time series and recalculation**

No specific issues for Tier 1 and 2.

For Tier 3 using facility-level data, it might occur that a different selection of facility-level data is included in different years. This can lead to time series inconsistencies. Moreover, PRTR data are generally available for specific years only. Splicing such recent reported data under EPRTR/EPER with historical data could be used to get consistent time series. Splicing could be used for both the activity data and the country-specific emission factors.

Unexpected discontinuities in time series can occur when specific pulp and paper production facilities come into operation or are closed in specific years. If this happens, it is good practice to clearly document such explanations in the inventory archives.

### **4.5 Uncertainty assessment**

No specific issues.

#### **4.5.1 Emission factor uncertainties**

No specific issues.

#### **4.5.2 Activity data uncertainties**

No specific issues.

### **4.6 Inventory quality assurance/quality control (QA/QC)**

No specific issues.

## 4.7 Gridding

It is good practice to consider pulp and paper production plants as point sources if plant-specific data are available. Otherwise national emissions can be disaggregated on the basis of plant capacity, employment or population statistics.

## 4.8 Reporting and documentation

No specific issues.

## 5 References

- Environment Canada, 1983. 'The Basic Technology of the Pulp and Paper Industry and Its Environmental Protection Practices'. *Training Manual, EPS 6*.
- European Commission, 2001. *Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques (BREF) in the Pulp and Paper Industry*. December 2001
- NCASI, 1993. *Emission Factors for NO<sub>x</sub>, SO<sub>2</sub>, and Volatile Organic Compounds for Boilers, Kraft Pulp Mills, and Bleach Plants*. National Council of the Paper Industry for Air and Stream Improvement Inc. Technical Bulletin No. 646. New York.
- SEPA, 1992. *Reduction of Atmospheric Emissions from Pulp Industry. Atmospheric Emission of Sulphur and Nitrogen Oxides from the Nordic Chemical Pulp Industry*. Swedish Environmental Protection Agency Report 4008. Information Department, Solna.
- Stockton, M.B. and Stelling, J.H.E., 1991. *Criteria Pollutant Emission Factors for the NAPAP Emissions Inventory, National Acid Precipitation Assessment Program*. Contract No. 68-02-3994, United States Environmental Protection Agency, Office of Research and Development.
- US EPA, 1991. *General Information Document for the Pulp and Paper Industry*. Draft. United States. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle, North Carolina.
- US EPA, 1997. *Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds*. EPA-454/R-97-012. United States Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.
- US EPA, 1999. *FIRE 6.22 Factor Information Retrieval Data System October 1999*. United States Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.
- US EPA, 1985. 'A Compilation of Air Pollutant Emission Factors. Volume 1: Stationary Point and Area Sources. Section 10.1 Chemical Wood Pulping'. In: *Compilation of Air Pollutant Emission Factors (AP-42) Fourth Edition, plus supplements*. United States Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.
- US EPA, 2011. SPECIATE database version 4.3, U.S. Environmental Protection Agency's (EPA). Available at: <http://cfpub.epa.gov/si/speciate/>. (accessed 5 June 2013).

## 6 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on combustion and industry. Please refer to the TFEIP website ([www.tfeip-secretariat.org/](http://www.tfeip-secretariat.org/)) for the contact details of the current expert panel leaders.